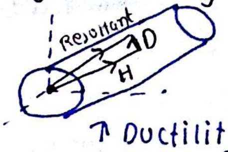
METAL FORMING

1- W. Drawing 2- T. drawing 3- Extrusion 4- Forging 5- Rolling 6- sheet m. forming

Stress devpt. when force applied:

$$\begin{bmatrix}\sigma_{xx} & \tau_{xy} & \tau_{xz}\\ \tau_{yx} & \sigma_{yy} & \tau_{yz}\\ \tau_{zx} & \tau_{zy} & \sigma_{zz}\end{bmatrix} = \begin{bmatrix}\sigma_{xx}-\sigma & \tau_{xy} & \tau_{xz}\\ \tau_{yx} & \sigma_{yy}-\sigma & \tau_{yz}\\ \tau_{zx} & \tau_{zy} & \sigma_{zz}-\sigma\end{bmatrix} + \begin{bmatrix}\sigma & 0 & 0\\ 0 & \sigma & 0\\ 0 & 0 & \sigma\end{bmatrix}$$

Deviator — Hydrostatic



Elastic: Res. Inside cyl

Plastic: " outside "

↑ Ductility if Elastic ie. Res. inside cyl i.e. ↑ Hydrostatic component

Types of Problems: Formula for Both $\sigma_1 - \sigma_2 = 2k'$ σ_1, σ_2 = Pri. stresses ∴ k' = Yield strength in shear

Plane stress - Tresca $k' = \sigma_0/2$ Bi-direcnal σ other wise

Plain strain - v-mises $k' = \sigma_0/\sqrt{3}$ " ε metal flow Restricted in any direcn

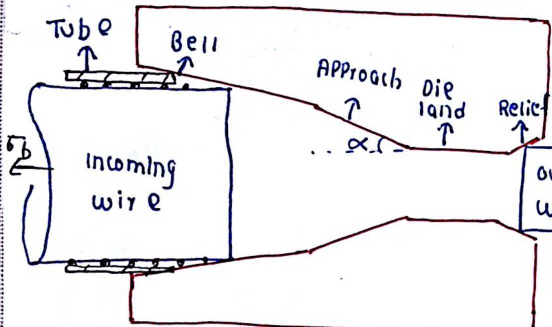
Nominal stress: σ_0 = pressure at which metal starts to flow & takes shape of dies.

(i) if y.s. given - $\sigma_0 = \sigma_y$ (Elastic Region)

(ii) if K, n " - $\sigma_0 = \sigma_{fm} = \dfrac{K\cdot\varepsilon_1^n}{n+1}$ (plastic Region) Hollomen Eqn. $\sigma_f = K\cdot\varepsilon^n$ (→ True σ; n → w. hard expo; K → Strength coeff; ε → True ε)

ε_1 = True strain at UTS   # $\varepsilon = \ln(1+e)$ ε = True strain, e = Engg "

WIRE DRAWING: Plain strain: $k' = \sigma_0/\sqrt{3}$. purpose: To use wire dia.



σ_b = Back pull

σ_d = Drawing stress

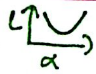
* Initially bended or given a twist: To Remove oxide layer

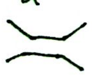
* Lubrication → Liq. - Bright finish (oil, soap soln); → Solid - Dull surface (Graphite, Al powder) but ↑er Reducn

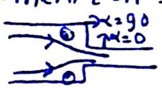
- pressurised lubrication (Thats why Tube)

* why σ_b: - keeps wire straight - prevents damage to bell secn.

* Deformation → Elastic - Bell; → Plastic - approach

* Load - α :  Initially L use with α b/c length in App. ↓ → fricn Energy ↓es; later L ↑se " " : α-B slip lines for metal flow with ↑α, dead metal zones

* Die land :  not  Though ↑er drawing load for ⌣⌢ but still used b/c other wise damage ✕ → ⌣⌢



* Relief, outgoing dia > die dia: Elastic Strain Recovery

TUBE DRAWING:

