PEER

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Introducing a New Uniaxial Material into OpenSees

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UniaxialMaterial Functionality

- Represent *all* one-dimensional material models
  - Stress-strain (σ–ε)
  - Force-deformation (s-e)
- Where are these objects used in OpenSees?
  - Truss elements (σ–ε)
  - Zero length elements (s-e)
  - Beam section fibers (σ–ε), e.g., steel, concrete
  - Resultant beam sections (s-e), e.g., M-κ
- Calling object (element or other material object) determines appropriate meaning, σ–ε or s-e

UniaxialMaterial

- Base class, UniaxialMaterial, provides its subclasses with a common interface
- The base class defines no data, only provides *virtual* methods, some with default behavior
- Subclasses provide specific implementations of the UniaxialMaterial interface

UniaxialMaterial Interface

```
class UniaxialMaterial : public Material
{
  public:
    UniaxialMaterial(int tag, int classTag);
    virtual ~UniaxialMaterial();

    virtual int setTrialStrain(double strain, double strainRate = 0.0) = 0;
    virtual double getStrain(void) = 0;
    virtual double getStrainRate(void);
    virtual double getStress(void) = 0;
    virtual double getTangent(void) = 0;
    virtual double getInitialtangent(void) =0;
    virtual double getDampTangent(void);

    virtual int commitState(void) = 0;
    virtual int revertToLastCommit(void) = 0;
    virtual int revertToStart(void) = 0;

    virtual UniaxialMaterial *getCopy(void) = 0;

    virtual Response *setResponse(const char **argv, int argc, Information &info);
    virtual int getResponse(int responseID, Information &info);
    virtual void Print(OPS_Stream &s, int flag =0);

  protected:
  private:
};
```

Must be overridden by subclass, “pure virtual”

Can be overridden by subclass

Constructor

```
UniaxialMaterial::UniaxialMaterial(int tag, int classTag):
Material(tag, classTag)
{
   // Does nothing
}
```

- This constructor calls its base class constructor (Material), which in turn calls the TaggedObject and MovableObject constructors
- Subclass constructors will take material parameters (floating point values or other data types) as arguments

Destructor

```
UniaxialMaterial::~UniaxialMaterial()
{
   // Does nothing
}
```

- This destructor does nothing
- Subclass destructors will deallocate any dynamically allocated memory

setTrialStrain

```
virtual int setTrialStrain(double strain,
                           double strainRate = 0.0);
```

- Must be implemented by subclasses
- Takes a strain and strain rate as arguments
- The default value passed for the strain rate is 0.0
- To store the current strain and strain rate (if used)

getStrain/getStrainRate

```
virtual double getStrain(void) = 0;
```

ε

- Must be implemented by subclasses
- To return the current value of strain

```
double
UniaxialMaterial::getStrainRate(void)
{
    return 0.0;
}
```

$\dot{\varepsilon}$

- This is the default implementation for strain rate

getStress

```
virtual double getStress(void) = 0;
```

$$\sigma = \sigma(\varepsilon, \dot{\varepsilon})$$

- Must be implemented by subclasses
- To return the current value of material stress including both strain and strain rate (if any) effects

getTangent/getDampTangent

```
virtual double getTangent(void) = 0;
```

$$\mathrm{D_t} = \frac{\partial\sigma}{\partial\varepsilon}$$

- Must be implemented by subclasses
- To return the current material tangent

```
double
UniaxialMaterial::getDampTangent(void)
{
   return 0.0;
}
```

$$\eta = \frac{\partial\sigma}{\partial\varepsilon \text{Ý}}$$

- This is the default implementation for the damping tangent

commitState

```
virtual int commitState(void) = 0;
```

- Must be implemented by subclasses
- UniaxialMaterial objects must manage their own history variables
- This method is invoked upon convergence during a time step
- To update the history variables for path dependence (if any) from time t_n to t_{n+1}
- To return 0 if successful and a negative number otherwise

revertToLastCommit/revertToStart

```
virtual int revertToLastCommit(void) = 0;
```

