

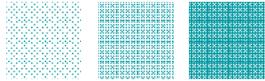
Explizite Finite Elemente Methode

LV03: Masterkurs für MK-M , ME-M und PE-M

Partical Flow Code (PFC)
Syntax, Kontaktdefinitionen



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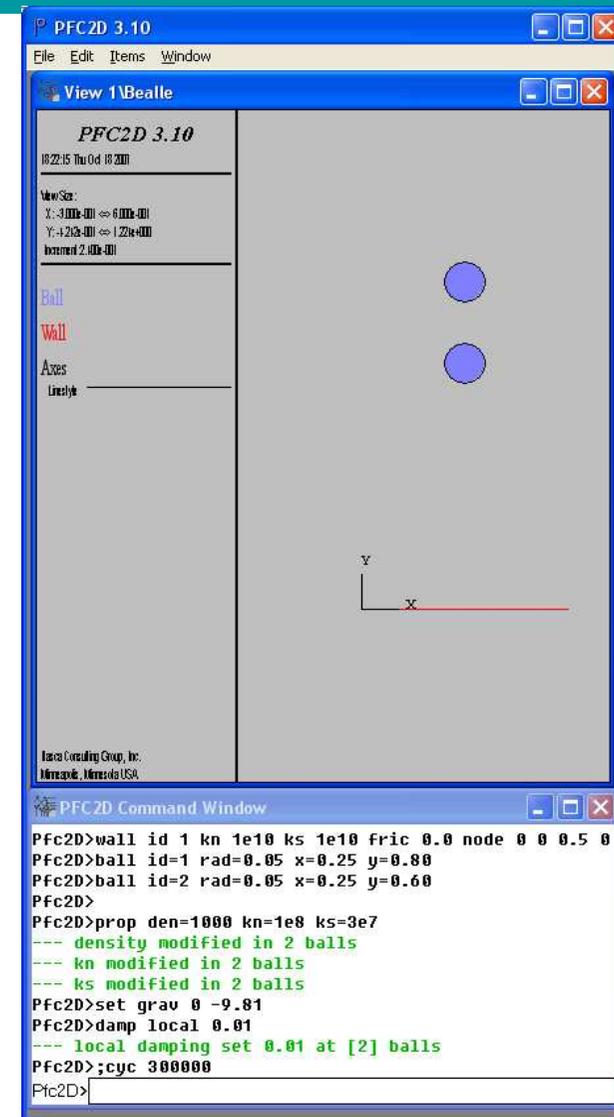
Einführendes PFC-Beispiel



- **new** ;löschen alter Daten
- **plot create** Baele ;neues Grafikfenster
- **pl add ball lblue wall red** ;Geometrie Balle Wand
- **pl add ax** ;Achenkreuz im Ursprung
- **pl set size -0.3 0.6 -0.2 1.0** ;Fenstergröße 0.9x1.2
- **pl show** ;Darstellung Grafikfenster

- **wall id 1 kn 1e10 ks 1e10 fric 0.0 node (0, 0) (0.5, 0)**
- **ball id=1 rad=0.05 x=0.25 y=0.80** ;Wände und Bälle
- **ball id=2 rad=0.05 x=0.25 y=0.60** ;haben eigene id

- **prop den=1000 kn=1e8 ks=3e7** ;Dichte u. Steifigkeit
- **set grav 0 -9.81** ;Gravitation in – Y-Richt.
- **damp local 0.01** ;Dämpfung bei Berührung
- **cyc 300000** ;Anzahl Zeitschritte



Variable definiert durch macro



- `title 'Bordstein Rad rauh mit macro'`
- `macro my '0.5'` ;Variable definiert mit Wert
- `macro knkswall 'kn=1e10 ks=1e10'`
- `set disk 0.5` ;Scheiben mit Dicke
- `wall id=1 kn=1e10 ks=1e10 fric=0.5 node (0, 0) (1.0, 0.00)`
- `wall id=2 knkswall fric=my node (1.0, 0.05) (12.00 0.05)`
- `ball id=1 rad=0.20 x=0.20 y=0.20`

