

Chapter 1

Demo problem: Large-amplitude shock-wave propagation in a circular disk

Detailed documentation to be written. Here's the already fairly well documented driver code...

```
//LIC// =====
//LIC// This file forms part of oomph-lib, the object-oriented,
//LIC// multi-physics finite-element library, available
//LIC// at http://www.oomph-lib.org.
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//LIC//
//LIC// The authors may be contacted at oomph-lib@maths.man.ac.uk.
//LIC//
//LIC//=====
// Driver for large-displacement elasto-dynamic test problem:
// Circular disk impulsively loaded by compressive load.
#include <iostream>
#include <fstream>
#include <cmath>
//My own includes
#include "generic.h"
#include "solid.h"
//Need to instantiate templated mesh
#include "meshes/quarter_circle_sector_mesh.h"
using namespace std;
using namespace oomph;

/// //////////////////////////////////////
/// //////////////////////////////////////
/// //////////////////////////////////////

//=====
/// Global variables
//=====
namespace Global_Physical_Variables
{
  /// Pointer to constitutive law
  ConstitutiveLaw* Constitutive_law_pt;

  /// Elastic modulus
  double E=1.0;

  /// Poisson's ratio
  double Nu=0.3;
}
```

```

/// Uniform pressure
double P = 0.00;

/// Constant pressure load
void constant_pressure(const Vector<double> &xi,const Vector<double> &x,
                      const Vector<double> &n, Vector<double> &traction)
{
  unsigned dim = traction.size();
  for(unsigned i=0;i<dim;i++)
  {
    traction[i] = -P*n[i];
  }
}

/// //////////////////////////////////////
/// //////////////////////////////////////
/// //////////////////////////////////////

//=====
/// Elastic quarter circle sector mesh with functionality to
/// attach traction elements to the curved surface. We "upgrade"
/// the RefineableQuarterCircleSectorMesh to become an
/// SolidMesh and equate the Eulerian and Lagrangian coordinates,
/// thus making the domain represented by the mesh the stress-free
/// configuration.
/// \n\n
/// The member function \c make_traction_element_mesh() creates
/// a separate mesh of SolidTractionElements that are attached to the
/// mesh's curved boundary (boundary 1).
//=====
template <class ELEMENT>
class ElasticRefineableQuarterCircleSectorMesh :
  public virtual RefineableQuarterCircleSectorMesh<ELEMENT>,
  public virtual SolidMesh
{
public:

  /// Constructor: Build mesh and copy Eulerian coords to Lagrangian
  /// ones so that the initial configuration is the stress-free one.
  ElasticRefineableQuarterCircleSectorMesh<ELEMENT>(GeomObject* wall_pt,
                                                    const double& xi_lo,
                                                    const double& fract_mid,
                                                    const double& xi_hi,
                                                    TimeStepper* time_stepper_pt=
                                                    &Mesh::Default_TimeStepper) :
    RefineableQuarterCircleSectorMesh<ELEMENT>(wall_pt,xi_lo,fract_mid,xi_hi,
                                              time_stepper_pt)
  {
#ifdef PARANOID
    /// Check that the element type is derived from the SolidFiniteElement
    SolidFiniteElement* el_pt=dynamic_cast<SolidFiniteElement*>
      (finite_element_pt(0));
    if (el_pt==0)
    {
      throw OomphLibError(
        "Element needs to be derived from SolidFiniteElement\n",
        OOMPH_CURRENT_FUNCTION,
        OOMPH_EXCEPTION_LOCATION);
    }
#endif
    /// Make the current configuration the undeformed one by
    /// setting the nodal Lagrangian coordinates to their current
    /// Eulerian ones
    set_lagrangian_nodal_coordinates();
  }

  /// Function to create mesh made of traction elements
  void make_traction_element_mesh(SolidMesh*& traction_mesh_pt)
  {
    /// Make new mesh
    traction_mesh_pt=new SolidMesh;
    /// Loop over all elements on boundary 1:
    unsigned b=1;
    unsigned n_element = this->nboundary_element(b);
    for (unsigned e=0;e<n_element;e++)
    {
      /// The element itself:
      FiniteElement* fe_pt = this->boundary_element_pt(b,e);

      /// Find the index of the face of element e along boundary b
      int face_index = this->face_index_at_boundary(b,e);

      /// Create new element
      traction_mesh_pt->add_element_pt(new SolidTractionElement<ELEMENT>
        (fe_pt,face_index));
    }
  }
}