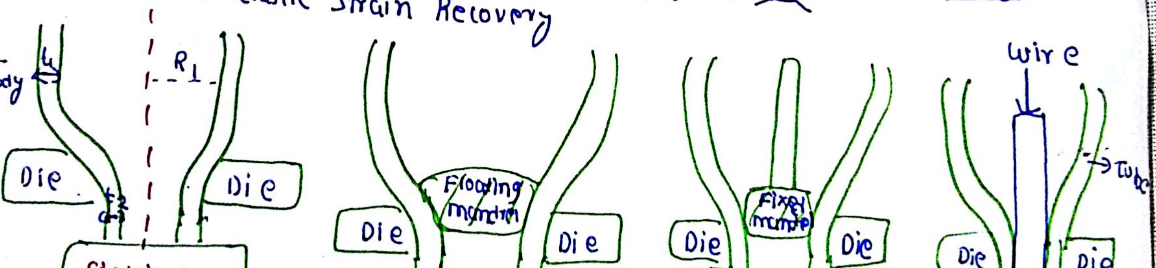
mandrel - non-deformable body

① t_2 not controlled

$\frac{t_1}{R_1} < .33$ ($t_2 > t_1$)

$\frac{t_1}{R_1} > .33$ ($t_1 > t_2$)

* Inside deformation not controlled i.e. Inside sur. finish not good

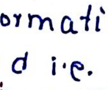


② (i) ✗ (ii) ✓   ③ (i) ✓ (ii) ✓   ④ (i) ✓ (ii) ✓ - wire moving at same speed as the tube - Dia of wire = Inside dia of outgoing tube

Adv: max. Reducn ∵ ↓ load needed (opposing fricn cancel) mandrel

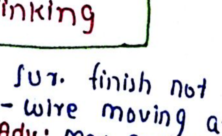
EXTRUSION 1- Forward:

σ_d = load for plastic def + load for die fricn



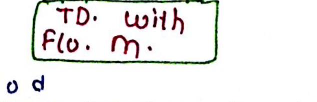
σ_f = load for billet fricn

→ $k'\pi D_i L_i = \sigma_f \cdot \frac{\pi}{4} D_i^2$ $k' = \sigma_0/\sqrt{3}$



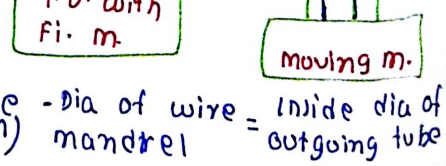
- Piston →
- metal →

2- BW:



- Die in piston itself
- only σ_d no σ_f

3- Hydrostatic:



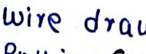
- used for brittle
- Ductility ↑es

4- Impact:

slug = soft material

DEFECTS: wire drawing (Central burst) Extrusion (fish tailing) Rolling (Crocodile crack or Alligatoring)

In W.D. → If oxide layer not removed properly, then during deformation it percolates down & settles at centre ∴ Induces weakness.



HOT: - Improper finish b/c of oxide layer
- bad dimnal tolerance b/c of shrinkage

Types of working: Cold < .4 Tm; warm .4-.6 Tm; HOT > .6 Tm   (< Trec; Transition; > Trecrys)

Cold: - Strong Product
- Dimnal tolerance good
- low σ_0 ∴ ↓ drawing load

Analysis of wire drawing: ① By Emprical formula : Johnson's formula ! * can be used for WD, FW, BW

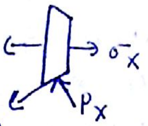
(i) cold working $\sigma_d = \sigma_0 (a + b \ln R)$ R = Extrusion Radio = $\frac{A_i}{A_f}$ a, b : J. constant

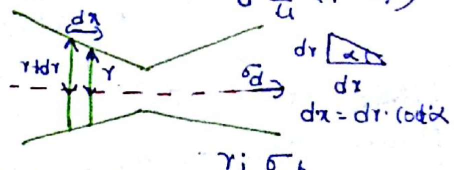
(ii) Hot " $\sigma_d = K \ln R$ K_1 = Extrusion constant ; Extrusion · only a, b changes

* Numerical : $A_i \cdot l_i = A_f \cdot l_f$ $e = l_f/l_i - 1$ $\varepsilon = \ln(1+e) = \ln l_f/l_i$; $\sigma_0 = \sigma_{fm}$ Ram force $= \sigma_d \cdot \frac{\pi}{4} (D_i^2 - D_f^2)$