- To revert to last commit, i.e., at time t_n
- For most materials, nothing needs to be done here
- To return 0 if successful and a negative number otherwise

```
virtual int revertToStart(void) = 0;
```

- To revert to initial state
- To return 0 if successful and a negative number otherwise

getCopy

```
virtual UniaxialMaterial *getCopy(void) = 0;
```

- Must be implemented by subclasses
- To return a pointer to a new object which is a copy of this UniaxialMaterial object
- Invoked by a calling object, which is responsible for deallocating the dynamically allocated memory

sendSelf/recvSelf

```
virtual int sendSelf(int cTag, Channel &theChannel) = 0;

virtual int recvSelf(int cTag, Channel &theChannel,
                     FEM_ObjectBroker &theBroker) = 0;
```

- Two methods inherited from MovableObject for parallel processing and database programming
- To return 0 if successfully moved, a negative number otherwise
- Just make them return –1, then we’ll sort it out for you later!

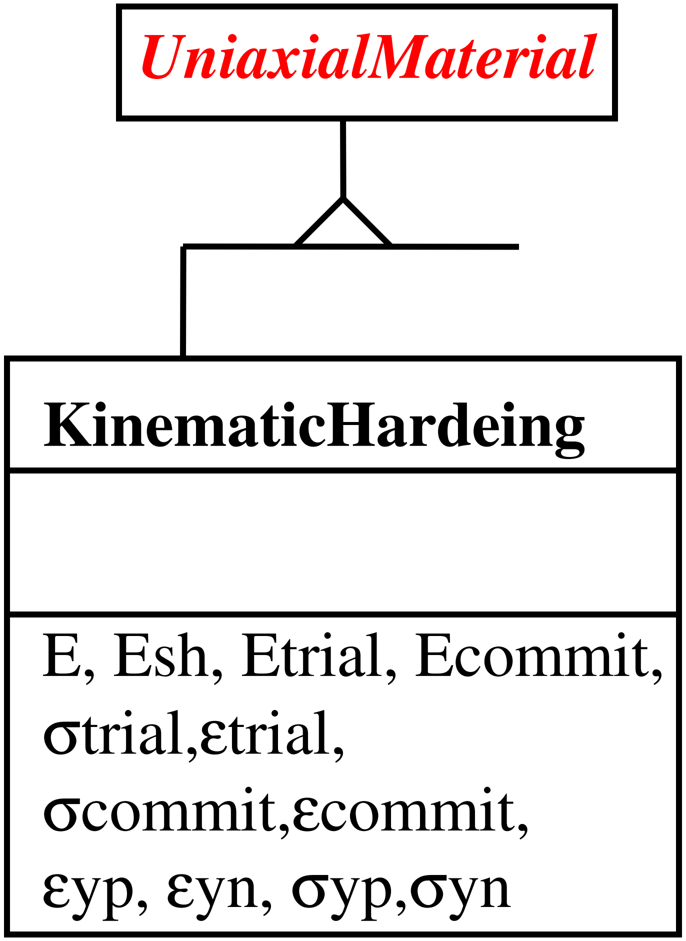
Print

```
  virtual void Print(ostream &s, int flag = 0) = 0;
```

- A utility method inherited from TaggedObject
- To print relevant information about the material, i.e., class name, tag, and material parameters to the stream object `s` passed as an argument
- For example:

```
s << “ElasticMaterial, tag: “ << this->getTag() << endl;
s << “E: “ << E << endln;
```