```

```

}

// Function to wipe and re-create mesh made of traction elements
void remake_traction_element_mesh(SolidMesh*& traction_mesh_pt)
{
    // Wipe existing mesh (but don't call it's destructor as this
    // would wipe all the nodes too!)
    traction_mesh_pt->flush_element_and_node_storage();
    // Loop over all elements on boundary 1:
    unsigned b=1;
    unsigned n_element = this->nboundary_element(b);
    for (unsigned e=0;e<n_element;e++)
    {
        // The element itself:
        FiniteElement* fe_pt = this->boundary_element_pt(b,e);

        // Find the index of the face of element e along boundary b
        int face_index = this->face_index_at_boundary(b,e);

        // Create new element
        traction_mesh_pt->add_element_pt(new SolidTractionElement<ELEMENT>
            (fe_pt,face_index));
    }
};

// =====
// "Shock" wave propagates through an impulsively loaded
// circular disk.
// =====
template<class ELEMENT, class TIMESTEPER>
class DiskShockWaveProblem : public Problem
{
public:

    // Constructor:
    DiskShockWaveProblem();

    // Run the problem; specify case_number to label output
    // directory
    void run(const unsigned& case_number);

    // Access function for the solid mesh
    ElasticRefineableQuarterCircleSectorMesh<ELEMENT>*& solid_mesh_pt()
    {
        return Solid_mesh_pt;
    }

    // Access function for the mesh of surface traction elements
    SolidMesh*& traction_mesh_pt()
    {
        return Traction_mesh_pt;
    }

    // Doc the solution
    void doc_solution();

    // Update function (empty)
    void actions_after_newton_solve() {}

    // Update function (empty)
    void actions_before_newton_solve() {}

    // Actions after adaption: Kill and then re-build the traction
    // elements on boundary 1 and re-assign the equation numbers
    void actions_after_adapt();

    // Doc displacement and velocity: label file with before and after
    void doc_displ_and_veloc(const int& stage=0);

    // Dump problem-specific parameters values, then dump
    // generic problem data.
    void dump_it(ofstream& dump_file);

    // Read problem-specific parameter values, then recover
    // generic problem data.
    void restart(ifstream& restart_file);
private:
    // Output
    DocInfo Doc_info;

    // Trace file
    ofstream Trace_file;
};

```

```

/// Vector of pointers to nodes whose position we're tracing
Vector<Node*> Trace_node_pt;

/// Pointer to solid mesh
ElasticRefineableQuarterCircleSectorMesh<ELEMENT*> Solid_mesh_pt;

/// Pointer to mesh of traction elements
SolidMesh* Traction_mesh_pt;
};
//=====
/// Constructor
//=====
template<class ELEMENT, class TIMESTEPPER>
DiskShockWaveProblem<ELEMENT, TIMESTEPPER>::DiskShockWaveProblem()
{
  //Allocate the timestepper
  add_time_stepper_pt(new TIMESTEPPER);

  // Set coordinates and radius for the circle that defines
  // the outer curvilinear boundary of the domain
  double x_c=0.0;
  double y_c=0.0;
  double r=1.0;

  // Build geometric object that specifies the fish back in the
  // undeformed configuration (basically a deep copy of the previous one)
  GeomObject* curved_boundary_pt=new Circle(x_c,y_c,r,time_stepper_pt());
  // The curved boundary of the mesh is defined by the geometric object
  // What follows are the start and end coordinates on the geometric object:
  double xi_lo=0.0;
  double xi_hi=2.0*atan(1.0);
  // Fraction along geometric object at which the radial dividing line
  // is placed
  double fract_mid=0.5;
  //Now create the mesh
  solid_mesh_pt() = new ElasticRefineableQuarterCircleSectorMesh<ELEMENT>(
    curved_boundary_pt,xi_lo,fract_mid,xi_hi,time_stepper_pt());
  // Set up trace nodes as the nodes on boundary 1 (=curved boundary) in
  // the original mesh (they exist under any refinement!)
  unsigned nnod0=solid_mesh_pt()->nboundary_node(0);
  unsigned nnod1=solid_mesh_pt()->nboundary_node(1);
  Trace_node_pt.resize(nnod0+nnod1);
  for (unsigned j=0;j<nnod0;j++)
  {
    Trace_node_pt[j]=solid_mesh_pt()->boundary_node_pt(0,j);
  }
  for (unsigned j=0;j<nnod1;j++)
  {
    Trace_node_pt[j+nnod0]=solid_mesh_pt()->boundary_node_pt(1,j);
  }
  // Build traction element mesh
  solid_mesh_pt()->make_traction_element_mesh(traction_mesh_pt());

  // Solid mesh is first sub-mesh
  add_sub_mesh(solid_mesh_pt());
  // Traction mesh is first sub-mesh
  add_sub_mesh(traction_mesh_pt());
  // Build combined "global" mesh
  build_global_mesh();
  // Create/set error estimator
  solid_mesh_pt()->spatial_error_estimator_pt(new Z2ErrorEstimator);

  // Fiddle with adaptivity targets and doc
  solid_mesh_pt()->max_permitted_error()=0.006; //0.03;
  solid_mesh_pt()->min_permitted_error()=0.0006; // 0.0006; //0.003;
  solid_mesh_pt()->doc_adaptivity_targets(cout);
  // Pin the bottom in the vertical direction
  unsigned n_bottom = solid_mesh_pt()->nboundary_node(0);
  //Loop over the node
  for(unsigned i=0;i<n_bottom;i++)
  {
    solid_mesh_pt()->boundary_node_pt(0,i)->pin_position(1);
  }
  // Pin the left edge in the horizontal direction
  unsigned n_side = solid_mesh_pt()->nboundary_node(2);
  //Loop over the node
  for(unsigned i=0;i<n_side;i++)
  {
    solid_mesh_pt()->boundary_node_pt(2,i)->pin_position(0);
  }
  //Find number of elements in solid mesh
  unsigned n_element =solid_mesh_pt()->nelement();

  //Set parameters and function pointers for solid elements
  for(unsigned i=0;i<n_element;i++)
  {

