

# Introducing a New Uniaxial Material into OpenSees

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# UniaxialMaterial Functionality

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

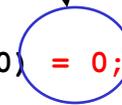
    virtual int commitState(void) = 0;
    virtual int revertToLastCommit(void) = 0;
    virtual int revertToStart(void) = 0;

    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;
```

$\epsilon$

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

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

$\dot{\epsilon}$

- 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;
```

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

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

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

$$\eta = \frac{\partial \sigma}{\partial \dot{\varepsilon}}$$

- 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/rcvSelf

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

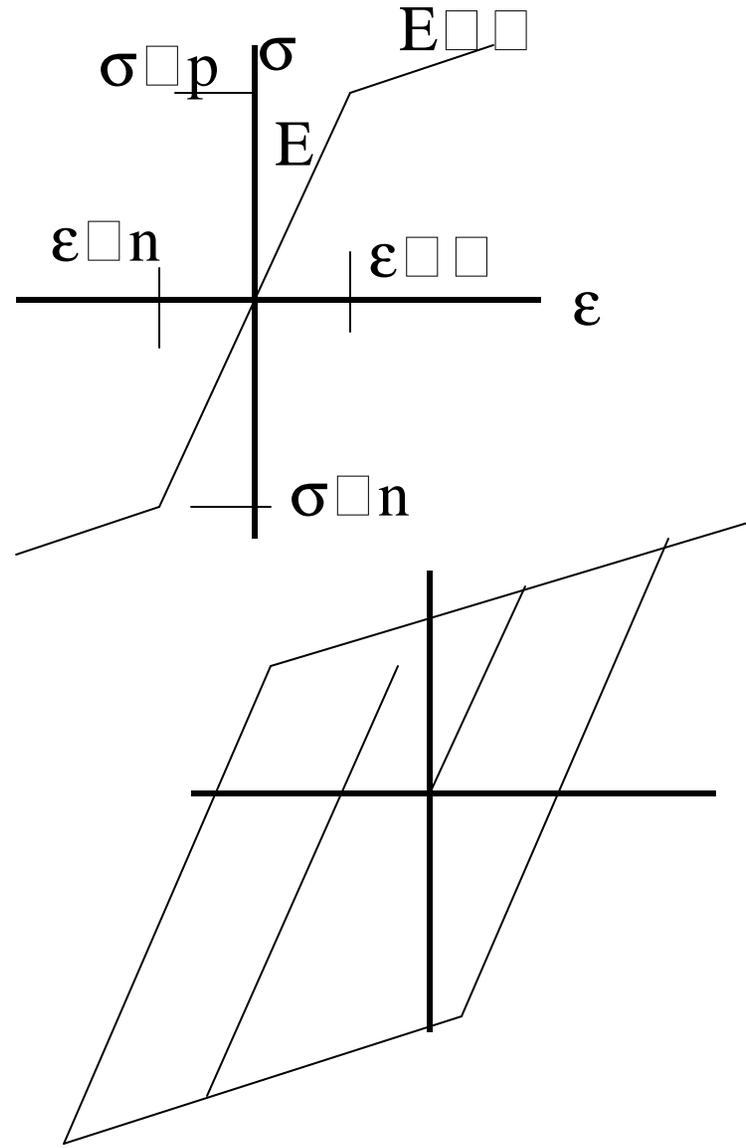
- A utility method inherited from TaggedObject
- To print relevant information about the material, i.e., class name, tag, and material parameters to the stream object `s` passed as an argument
- For example:

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

# New Kinematic Hardening Material

*UniaxialMaterial*

<b>Isotropic Hardening</b>
<p>E, Esh, Etrial, Ecommit,  <math>\sigma_{trial}, \epsilon_{trial},</math>  <math>\sigma_{commit}, \epsilon_{commit},</math>  <math>\epsilon_{yp}, \epsilon_{yn}, \sigma_{yp}, \sigma_{yn}</math></p>



# 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 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;
};
```

# 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 KinematicHardening ::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 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:

```
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);
}
```



# Numerical Roundoff

## Implementation Issue

```
int KinematicHardening ::commitState(void)
{
    if (fabs(trialStrain-commitStrain) < DBL_EPSILON)
        return 0;

    if (trialStrain > eyp || trialStrain < eyn) {
        .....
        .....
    }
}

int KinematicHardening ::setTrialStrain(double strain, double strainRate)
{
    if (fabs(trialStrain-strain) < DBL_EPSILON)
        return 0;

    trialStrain = strain;
    .....
    .....
    return 0;
}
```