Appendix B

Tcl Commands to Create Material Models using Template Elasto–Plastic Framework

B.1 Yield Surface Command

```
set ys "-YieldSurfaceType <parameter list>"
```

This command sets the yield surface variable `ys` to be the specified type. A list of paramaters can be passed to define the yield surface and the number of parameters depend on the type of yield surface. Valid strings for YieldSurfaceType are `DP`, `VM`, and `CC`, which are described in the following subsections.

B.1.1 Drucker-Prager Yield Surface

```
set ys "-DP"
```

`DP` stands for Drucker-Prager type, i.e. cone shaped yield surface. In this case, no parameter needs to be supplied since the slope α is treated as an internal variable.

B.1.2 von Mises Yield Surface

```
set ys "-VM"
```

`VM` stands for von Mises type, i.e. cylinder shaped yield surface. In this case, no parameter needs to be supplied since the size of the cylinder is treated as an internal variable.

B.1.3 Cam-Clay Yield Surface

```
set ys "-CC M?"
```

`CC` stands for Cam-Clay type, i.e. ellipsoid shaped yield surface. For `CC` type yield surface, the slope of the critical state line in p–q space, i.e. M, need to be supplied.

B.2 Potential Surface Command

```
set ps "-PotentialSurfaceType <parameter list>"
```

This command sets the potential surface variable `ps` to be the specified type. A list of paramaters can be passed to define the potential surface and the number of parameters depend on the type of potential surface. Valid strings for PotentialSurfaceType are `DP`, `VM`, and `CC`, which are described in the following subsections.

B.2.1 Drucker-Prager Potential Surface

```
set ps "-DP"
```

`DP` stands for Drucker-Prager type, i.e. cone shaped potential surface. In this case, no parameter needs to be supplied since the slope α is treated as an internal variable.

B.2.2 von Mises Potential Surface

```
set ps "-VM"
```

`VM` stands for von Mises type, i.e. cylinder shaped potential surface. In this case, no parameter needs to be supplied since the size of the cylinder is treated as an internal variable.

B.2.3 Cam-Clay Potential Surface

```
set ps "-CC M?"
```

`CC` stands for Cam-Clay type, i.e. ellipsoid shaped potential surface. For `CC` type potential surface, the slope of the critical state line in p–q space, i.e. M, need to be supplied.

B.3 Evolution Law Command

```
set el "-EvolutionLawType <parameter list>"
```

This command sets the evolution law variable `el` to be the specified type. A list of paramaters can be passed to define the potential surface and the number of parameters depend on the type of potential surface. Valid strings for EvolutionLawType are `Leq`, `NLp`, and , which are described in the following subsections.

B.3.1 Linear Scalar Evolution Law

```
set el "-Leq a?"
```

`Leq` stands for Linear Scalar Evolution Law. This hardening rule is based on the equivalent deviatoric plastic strain ϵ_q^{pl}. In this case, linear hardening coefficient `a` needs to be supplied. This hardening rule can be applied to any scalar internal variable, such as the slope of Drucker–Prager yield surface, the diameter of von Mises yield surface, and so on.

B.3.2 Nonlinear Scalar Evolution Law

`set el "-NLp` e_o? λ? κ? `"`

`NLp` stands for Nonlinear Scalar Evolution Law. This hardening rule is based on the volumetic plastic strain ϵ_p^{pl}. In this case, parameters including void ration e_o, λ and κ need to be supplied. This hardening rule is primarily for the evolution of the tip stress $p_o^{'}$ in Cam-Clay model.

B.3.3 Linear Tensorial Evolution Law

```
set et "-LEij a?"
```

`LEij` stands for Linear Tensorial Evolution Law. This hardening rule is based on the plastic strain ϵ_{ij}^{pl}. In this case, linear hardening coefficient `a` needs to be supplied. This hardening rule can be applied to any tensorial internal variable, such as the the center α_{ij} of Drucker–Prager yield surface or von Mises yield surface, and so on.

B.3.4 Nonlinear Tensorial Evolution Law (Armstrong-Frederick model)

`set et "-NLEij` h_a? C_r? `"`

`NLEij` stands for Nonlinear Tensorial Evolution Law from Armstong–Frederick nonlinear model. This kinematic hardening law is based on the plastic strain ϵ_{ij}^{pl}. In this case, nonlinear hardening coefficients h_a and C_r need to be supplied. This hardening rule can be applied to any tensorial internal variable, such as the the center α_{ij} of Drucker–Prager yield surface or von Mises yield surface, and so on.