② By slab Analysis : wire drawing

$(\sigma_x + d\sigma_x)\pi(r+dr)^2 - \sigma_x \cdot \pi r^2 + \tau_x \cos\alpha \left(2\pi r \cdot \frac{dx}{\cos\alpha}\right)$
$+ P_x \sin\alpha \left(2\pi r \cdot \frac{dx}{\cos\alpha}\right)$





* σ_x, P_x(comp.) as σ_1, σ_2 ∵ $\sigma_1 - \sigma_2 = 2K'$ $\sigma_x + P_x = 2K'$ * $B = \mu \cot\alpha$ *

$$\sigma_d = \sigma_0 \left(\frac{1+B}{B}\right)\left\{1 - \left(\frac{r_f}{r_i}\right)^{2B}\right\} + \sigma_b \left(\frac{r_f}{r_i}\right)^{2B}$$

* $\sigma_b = 0$ if no back pull

* Num - σ_0 given α, μ given (B) d_f, d_i given $\sigma_b = 0$ * Max Reducn $\sigma_d = \sigma_0$

* if friction less Then $\tau_x = 0$ $\sigma_d = \sigma_0 \ln \frac{A_i}{A_f} = \sigma_0 \ln R$ * max · Reducn : 63·2 %

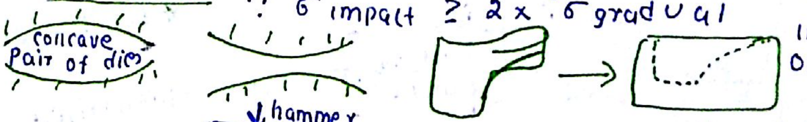
Extrusion : $\sigma_d = \sigma_0 \left(\frac{1+B}{B}\right)(R^B - 1) = \sigma_0 \left(\frac{1+B}{B}\right) \cdot \left\{\left(\frac{r_i}{r_f}\right)^{2B} - 1\right\}$ || $K' \cdot \pi D_i L_i = \frac{\pi}{4} \cdot D_i^2 \sigma_f$

Force = $\sigma_{net} \times A_i$ $\sigma_{net} = \sigma_d + \sigma_f$ $K' = \sigma_0/\sqrt{3}$

* Types of hammers = Gravity, Power

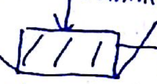
FORGING - material sheared by impact Energy ∵ σ impact ≥ 2 × σ gradual

Edging, Fullering, Hubbing:

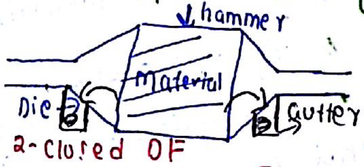


Classification of Forging:

1- open die F



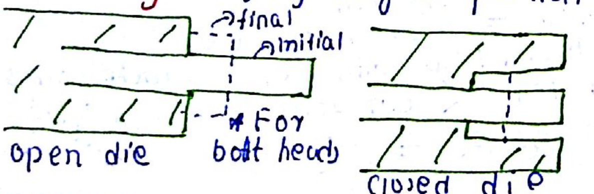
• material utilisation ↓ • surface finish ↓ • cracks chances ↑



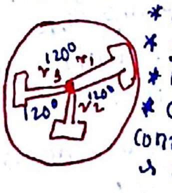
2- Closed OF

3- Impression die F: - similar to CDF No - calculated material kept ∴ Gutter

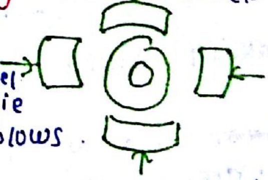
4- upsetting: Forging only a portion of work



5- Roll forging
* Rly · wheels
* 3 Rolls (diff · r)
* Rotated hori ·
* Chaingin r → contact b/w work & Roll

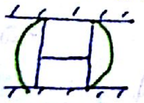


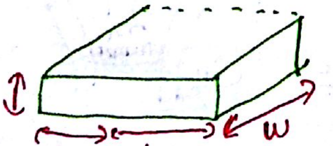
6- swagging · Rifles, barrels
* Drill hole
* insert Tapered mandrel
* keep in die
* Repeated blows to die ·



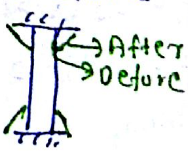
DEFECTS: Cold shut : when 2 streams not able to forge together Fold : The gap that appears

Barreling : in hot working - Temp · of edges ↓er, centre T ↑, ∵ σ ↓ for ↑ T ∴ more deformation at centre · In cold working - if length of workpiece more