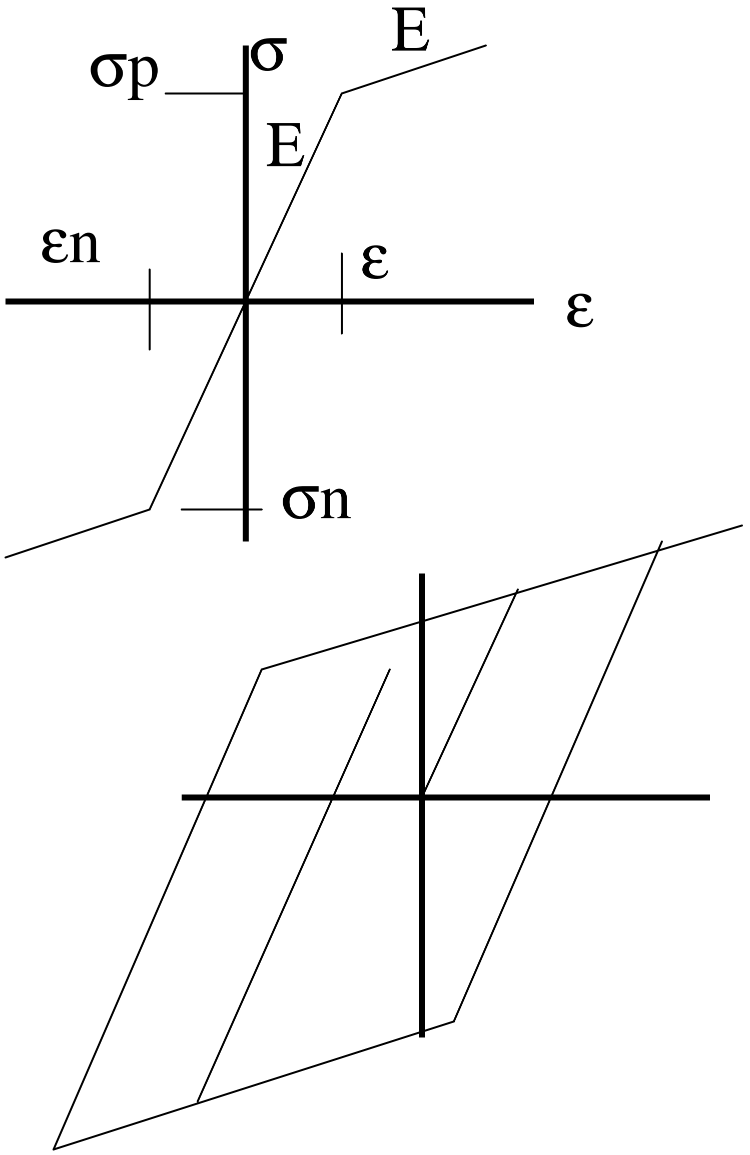
New KinematicHardening Material



UniaxialMaterial

KinematicHardeing

E, Esh, Etrial, Ecommit,
σtrial,εtrial,
σcommit,εcommit,
εyp, εyn, σyp,σyn



Implementation Exercise

Now it’s time to see how it really works …

- Save SRC/material/uniaxial/NewUniaxialMaterial.h/.cpp as KinematicHardening.h/.cpp and add these new files to the VC++ workspace (or Makefile).
- Check they compile & link.
- Make the changes outlined in following slides. (hint suggest compile & link after each method)
- Save SRC/material/uniaxial/TclNewMaterial.cpp as TclHardeningMaterial.cpp and make changes.
- Test it using the OpenSees/Tk UniaxialMaterial tester to see if your implementation works!!!