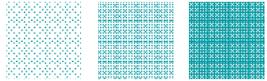
- `hist nstep 5 ball spin id=1` ;alle 5 Zeitschritte eine Ausgabe
- `plot create Spin`
- `plot hist 1` ;Time-History der Drehung
- `plot create Baele`
- `pl add ball lblue wall red`
- `pl set size -0.30 14.0 -0.20 0.60`
- `pl show`
- `prop dens=1000 kn=1e8 ks=3e7 fric= my`
- `set grav 0 -9.81`
- `damp local 0.0001`
- `init xv=5 yv=0 spin=-25` ;Anfangsgeschwindigkeiten
- `cyc 12000`

```
PFC2D 3.10
File Settings Views Window Help

View 3DBaele
PFC2D 3.10
21:13:40 Thu Oct 18 2000
View Size:
X: -2.30e+001 to 1.40e+001
Y: -1.17e+000 to 1.65e+000
Increment 2.300e+000

Title: Bordstein Rad rauh mit macro

PFC2D Command Window
Pfc2D>set grav 0 -9.81
Pfc2D>prop fric=my
--- friction modified in 1 balls
Pfc2D>damp local 0.0001
--- local damping set 0.0001 at [1] balls
Pfc2D>init xv=5 yv=0 spin=-25
--- xvelocity modified in 1 balls
--- yvelocity modified in 1 balls
--- spin modified in 1 balls
Pfc2D>
Pfc2D>
Pfc2D>;cyc 12000
Pfc2D>
Pfc2D>
```



Zeitschritt bei Bällen und Scheiben



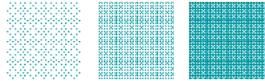
| | Bälle | Disk |
|-------|----------------------------|------------------|
| m | $\rho \frac{4}{3} \Pi r^3$ | $\rho \Pi r^2 s$ |
| J_s | $0,4 m r^2$ | $0,5 m r^2$ |

- **set** disk on ; es wird die Scheibendicke $s=1$ gesetzt
- Die kleinen Partikel bestimmen den Zeitschritt:

$$\Delta t = \min [(m/k_n)^{0,5} , (J_s/k_{rot})^{0,5}] \quad \text{mit } k_{rot} = r^2 k_s$$

- **set** dt max=1e-5 ; es wird unabhängig von Partikeln Δt gesetzt





Strukturen: def, loop, command



- title 'Stab gleitet ab'
- new
- wall id=1 kn=1e10 ks=1e10 fric=0.0001 node (0,0) (0.6,0.01)

- def baelle
 - loop n (1,10)
 - y_n=-0.05+n*0.2
 - command
 - ball id n rad 0.10 x 0.1 y=y_n
 - end_command
 - end_loop
- end

- baelle
 - pl add ball lblue wall red pb green pf black cont black
 - pl set size -0.30 0.60 -1.80 2.20
 - pl show
 - prop dens 1000 kn 2e5 ks 1e5
 - prop n_bond 1e6 s_bond 1e5
 - prop pb_n 1e10 pb_s 1e9 pb_kn 2e10 pb_ks 1e10 pb_r 0.8
 - set grav 0 -9.81
 - prop fric 0.1
 - cyc 60000

PFC2D 3.10

File Edit Items Window

View OBase

PFC2D 3.10 Job Title: Stab gleitet ab

Step 60000 21:32:28 Thu Oct 18 2001

View Size:
X: -0.91e+001 ↔ 1.19e+000
Y: -1.800e+000 ↔ 2.200e+000
Increment 2.191e-001

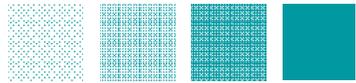
Ball
Wall
Fluid Location
Force Chains
Compression
Tension
Maximum = 1.190e+002

Tasca Consulting Group, Inc.
Minneapolis, Minnesota USA

PFC2D Command Window

```

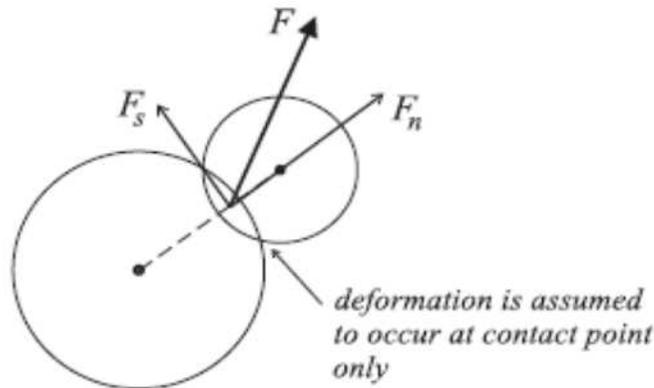
--- pb_radius modified in 10 contacts
Pfc2D>set grav 0 -9.81
Pfc2D>prop fric 0.1
--- friction modified in 10 balls
Pfc2D>
Pfc2D>cyc 60000
starting cycle:      0      av-unbal force:  0.
starting time: 21:26:20  max-unbal force:  0.
step      of      total time-step      time av
-----
60000    60000    60000  4.494e-005  2.699e+000  2.05
ending cycle:      60000      av-unbal force:  2.
ending time: 21:26:28  max-unbal force:  4.
Pfc2D>
  