B.3.5 Nonlinear Tensorial Evolution Law (Manzari-Dafalias model)

`set et "-NLEijMD` h_a? C_r? `"`

`NLEij` stands for Nonlinear Tensorial Evolution Law from Manzari–Dafalias model. This kinematic hardening law is based on the plastic strain ϵ_{ij}^{pl}. In this case, nonlinear hardening coefficients h_a and C_r need to be supplied. This hardening rule can be applied to any tensorial internal variable, such as the the center α_{ij} of Drucker–Prager yield surface or von Mises yield surface, and so on.

B.4 EPState Command

`set sts "` σ_{xx}? σ_{xy}? σ_{xz}? σ_{yx}? σ_{yy}? σ_{yz}? σ_{zx}? σ_{zy}? σ_{zz}?`"`

`set eps "` E_o? E? ν? ρ? -NOD nt? -NOS ns? scaler1? scaler2? ... -stressp $sts"

First statement sets the initial stress tensor to variable `sts`. Second statement assigns to the Elasto-Plastic State variable `eps` the specified state parameters, including Young's Modulus at atmospheric pressure E_o, current Young's Modulus E, Poisson's ratio ν, mass density ρ, number of tensorial internal variables `nt`, number of scalar internal variables `ns` and corresponding initial values scaler1, scaler2 ..., and initial stresses defined in $sts.

B.5 Template Elasto-Plastic Material Command

`nDMaterial Template3Dep` matTag? -YS $ys? -PS $ps? -EPS $eps? -ELS1 $el? <-ELT1? $et?>

A template elasto-plastic material is contructed using `nDMaterial` command. The argument matTag is used to uniquely identify this nDMaterial object among nDMaterial objects in the BasicBuilder object. The other parameters include previously defined yield surface object `ys`, potential surface object `ps`, elasto-plastic state object `eps`, scalar evolution law object `el`, and tensorial evolution law object `et`.

B.6 Examples

B.6.1 von Mises Model

```
# Yield surface
set DPys "-VM"

# Potential surface
set DPps "-VM"

# Scalar evolution law: linear hardening coef = 1.0
set ES1  "-Leq  1.10"

# Initial stress
set sts "0.10 0 0  0 0.10 0  0 0 0.10"

# EPState
#__________E________Eo____v___rho______________k=f(Cu)
set EPS "70000.0 70000.0 0.35 1.8 -NOD 0 -NOS 1  20  -stressp $sts"#

# Creating nDMaterial using Template Elastic-PLastic Model
nDMaterial Template3Dep 1 -YS $DPys -PS $DPps -EPS $EPS -ELS1 $ES1
```

B.6.2 Drucker–Prager Model

```
# Yield surface
set DPys "-DP"

# Potential surface
set DPps "-DP 0.1"

# Scalar evolution law: linear hardening coef = 1.0
```

```
set ES1  "-Leq  1.10"

# Initial stress
set sts "0.10 0 0  0 0.10 0  0 0 0.10"

# EPState
#__________E________Eo____v___rho______________alpha___k
set EPS "70000.0 70000.0 0.35 1.8 -NOD 0 -NOS 2  0.2    0.0 -stressp $sts"
#
# where
#alpha = 2 sin(phi) / (3^0.5) / (3-sin(phi) ), phi is the friction angle
# and k is the cohesion

# Creating nDMaterial using Template Elastic-PLastic Model
nDMaterial Template3Dep 1 -YS $DPys -PS $DPps -EPS $EPS -ELS1 $ES1
```

B.6.3 Cam-clay Model

```
# Yield surface M = 1.2
set DPys "-CC 1.2"

# Potential surface M = 1.2
set DPps "-CC 1.2"

# Scalar evolution law___void ratio___Lamda___Kappa
set ES1  "-NLp           0.85        0.19   0.06"

# Tensorial evolution law
set ET1  "-Linear  0.0"

# Initial stress
set sts "0.10 0 0  0 0.10 0  0 0 0.10"

#____________E______Eo_____v__rho________________po
set EPS "70000.0 70000.0 0.3 1.8 -NOD 0 -NOS 1 200.1 -stressp $sts"

#
nDMaterial Template3Dep 1 -YS $DPys -PS $DPps -EPS $EPS -ELS1 $ES1
```