Storage and Transport of Bulk Solids

(Mechanical Operations, Audio-Visual Lecture Series)

Powders and Bulk Solids (D. Schulze)
Relevant chapters: 9, 10

Mechanical Operations

Length scale: micron to cm

Study of processing, handling, characterization, and application of wide variety of **Particulate Solids / Bulk Solids**.

Abrasive, tough, rubbery, soft, fragile, dusty, cohesive, free flowing, sticky etc.

(powder, liquid dispersions, granules, slurries, paste etc.)

Few major mechanical operations:

- Comminution (size reduction via crushing/grinding),
- **Handling : Storage and Conveying (transport)**
- Mixing/Agitation of Solids & Pastes
- Separation: Screening, Filtration, Centrifugation based separation (cyclone separator), Gravity based Settling
- Fluidization

Storage and Transport of Bulk Solids

Agriculture

Mineral processing

Fertilizer industry

Construction materials

Food processing

Pharmaceutical production

- chemical processing
- power generation
- Pulp and Paper Industry
- Rubber/Plastic industry.........etc.

the way you store, it matters..

Is storage is really an important issue??

- **Long term preservation**: minimizing the quality degradation of stored material .
  (Protection from external factors: Humidity, Temperature fluctuation, insects, chemical impurities etc.)

- **Bulk solids are complex fluids** (neither liquid nor solid) : nature of flow is very complex. The **way of storage** is **very crucial for transportation/flowability of materials**.

- The inadequate knowledge of stress profile lead to bad design, and causing **over-run, downtime, production losses and rectification costs**, and ultimately maximizing the production cost.

Value addition to the final product.

Bins

- Larger diameter, Small height
- Made of steel
- specified humidity and temperature condition
- Vented
- Mainly for dry materials

Silos

- Smaller diameter, Tall
- Made of concrete, wood, steel
- specified humidity and temperature condition
- Sealed (air-tight)