```



Einheiten für poperty



| | | | |
|---|--------|------------------|--------------------------------------|
| ■ | n_bond | N | Normalbruchkraft |
| ■ | s_bond | N | Scherbruchkraft) |
| ■ | kn | N/m | Normalfedersteifigkeit |
| ■ | ks | N/m | Scherfedersteifigkeit |
| ■ | pb_n | N/m ² | Normalbruchspannung (parallel bond) |
| ■ | pb_s | N/m ² | Scherbruchspannung („ „) |
| ■ | pb_kn | N/m ³ | Bettung in Normalen-Richtung („ „) |
| ■ | pb_ks | N/m ³ | Bettung in Scher-Richtung („ „) |
| ■ | pb_r | 0.8 | Kontaktfläche 80% des Partikalradius |



Linear contact law

$$F_n = k_n U_n$$

$$\Delta F_s = k_s \Delta U_s$$

Hertz-Mindlin contact law

*Non-linear relation between force and displacement
(for elastic spheres in contact)*

Slip condition

$$F_s \leq \mu F_n$$

friction coefficient

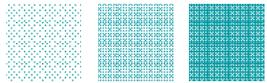
Contact logic

ball id=1 , rad=0.05 &
x=0.40 , y=0.80 , hertz

prop kn=1e8 , ks=3e7
;bei hertz nicht wirksam

prop pois=0.3 ,shear=1e5
;ohne hertz nicht wirksam

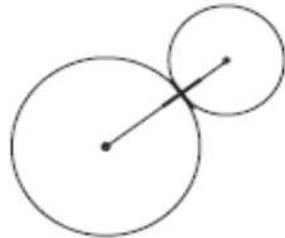
prop fric=ny



Bindungen bis zum Bruch

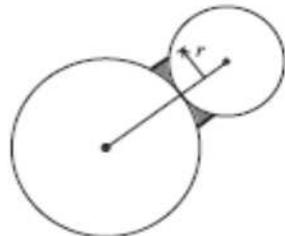


contact bond



*models adhesion over vanishingly small area of contact point
(does not resist moment)
breaks if normal or shear force exceeds bond strength*

parallel bond



*models additional material deposited after balls are in contact
(does resist moment)
breaks if normal or shear stress exceeds bond strength*

```
prop n_bond=1e6 ;N  
prop s_bond=1e5 ;N
```

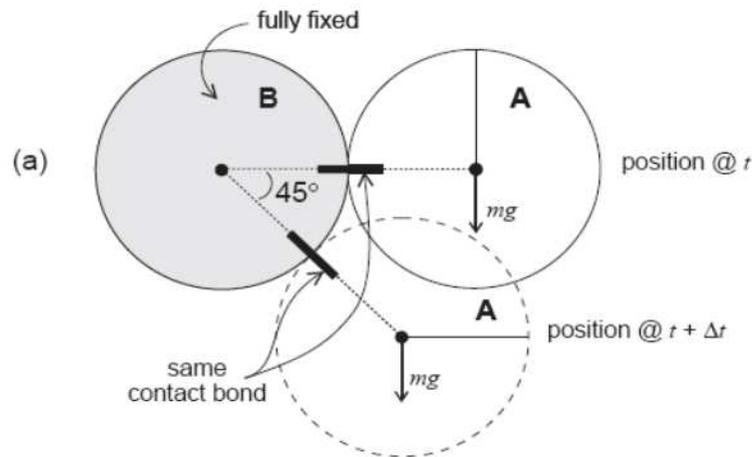
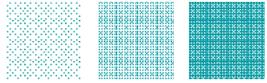
```
prop kn 2e5 ;N/m  
prop ks 1e5 ;N/m
```

```
prop pb_n=1e10 ;N/m^2  
prop pb_s=1e9 ;N/m^2
```