Dimensions : 2L ↑, h ↓, w same
* All Calculation on final dimn



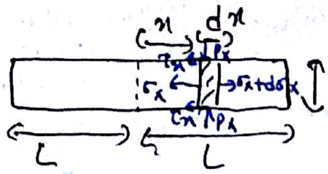
ANALYSIS:

$K' = \sigma_0/\sqrt{3}$ For σ_0 : Even if flow curve $\sigma_0 = K\varepsilon^n$

$\tau_x = \mu P_x$

* $(\sigma_x + d\sigma_x) hw - \sigma_x \cdot hw - 2 \cdot \tau_x \cdot w \cdot dx = 0$

* $d\sigma_x = \frac{2 \cdot \tau_x}{h} \cdot dx = \frac{2 \cdot \mu \cdot P_x \cdot dx}{h}$



* $\sigma_1 - \sigma_2 = 2K'$ $\sigma_x + P_x = 2K'$ $d\sigma_x = -dP_x$

* $\int \frac{dP_x}{P_x} = \int -\frac{2\mu}{h} \cdot dx$ $\ln P_x = \frac{-2\mu}{h} x + C_1$

* $x = L$ $\sigma_x = 0$. $P_x = 2K'$ $P_{x_1} = 2K' \cdot e^{\frac{2\mu}{h}(L-x)}$

exp · variation

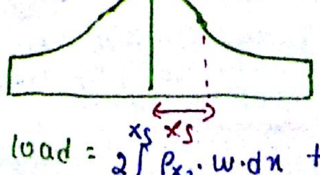
Sticking length : $\tau_x \leq K'$ ∴ $\mu P_x \leq K'$

when $\tau_x = K'$ sticking → metal sticks to die ·

at $x = x_s$ $\tau_x = K'$ $P_x = K'/\mu$

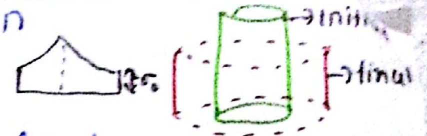
$P_{x_2} = \frac{K'}{\mu} + \frac{2K'}{h}(x_s - x)$ - linear

$x_s = L - \frac{h}{2\mu} \cdot \ln \frac{1}{2\mu}$ ↳ if -ve then no sticking



Total load = $2\int_0^{x_s} P_{x_2} \cdot w \cdot dx + 2\int_{x_s}^{L} P_{x_1} \cdot w \cdot dx$

Circular billet: - R ↑ - h ↓ - calculate on final dimn

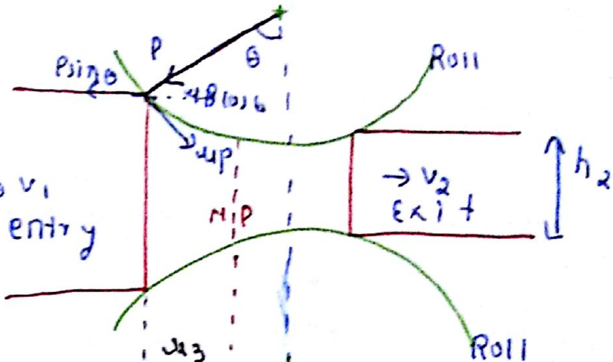


Difference: CIR (P. stress $K' = \sigma_0/2$) HORI (P. strain $K' = \sigma_0/\sqrt{3}$)

$P_{r_1} = 2K' \cdot e^{\frac{2\mu}{h}(R-r)}$ $P_{r_2} = \frac{K'}{\mu} + \frac{2K'}{h}(R_s - r)$ $R_s = R - \frac{h}{2\mu} \ln \frac{1}{\sqrt{3}\mu}$ → Diff. in hori. 2μ

Load = $\int P \cdot 2\pi r \cdot dr$ Don't double.

