

1 Hysteretic Damping Model

The contact model **hysdamp** is intended to introduce energy dissipation by hysteretic damping to a linear contact model with frictional slip.

The model has the following properties.

hys_knm	normal stiffness, the average of the normal stiffness on loading, Kn_load , and on unloading, Kn_unload
hys_dampn	the ratio of normal stiffness on loading, Kn_load , to that on unloading, Kn_unload , ($0.4 \leq \mathbf{hys_dampn} \leq 1.0$ (with tensile force); $0.05 \leq \mathbf{hys_dampn} \leq 1.0$ (without tensile force); default 0.8)
hys_ks	shear stiffness
hys_fric	friction coefficient
hys_nstr	contact bond normal strength [force]
hys_sstr	contact bond shear strength [force]
hys_notension	switch (0: tensile force allowed (default); 1: no tension allowed)
hys_inheritprop	switch (0: the model does not inherit properties from <i>PFC^{2D}</i> , (default); 1: the model inherits the properties)

The normal stiffness on loading, **Kn_load**, and on unloading, **Kn_unload**, used in this model are calculated (Eqs. (1.1) and (1.2)) using **hys_dampn** and **hys_knm**.

$$K_{n_load} = \frac{2 \cdot \mathbf{hys_dampn} \cdot \mathbf{hys_knm}}{(1 + \mathbf{hys_dampn})} \quad (1.1)$$

$$K_{n_unload} = \frac{2 \cdot \mathbf{hys_knm}}{(1 + \mathbf{hys_dampn})} \quad (1.2)$$

where **hys_knm** is taken as the average of **Kn_load** and **Kn_unload**.

Note that if **hys_inheritprop** is set to 1, the model sets the parameters, **hys_knm**, **hys_ks**, **hys_fric**, **hys_nstr** and **hys_sstr** to the values of normal stiffness, shear stiffness, friction coefficient, contact bond normal strength and contact bond shear strength to those values associated with contacts before cycling, even though these parameters are specified explicitly. If

hys_inheritprop is set to 0 (default), users must specify these values (**hys_knm** at minimum). Otherwise, *PFC^{2D}* posts an error message before cycling.

In the hysteretic damping model, normal stiffness on unloading is greater than that on loading (see [Figure 1.1](#)). The hysteretic damping is independent of the relative velocity before and after contact between two entities. It is suggested that the ratio between the two stiffnesses, **hys_dampn**, should be determined with a parametric pretest to obtain a measurable quantity, such as the restitution coefficient (see [Figure 1.2](#)), which illustrates the results of drop tests. Also, the local-damping coefficient should be set to zero in advance by the command **PROP damp** or the *FISH* function **b_damp(bp)** (see the **zero_damp** function in [Example 1.1](#)). The data file used for the drop tests is shown in [Example 1.1](#).

This damping model is applicable to impact problems in which there is large relative particle movement, but it should not be used for problems of compact particle assemblies.