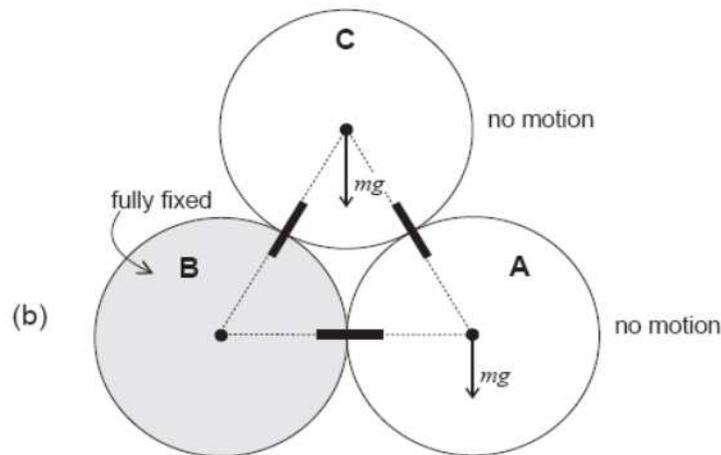
```
prop pb_kn=2e10 ;N/m^3  
prop pb_ks=1e10 ;N/m^3  
prop pb_r=0.8 ;m
```

Bonding logic





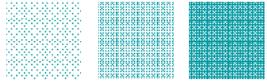
Auch bei
Normal- und/oder
Scherverbund ist
reines rollen möglich



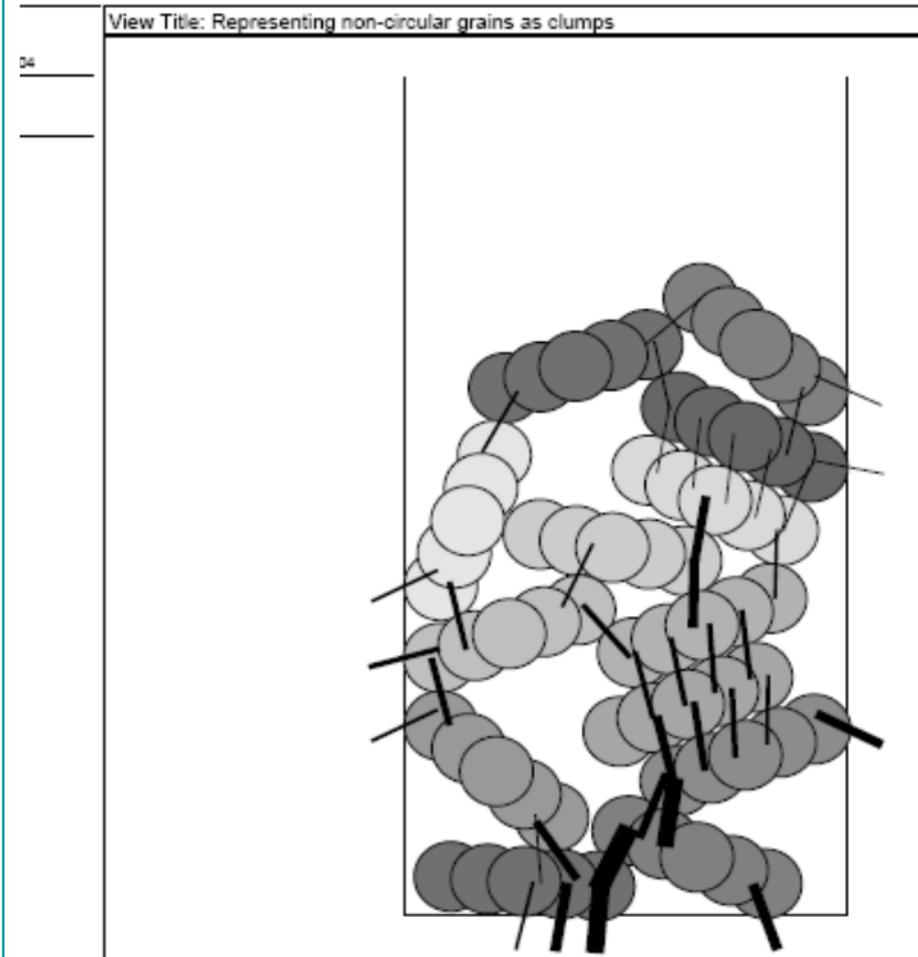
bei 3 Körperkontakten
Blockierung,
bei 4 eventuell
reines rollen möglich