```

```

//Cast to a solid element
ELEMENT *el_pt = dynamic_cast<ELEMENT*>(mesh_pt()->element_pt(i));
//Set the constitutive law
el_pt->constitutive_law_pt() =
    Global_Physical_Variables::Constitutive_law_pt;

// Switch on inertia
el_pt->enable_inertia();
}
// Pin the redundant solid pressures
PVDEquationsBase<2>::pin_redundant_nodal_solid_pressures(
    solid_mesh_pt()->element_pt());
//Find number of elements in traction mesh
n_element=traction_mesh_pt()->nelement();

//Set function pointers for traction elements
for(unsigned i=0;i<n_element;i++)
{
    //Cast to a solid traction element
    SolidTractionElement<ELEMENT> *el_pt =
        dynamic_cast<SolidTractionElement<ELEMENT*>>
            (traction_mesh_pt()->element_pt(i));
    //Set the traction function
    el_pt->traction_fct_pt() = Global_Physical_Variables::constant_pressure;
}
//Attach the boundary conditions to the mesh
cout << assign_eqn_numbers() << std::endl;
// Refine uniformly
refine_uniformly();
refine_uniformly();
refine_uniformly();

// Now the non-pinned positions of the SolidNodes will have been
// determined by interpolation. This is appropriate for uniform
// refinements once the code is up and running since we can't place
// new SolidNodes at the positions determined by the MacroElement.
// However, here we want to update the nodes to fit the exact
// initial configuration.
// Update all solid nodes based on the Mesh's Domain/MacroElement
// representation
bool update_all_solid_nodes=true;
solid_mesh_pt()->node_update(update_all_solid_nodes);
// Now set the Eulerian equal to the Lagrangian coordinates
solid_mesh_pt()->set_lagrangian_nodal_coordinates();
}
//=====
/// Kill and then re-build the traction elements on boundary 1,
/// pin redundant pressure dofs and re-assign the equation numbers.
//=====
template<class ELEMENT, class TIMESTEPPER>
void DiskShockWaveProblem<ELEMENT,TIMESTEPPER>::actions_after_adapt()
{
    // Wipe and re-build traction element mesh
    solid_mesh_pt()->remake_traction_element_mesh(traction_mesh_pt());

    // Re-build combined "global" mesh
    rebuild_global_mesh();
    //Find number of elements in traction mesh
    unsigned n_element=traction_mesh_pt()->nelement();

    //Loop over the elements in the traction element mesh
    for(unsigned i=0;i<n_element;i++)
    {
        //Cast to a solid traction element
        SolidTractionElement<ELEMENT> *el_pt =
            dynamic_cast<SolidTractionElement<ELEMENT*>>
                (traction_mesh_pt()->element_pt(i));
        //Set the traction function
        el_pt->traction_fct_pt() = Global_Physical_Variables::constant_pressure;
    }
    // Pin the redundant solid pressures
    PVDEquationsBase<2>::pin_redundant_nodal_solid_pressures(
        solid_mesh_pt()->element_pt());
    //Do equation numbering
    cout << assign_eqn_numbers() << std::endl;
}
//=====
/// Doc the solution
//=====
template<class ELEMENT, class TIMESTEPPER>
void DiskShockWaveProblem<ELEMENT,TIMESTEPPER>::doc_solution()
{
    // Number of plot points
    unsigned npts;
    npts=5;
    // Output shape of deformed body

