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
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
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**

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

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

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

- 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
virtual double getTangent(void) = 0;
• Must be implemented by subclasses
• To return the current material tangent

double UniaxialMaterial::getDampTangent(void) {
    return 0.0;
}
• This is the default implementation for the damping tangent

\[ D_t = \frac{\partial \sigma}{\partial \varepsilon} \]

\[ \eta = \frac{\partial \sigma}{\partial \dot{\varepsilon}} \]
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

```c
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:

\[
\begin{align*}
\text{s} & \ll \text{"ElasticMaterial, tag: "} \ll \text{this->getTag()} \ll \text{endl;} \\
\text{s} & \ll \text{"E: "} \ll E \ll \text{endln;}
\end{align*}
\]
New KinematicHardening Material

UniaxialMaterial

KinematicHardening

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!!!
class KinematicHardening : public UniaxialMaterial {
  public:
    KinematicHardening(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;
};
KinematicHardening ::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),
commitStrain(0.0),commitStress(0.0),commitTangent(e)
{
    eyp = sY/e;
    eyn = -eyp;
    Syp = sY;
    Syn =-Sy;
}
KinematicHardening ::KinematicHardening()
:UniaxialMaterial(tag, MAT_TAG_KinematicHardening)
E(e), Ekh(ekh), trialStrain(0.0),trialStress(0.0),trialTangent(e),
commitStrain(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;
};
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;
}
int KinematicHardening::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:

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

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

TclKinematicHardening.cpp changes:

```c
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);
}