3.10 Rolling without slip at a contact bond





Clumps, Bildung neuer Patrikelgeometrien



```
ball x 0 y 2 rad 1
ball x 2 y 2 rad 1
ball x 4 y 2 rad 1
clump id=1 range y=1,3
ball x 2 y 5 rad 1
ball x 4 y 5 rad 1
ball x 6 y 5 rad 1
clump id=2 range y=4,6
```

State of the system at equilibrium (13 clumps)



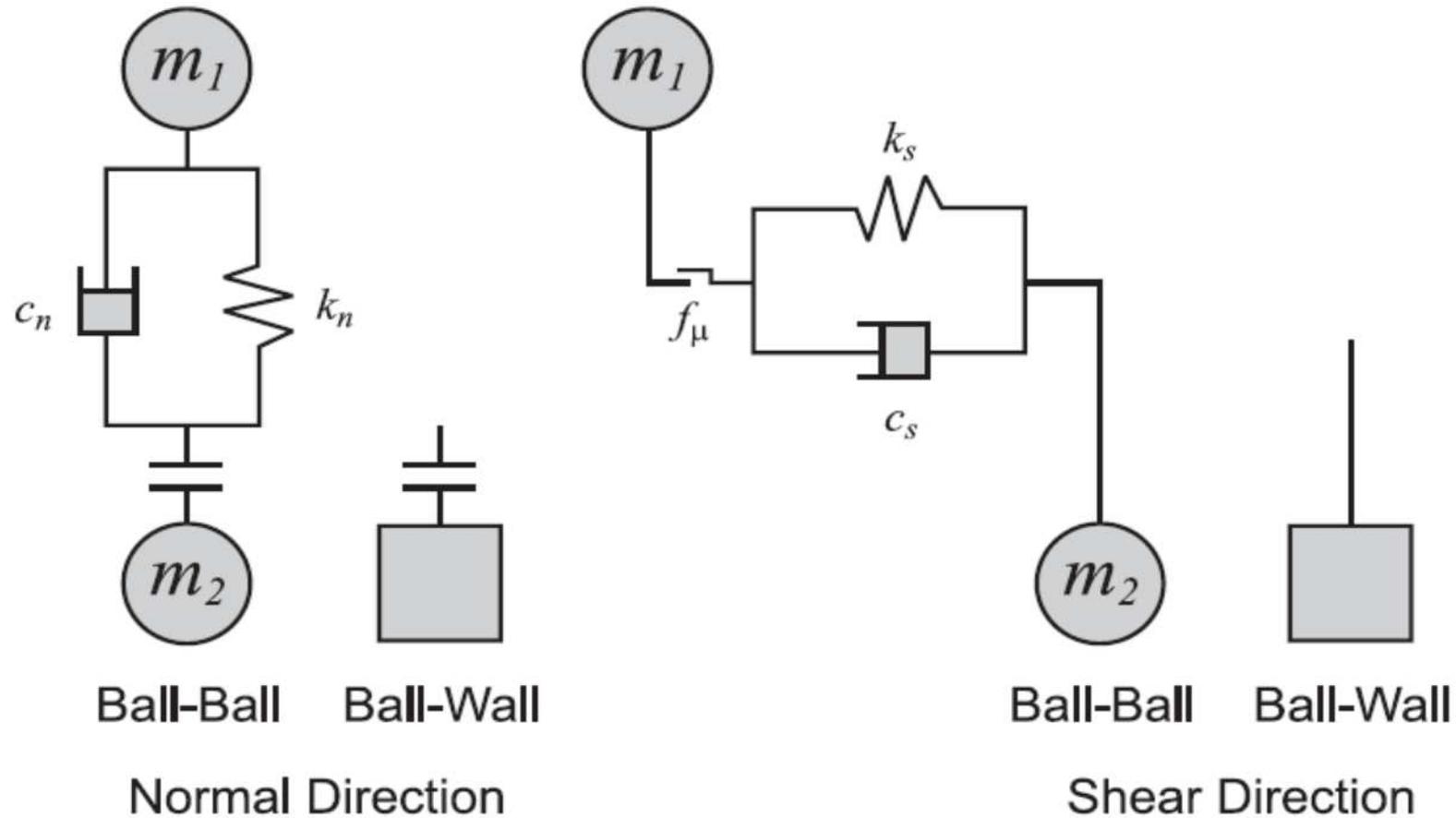


Figure 1.8 Viscous damping activated at a contact with the linear contact model

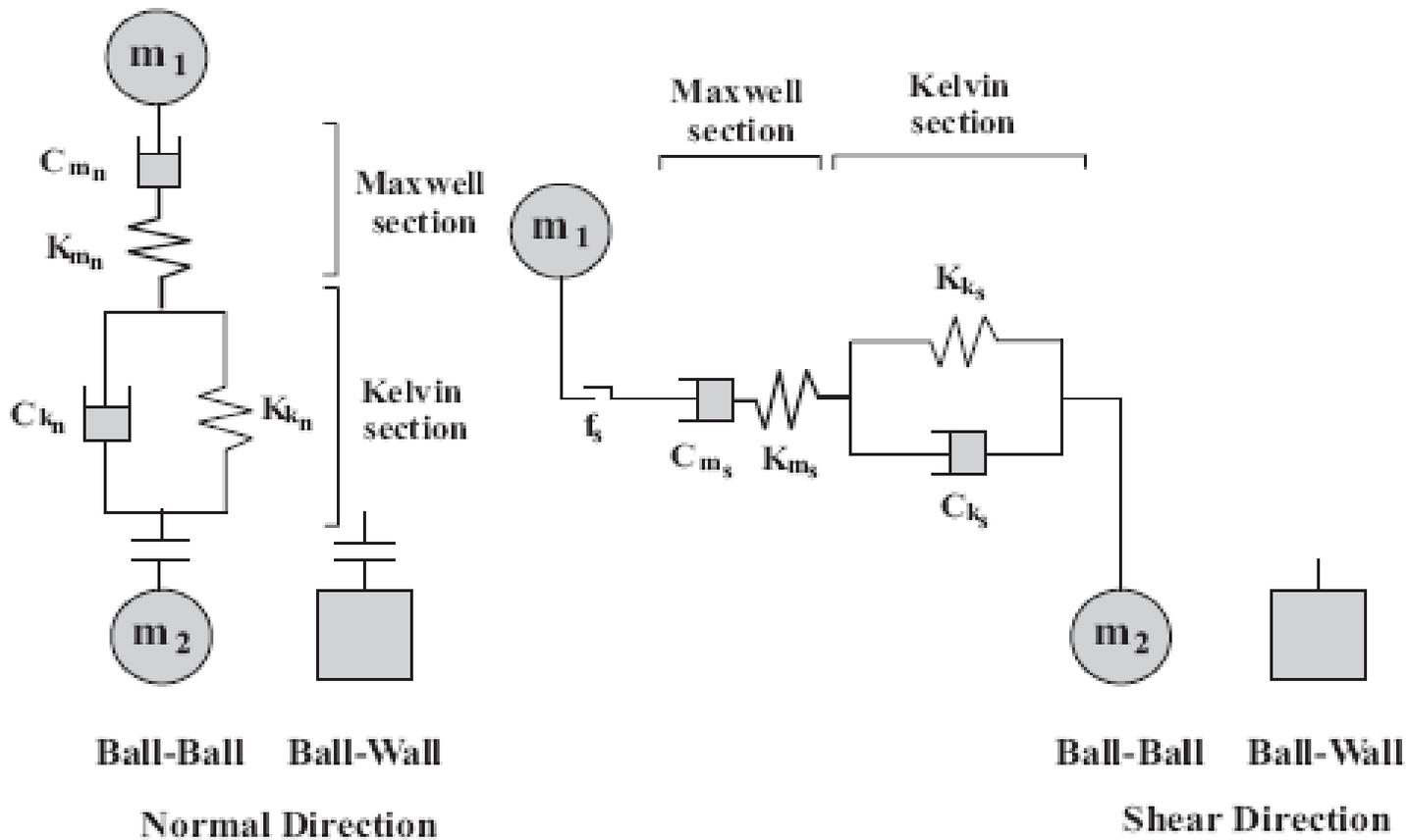


Figure 2.7 *The Burger's model in PFC^{2D}*