```

```

ofstream some_file;
char filename[100];
sprintf(filename,"%s/soln%i.dat",Doc_info.directory().c_str(),
        Doc_info.number());
some_file.open(filename);
solid_mesh_pt()->output(some_file,npts);
some_file.close();
// Output traction
unsigned nel=traction_mesh_pt()->nelement();
sprintf(filename,"%s/traction%i.dat",Doc_info.directory().c_str(),
        Doc_info.number());
some_file.open(filename);
Vector<double> unit_normal(2);
Vector<double> traction(2);
Vector<double> x_dummy(2);
Vector<double> s_dummy(1);
for (unsigned e=0;e<nel;e++)
{
    some_file << "ZONE " << std::endl;
    for (unsigned i=0;i<npts;i++)
    {
        s_dummy[0]=-1.0+2.0*double(i)/double(npts-1);
        SolidTractionElement<ELEMENT>* el_pt=
            dynamic_cast<SolidTractionElement<ELEMENT>*>(
                traction_mesh_pt()->finite_element_pt(e));
        el_pt->outer_unit_normal(s_dummy,unit_normal);
        el_pt->traction(s_dummy,traction);
        el_pt->interpolated_x(s_dummy,x_dummy);
        some_file << x_dummy[0] << " " << x_dummy[1] << " "
            << traction[0] << " " << traction[1] << " "
            << std::endl;
    }
}
some_file.close();
// Doc displacement and velocity
doc_displ_and_veloc();
// Get displacement as a function of the radial coordinate
// along boundary 0
{
    // Number of elements along boundary 0:
    unsigned nelelem=solid_mesh_pt()->nboundary_element(0);
    // Open files
    sprintf(filename,"%s/displ%i.dat",Doc_info.directory().c_str(),
            Doc_info.number());
    some_file.open(filename);

    Vector<double> s(2);
    Vector<double> x(2);
    Vector<double> dxdt(2);
    Vector<double> xi(2);
    Vector<double> r_exact(2);
    Vector<double> v_exact(2);
    for (unsigned e=0;e<nelelem;e++)
    {
        some_file << "ZONE " << std::endl;
        for (unsigned i=0;i<npts;i++)
        {
            // Move along bottom edge of element
            s[0]=-1.0+2.0*double(i)/double(npts-1);
            s[1]=-1.0;
            // Get pointer to element
            SolidFiniteElement* el_pt=dynamic_cast<SolidFiniteElement*>
                (solid_mesh_pt()->boundary_element_pt(0,e));

            // Get Lagrangian coordinate
            el_pt->interpolated_xi(s,xi);
            // Get Eulerian coordinate
            el_pt->interpolated_x(s,x);
            // Get velocity
            el_pt->interpolated_dxdt(s,1,dxdt);

            // Plot radial distance and displacement
            some_file << xi[0] << " " << x[0]-xi[0] << " "
                << dxdt[0] << std::endl;
        }
    }
    some_file.close();
}

// Write trace file
Trace_file << time_pt()->time() << " ";
unsigned ntrace_node=Trace_node_pt().size();
for (unsigned j=0;j<ntrace_node;j++)
{
    Trace_file << sqrt(pow(Trace_node_pt[j]->x(0),2)+
        pow(Trace_node_pt[j]->x(1),2)) << " ";
}