ROLLING



Velocity of material:
↑es from $V_1 (< V_r)$ to $V_2 > (V_r)$

$V_r = \frac{\pi D N}{60}$ when $V = V_r$ (N. plane) (S. stress = 0) (P_{max})

Before NP - $V < V_r$ lagging Bw slip $\left(\frac{V_r - V}{V_r}\right)$

After NP - $V > V_r$ leading Fw slip $\left(\frac{V - V_r}{V_r}\right)$

frictn < before μP → ; After μP ←

Self Entry: $\mu P \cos\theta \geq P \sin\theta$ $\boxed{\tan\theta \leq \mu}$

For $\tan\theta > \mu$ apply comp. σ at entry

Deformation: $\Delta h = h_1 - h_2$

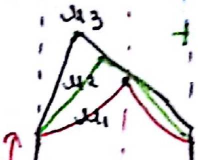
* h_2 > distance b/w Rolls b/c of e. Recovery

P = Roll separating force - Applied by Roll on material (Equal opp. force on Roll)

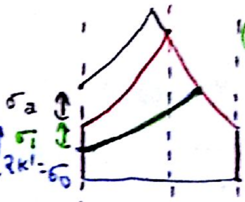
Pressure variation: (exponential) P_{max} - At N. plane

* b/w Entry till dis. b/w Rolls min
* Frictn Hill = plot of P. variation
* Total Rolling load = Area within F. hill

Effect of μ: on ↑ing μ < F. hill ↑es ; N.P. towards entry

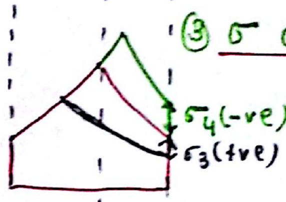


① Effect of μ: $\mu_3 > \mu_2 > \mu_1$

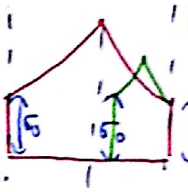


② To ↑se deformation
• σ at Entry

$2K' = \sigma_0$; σ_1 comp - NP Rt ; σ_2 Ten - NP left



③ σ at Exit
σ_4 comp - NP Rt. ; σ_3 Ten - NP Left



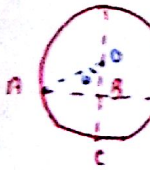
④ if Roll Radius ↓
- smaller F. hill
- Rolling load ↓es
- But this small load can bend small Rolls

② To ↑se deformation or Effect of σ at entry

σ_1 at entry (comp.) : NP toward →

σ_2 " " (Ten) : NP " ←

if σ_1 ↑ing → deformation ↑se limit when NP Reaches exit. Then ∵ fricn will be 0 then Roll will slip over material called as Rolling limit & bite ∠. at this pt. called NIP angle = 2μ Rad.



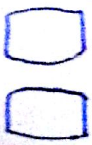
length of contact
AC = Arc of contact
AB = l of contact
$l \cdot l = (2R - \frac{\Delta h}{2}) \cdot \frac{\Delta h}{2}$
$\boxed{l = \sqrt{R \cdot \Delta h}}$

Bite ∠ θ
$\tan\theta = AB/OB$
$= \sqrt{R \cdot \Delta h} / R - \frac{\Delta h}{2}$
$\boxed{\tan\theta = \sqrt{\frac{\Delta h}{R}}}$

max. Reducn for self entry
$\tan\theta \leq \mu$ (SE) for Δh_{max} $\tan\theta = \mu$
$\tan\theta = \mu = \sqrt{\frac{\Delta h_{max}}{R}}$
$\boxed{\Delta h_{max} = \mu^2 R}$

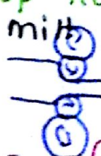
If Roll dia Reduced: Rolling load ↓ but chances of bending ↑

1- Camber Rolls:

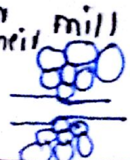


convexity given = deformation

2- Back up Rolls: (i) 4-high mill
Power to small Rolls

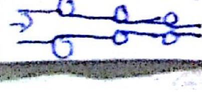


(ii) Cluster mill
Sendzimir

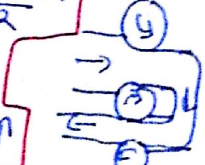


~~(iii) Tandom~~

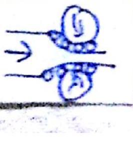
(iii) Tandom mill



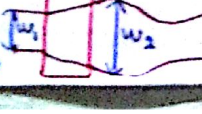
Other mills (i) 3-high mill
2 stage Reducn



(ii) planetary mill:
Thick plate → Thin foil
Power only to large Roll
multistage Rolling in single stage



Rolling defects
1- spread - ↑ in w after rolling
2- wavy edges - due to ...