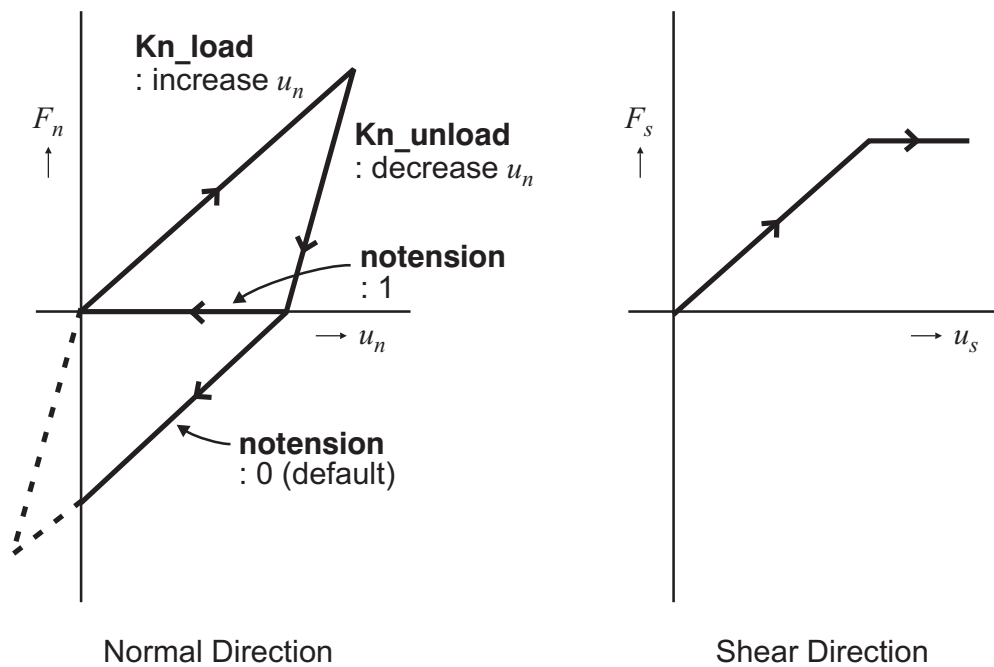


Figure 1.1 *Hysteretic response*

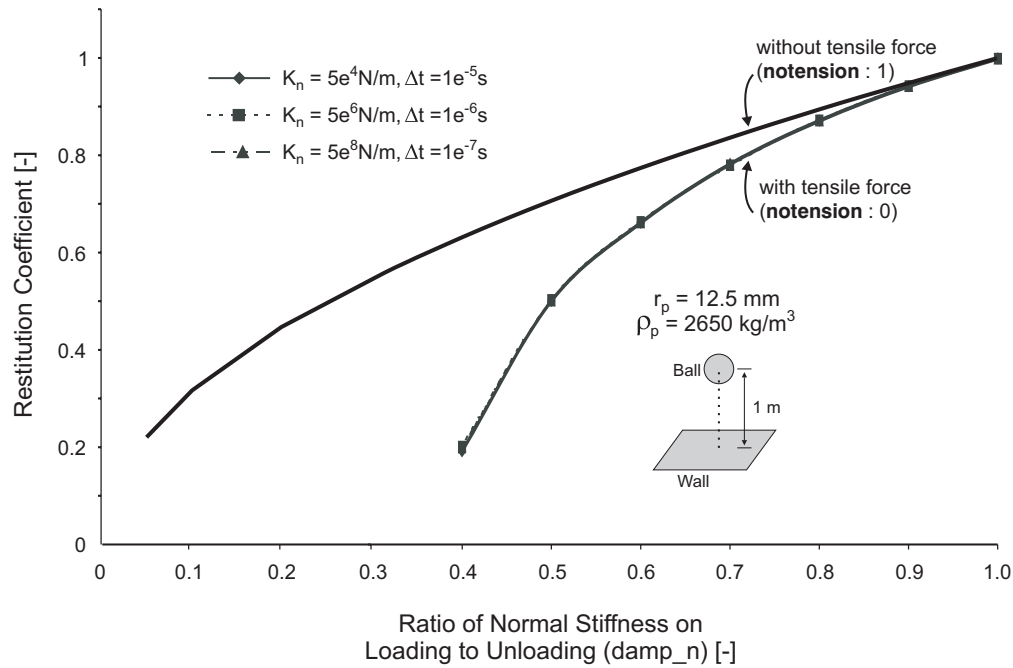


Figure 1.2 Relation between restitution coefficient and ratio of normal stiffness on loading to unloading, `hys_dampn`

Example 1.1 Data file for drop tests

```

; fname: drop2dhys.DAT
new
set dt max 1.0e-4
set pinterval 200
config cppudm
model load hys2wrv.dll
;-----
def make_ball
  command
    ball id = 1 rad = 0.04 x = 0.0 y = 1.0 ;0.03 ; 1.0
    prop dens = 2600 kn = 1.0e6 ks = 1.0e6 fric = 0.0
  end_command
end
;-----
def zero_damp
  bp = ball_head
  loop while bp # null
    b_damp(bp) = 0.0
    bp = b_next(bp)
  end_loop

```

```

end
;-----
def catch_contact_hys
  cp = fc_arg(0);
  c_model(cp) = 'hysdamp'
  c_prop(cp, 'hys_dampn')= setv
  c_prop(cp, 'hys_notension')= 1 ; 0 if you want tensile force
  c_prop(cp, 'hys_inheritprop')= 1
end
;-----
def plot_view
  command
    title 'Drop Tests with Hysteretic Damping (damp_n: 1.0, 0.8, 0.5)'
    plot create 1
    plot add axes black
    plot add ball yellow
    plot add wall lblue
    plot add cf white
  end_command
end

model hysdamp
set fishcall 6 catch_contact_hys
plot_view

wall id = 1 kn = 1.0e6 ks = 1.0e6 fric = 0.0 &
  nodes (-0.5,0.0) (0.5,0.0)
set grav 0 -9.8

; ----- case damp_n = 1.0 -----
make_ball
zero_damp
set setv = 1.0
plot show
cycle 30000
del ball 1
; ----- case damp_n = 0.8 -----
make_ball
zero_damp
set setv = 0.8
cycle 70000
del ball 1
; ----- case damp_n = 0.5 -----
make_ball
zero_damp
set setv = 0.5

```

```
cycle 20000  
return
```