```

```

Trace_file << std::endl;
// removed until Jacobi eigensolver is re-instated
// // Output principal stress vectors at the centre of all elements
// SolidHelpers::doc_2D_principal_stress_vectors<ELEMENT>(Doc_info,solid_mesh_pt());
// // Write restart file
// sprintf(filename,"%s/restart%i.dat",Doc_info.directory().c_str(),
//         Doc_info.number());
// some_file.open(filename);
// dump_it(some_file);
// some_file.close();

cout << "Doced solution for step "
      << Doc_info.number()
      << std::endl << std::endl << std::endl;
}
//=====
/// Doc displacement and veloc in displ_and_veloc*.dat.
/// The int stage defaults to 0, in which case the '*' in the
/// filename is simply the step number specified by the Problem's
/// DocInfo object. If it's +/-1, the word "before" and "after"
/// get inserted. This allows checking of the veloc/displacement
/// interpolation during adaptive mesh refinement.
//=====
template<class ELEMENT, class TIMESTEPPER>
void DiskShockWaveProblem<ELEMENT,TIMESTEPPER>::doc_displ_and_veloc(
    const int& stage)
{
    ofstream some_file;
    char filename[100];
    // Number of plot points
    unsigned npts;
    npts=5;
    // Open file
    if (stage==1)
    {
        sprintf(filename,"%s/displ_and_veloc_before%i.dat",
            Doc_info.directory().c_str(),Doc_info.number());
    }
    else if (stage==0)
    {
        sprintf(filename,"%s/displ_and_veloc%i.dat",
            Doc_info.directory().c_str(),Doc_info.number());
    }
    else
    {
        sprintf(filename,"%s/displ_and_veloc_after%i.dat",
            Doc_info.directory().c_str(),Doc_info.number());
    }
    some_file.open(filename);
    Vector<double> s(2),x(2),dxdt(2),xi(2),displ(2);
    //Loop over solid elements
    unsigned nel=solid_mesh_pt()->nelement();
    for (unsigned e=0;e<nel;e++)
    {
        some_file << "ZONE I=" << npts << ", J=" << npts << std::endl;
        for (unsigned i=0;i<npts;i++)
        {
            s[0]=-1.0+2.0*double(i)/double(npts-1);
            for (unsigned j=0;j<npts;j++)
            {
                s[1]=-1.0+2.0*double(j)/double(npts-1);
                // Cast to full element type
                ELEMENT* el_pt=dynamic_cast<ELEMENT*>(solid_mesh_pt()->
                    finite_element_pt(e));

                // Eulerian coordinate
                el_pt->interpolated_x(s,x);
                // Lagrangian coordinate
                el_pt->interpolated_xi(s,xi);
                // Displacement
                displ[0]=x[0]-xi[0];
                displ[1]=x[1]-xi[1];
                // Velocity (1st deriv)
                el_pt->interpolated_dxdt(s,1,dxdt);
                some_file << x[0] << " " << x[1] << " "
                    << displ[0] << " " << displ[1] << " "
                    << dxdt[0] << " " << dxdt[1] << " "
                    << std::endl;
            }
        }
    }
    some_file.close();
}
//=====
/// Dump the solution
//=====
template<class ELEMENT, class TIMESTEPPER>
void DiskShockWaveProblem<ELEMENT,TIMESTEPPER>::dump_it(ofstream& dump_file)