Interface

```
class KinematicHardeining : public UniaxialMaterial {
      public:
         KinematicHardeing(int tag, double E, double Ekh, double sigY);
         KinematicHardening();
        ~KinematicHardening();
         int setTrialStrain(double strain, double strainRate=0.0);
         double getStrain(void);
         double getStress(void);
        double getTangent(void);
         double getInitialTangent(void);

         int commitState(void);
         int revertToLastCommit(void);
         int revertToStart(void);

        UniaxialMaterial *getCopy(void);
        void Print(OPS_Stream &s, int flag = 0);
  private:
         double E, Ekh;
         double trialStrain, trialStress, trialTangent;
         double commitStrain, commitStress, commitTangent;
         double eyp, eyn, Syp, Syn;
};
```

Implementation

```
KinematicHardeining ::KinematicHardening(int tag, double e, double ekh, double sY)
:UniaxialMaterial(tag, MAT_TAG_KinematicHardening),
 E(e), Ekh(ekh), trialStrain(0.0),trialStress(0.0),trialTangent(e),
 commitStreain(0.0),commitStress(0.0),commitTangent(e)
{
   eyp = sY/e;
   eyn = -eyp;
   Syp = sY;
   Syn =-Sy;
}
KinematicHardeining ::KinematicHardening()
:UniaxialMaterial(tag, MAT_TAG_KinematicHardening)
 E(e), Ekh(ekh), trialStrain(0.0),trialStress(0.0),trialTangent(e),
 commitStreain(0.0),commitStress(0.0),commitTangent(e),eyp(0),eyn(0),Syp(0),Syn(0)
{
 }
KinematicHardening::~KinematicHardening
{
   // does nothing .. No memory to clean up
}
UniaxialMaterial *KinematicHardening::getCopy(void)
{
      KinematicMaterial *theCopy = new KinematicMaterial(this->getTag(), E, Ekh, Syp);
      return theCopy;
};
```

Implementation

```
int KinematicHardeining ::setTrialStrain(double strain, double strainRate)
{
     trialStrain = strain;
     if (trialStrain > eyp) {
       trialTangent = Ekh;
       trialStress = (trialStrain-eyp)*Ekh + Syp;
   } else if (trialStrain < eyn) {
       trialTangent = Ekh;
       trialStress = (trialStrain-eyn)*Ekh + Syn;
   } else {
        trialTangent = E;
        trialStress = (trialStrain - eyn)*E +Syn;
   }
    return 0;
}
double KinematicHardening::getStress(void)
{
     return trialStress;
}
double KinematicHardening::getTangent(void)
{
      return trialTangent;
}
```

Implementation

```
int KinematicHardeining ::commitState(void)
{
    if (trialStrain > eyp || trialStrain < eyn) {
      double diff ;
      if (trialStrain > eyp)
         diff =  trialStrain-eyp;
     else
         diff = trialStrain-eyn;
      eyp += diff;
      eyn += diff;
      Syp += diff*Ekh;
      Syn += diff*Ekh;
    }
    commitStrain = trialStrain;
    commitStress = trialStress;
    commitTangent = trialTangent;
    return 0;
 }
int KinematicHardening::revertToLastCommit(void)
{
     trialStrain = commitSTrain;
     trialStress = commitStress;
     trialTangent = commitTangent;
}
```

TclModelBuilderMaterialCommand.cpp additions:

```
int TclCommand_KinematicHardening(ClientData clientData, Tcl_Interp
      *interp, int argc, TCL_Char **argv, TclModelBuilder *tB);
```

```
else if strcmp(argv[1],”KinematicHardening” == 0) {
   return  TclCommand_KinematicHardening(clientData, interp, argc, argv,
      theTclBuilder);
}
```

TclKinematicHardening.cpp changes:

```
int TclCommand_KinematicHardening(ClientData clientData, Tcl_Interp
      *interp, int argc, TCL_Char **argv, TclModelBuilder *tB)
{
    int tag;
   double E, Ekh, Sy;
   UniaxialMaterial *theUniaxialMaterial = 0;
   Tcl_GetInt(interp, argv[2], &tag);
    Tcl_GetDouble(interp, argv[3], &E);
    Tcl_GetDouble(interp, argv[4], &Ekh);
    Tcl_GetDouble(interp, argv[5], &Sy);
    theUniaxialMaterial = new KinematicHardening(tag, E, Ekh, Sy);
    return theTclBuilder->addUniaxialMaterial(*theMaterial);
```