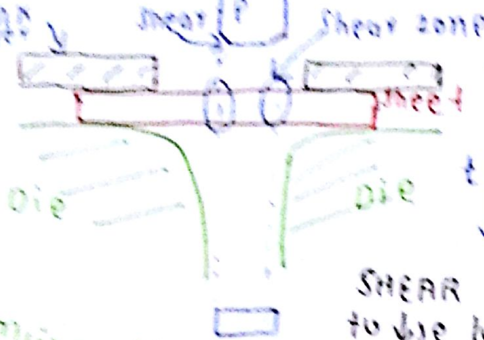


Sheet metal Forming

	Exact	clearance on	shear
P: sheared part is scrap	P	D	P
B: sheared part is useful	D	P	D

Punching & Blanking:

* Die > Punch



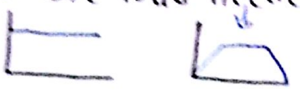
RoD - elastic deform
BD - plastic "

* Fracture appears after penetration i.e. shear force appear only till Pene.

→ Burr: ∵ material fractured at ℄ ∴ some extramaterial called burr.

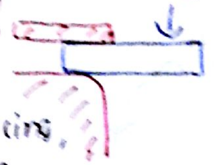
* To accomodate it → Burr clearance provide
* If ↑ ductile → ↑α → ↑ Burr

SHEAR provided to ↓se load needed

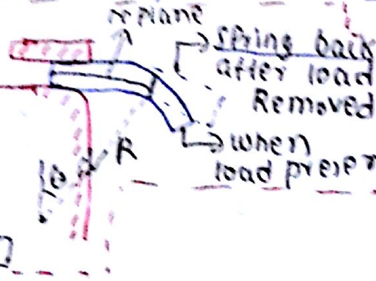


Num (i) punching:
P = dia (Exact)
Die = dia + $\frac{2 \times \% \times t}{100}$
* clearance as % of t

(ii) Blanking: Die = dia, punch = dia $- \frac{2 \times \% \times t}{100}$



BENDING:



length of Neutral axis in Bend Region $(R+\frac{t}{2})\theta$

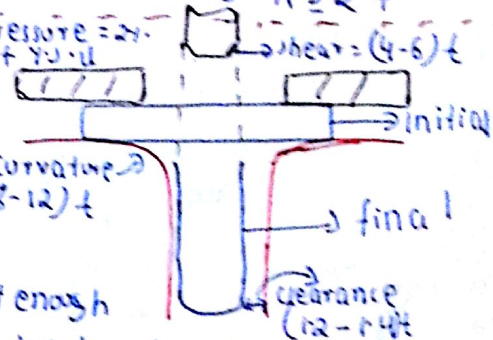
B.A. = $\theta(R + K_2 t)$ → called Bend Allowance

K_2 → .33 $R < 2t$; .5 $R \geq 2t$

* Notching, lancing, slitting, parting off, Perforating, nibbling

Deep Drawing

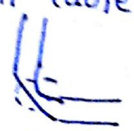
circular blank → cup shaped component



Types of stress:

Due to comp. σ_h sheet will try to fold & wrinkles may appear if holding p. not enough
* And σ_h will cause thickening in cup wall

* Necking: (< t) in punch corner Region

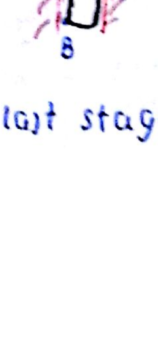


b/c → max. load here; → σ conc^n lines converging

↳ ↑es with ↑ in blank dia, b/c ↑er loads will be needed.
↳ once it ↑es beyond a limit (Dmax) fracture will occur.

* Ⓓ L d h: Equate A_{sur}: $\frac{\pi D^2}{4} = \frac{\pi d^2}{4} + \pi d h$
* Draw Ratio D/d (↑es with D)
* LDR - limiting Draw Ratio: $\frac{D_{max}}{d}$ [Technically formability represented by LDR]

Redrawing ∵ There is a limit to draw ∴ To draw deeper use Redrawing
- position of neck changes
- Contact Area ↓es



neck changes from A to B

Step Rings: if Redrawing done close to LDR the Rings appear

* IRONING - To make thickness in drawn cup uniform.
- done by ↓ing clearance b/w P & D in last stage → Plastic deformation over the wall