```

```

{
  // Call generic dump()
  Problem::dump(dump_file);
}
//=====
/// Read solution from disk
//=====
template<class ELEMENT, class TIMESTEPPER>
void DiskShockWaveProblem<ELEMENT,TIMESTEPPER>::restart(istream& restart_file)
{
  // Read generic problem data
  Problem::read(restart_file);
}
//=====
/// Run the problem; specify case_number to label output directory
//=====
template<class ELEMENT, class TIMESTEPPER>
void DiskShockWaveProblem<ELEMENT,TIMESTEPPER>::run(
  const unsigned& case_number)
{
  // If there's a command line argument, run the validation (i.e. do only
  // 3 timesteps; otherwise do a few cycles
  unsigned nstep=400;
  if (CommandLineArgs::Argc!=1)
  {
    nstep=3;
  }
  // Define output directory
  char dirname[100];
  sprintf(dirname,"RESLT%i",case_number);
  Doc_info.set_directory(dirname);
  // Step number
  Doc_info.number()=0;
  // Open trace file
  char filename[100];
  sprintf(filename,"%s/trace.dat",Doc_info.directory().c_str());
  Trace_file.open(filename);
  // Set up trace nodes as the nodes on boundary 1 (=curved boundary) in
  // the original mesh (they exist under any refinement!)
  unsigned nnod0=solid_mesh_pt()->nboundary_node(0);
  unsigned nnod1=solid_mesh_pt()->nboundary_node(1);
  Trace_file << "VARIABLES=\"time\"";
  for (unsigned j=0;j<nnod0;j++)
  {
    Trace_file << ", \"radial node \" << j << "\" ";
  }
  for (unsigned j=0;j<nnod1;j++)
  {
    Trace_file << ", \"azimuthal node \" << j << "\" ";
  }
  Trace_file << std::endl;
  // // Restart?
  // //-----
  // // Pointer to restart file
  // ifstream* restart_file_pt=0;
  // // No restart
  // //-----
  // if (CommandLineArgs::Argc==1)
  // {
  //   cout << "No restart" << std::endl;
  // }
  // // Restart
  // //-----
  // else if (CommandLineArgs::Argc==2)
  // {
  //   // Open restart file
  //   restart_file_pt=new ifstream(CommandLineArgs::Argv[1],ios_base::in);
  //   if (restart_file_pt!=0)
  //   {
  //     cout << "Have opened " << CommandLineArgs::Argv[1] <<
  //       " for restart. " << std::endl;
  //   }
  //   else
  //   {
  //     cout << "ERROR while trying to open " << CommandLineArgs::Argv[1] <<
  //       " for restart." << std::endl;
  //   }
  //   // Do the actual restart
  //   pause("need to do the actual restart");
  //   //problem.restart(*restart_file_pt);
  // }
  // // More than one restart file specified?
  // else
  // {
  //   cout << "Can only specify one input file " << std::endl;
  //   cout << "You specified the following command line arguments: " << std::endl;
  //   CommandLineArgs::output();

```



```

//      //assert(false);
//    }
// Initial parameter values
Global_Physical_Variables::P = 0.1;
// Initialise time
double time0=0.0;
time_pt()->time()=time0;
// Set initial timestep
double dt=0.01;
// Impulsive start
assign_initial_values_impulsive(dt);

// Doc initial state
doc_solution();
Doc_info.number()++;
// First step without adaptivity
unsteady_newton_solve(dt);
doc_solution();
Doc_info.number()++;
//Timestepping loop for subsequent steps with adaptivity
unsigned max_adapt=1;
for(unsigned i=1;i<nstep;i++)
{
    unsteady_newton_solve(dt,max_adapt,false);
    doc_solution();
    Doc_info.number()++;
}
}
//=====
/// Driver for simple elastic problem
//=====
int main(int argc, char* argv[])
{
    // Store command line arguments
    CommandLineArgs::setup(argc,argv);
    //Initialise physical parameters
    Global_Physical_Variables::E = 1.0; // ADJUST
    Global_Physical_Variables::Nu = 0.3; // ADJUST
    // "Big G" Linear constitutive equations:
    Global_Physical_Variables::Constitutive_law_pt =
        new GeneralisedHookean(&Global_Physical_Variables::Nu,
                               &Global_Physical_Variables::E);

    //Set up the problem:
    unsigned case_number=0;
    // Pure displacement formulation
    {
        cout << "Running case " << case_number
              << ": Pure displacement formulation" << std::endl;
        DiskShockWaveProblem<RefineableQPVElement<2,3>, Newmark<1> > problem;
        problem.run(case_number);
        case_number++;
    }

    // Pressure-displacement with Crouzeix Raviart-type pressure
    {
        cout << "Running case " << case_number
              << ": Pressure/displacement with Crouzeix-Raviart pressure" << std::endl;
        DiskShockWaveProblem<RefineableQPVElementWithPressure<2>, Newmark<1> >
            problem;
        problem.run(case_number);
        case_number++;
    }

    // Pressure-displacement with Taylor-Hood-type pressure
    {
        cout << "Running case " << case_number
              << ": Pressure/displacement with Taylor-Hood pressure" << std::endl;
        DiskShockWaveProblem<RefineableQPVElementWithContinuousPressure<2>,
            Newmark<1> > problem;
        problem.run(case_number);
        case_number++;
    }

    // Clean up
    delete Global_Physical_Variables::Constitutive_law_pt;
    Global_Physical_Variables::Constitutive_law_pt=0;
}

```

1.1 PDF file

A [pdf version](#) of this document is available.