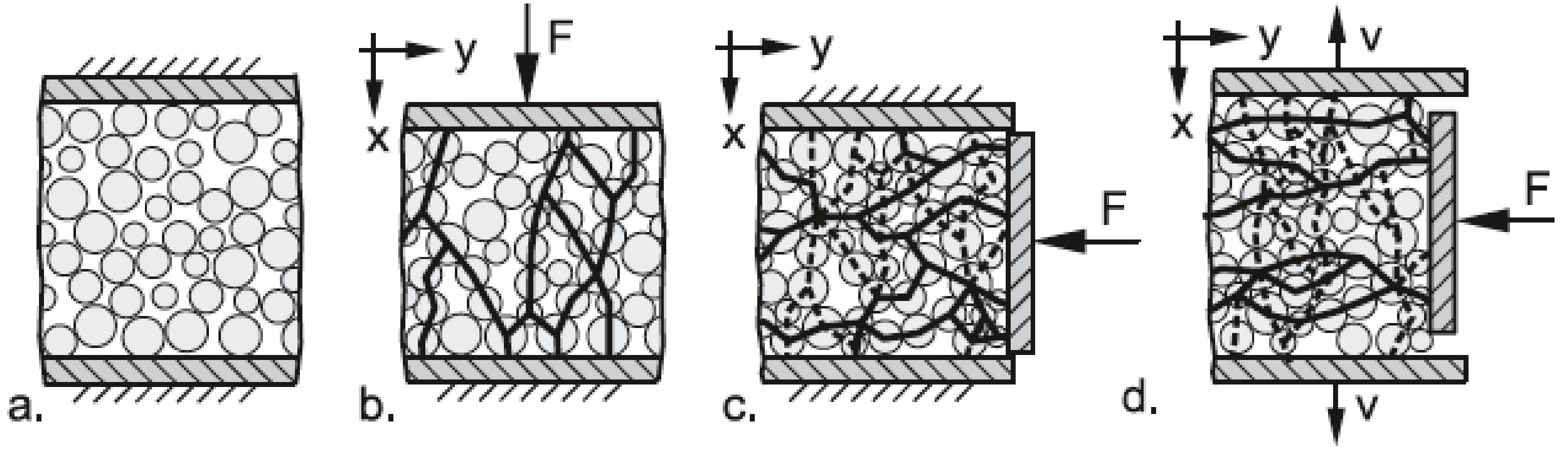
Stress Distribution in bulk solids

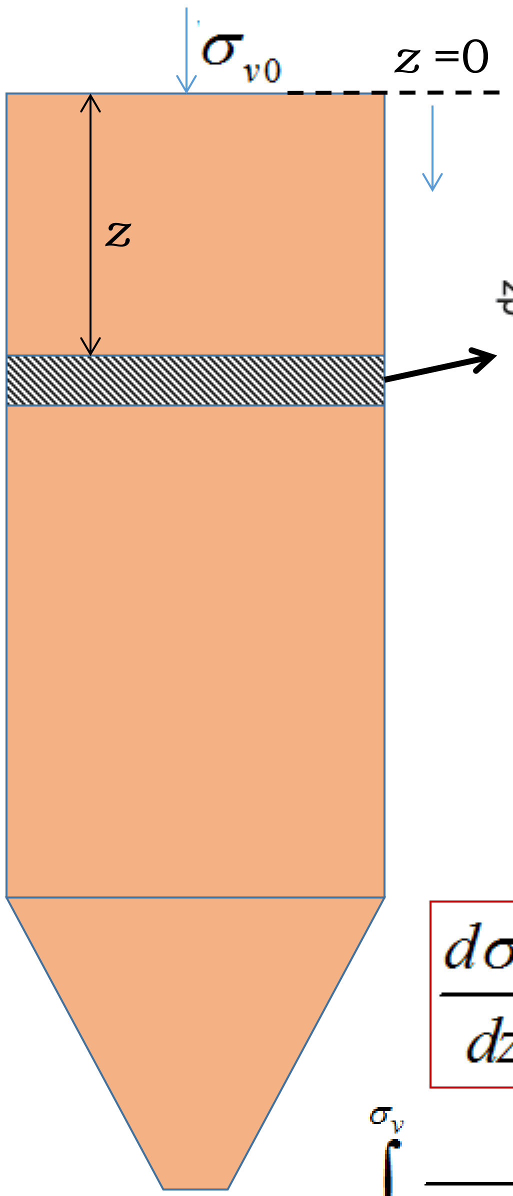
the way you store, it matters..

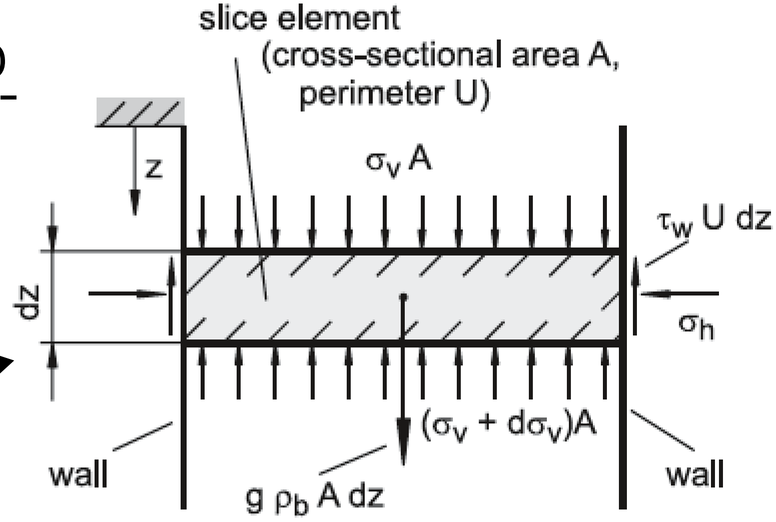
Flow problems: Bridging/Arching and Ratholing

https://www.siperm.com/en/

Stress Propagation in Bulk Solids







Force Balance for slice element

$$\cancel{A\sigma_v} + g\,\rho_b\,A\,dz = A(\cancel{\sigma_v} + d\sigma_v) + \tau_w U\,dz$$

$$\frac{d\sigma_v}{dz} = g\rho_b - \frac{\tau_w U}{A}$$

$$\boxed{K = \sigma_h / \sigma_v}$$

Angle of Wall Friction

$$\tan\varphi_x = \tau_w / \sigma_h$$

K: Lateral Stress Ratio (Principle stress ratio)

We assume ***K*** is constant throughout the material.

In reality *K* varies through out the material.

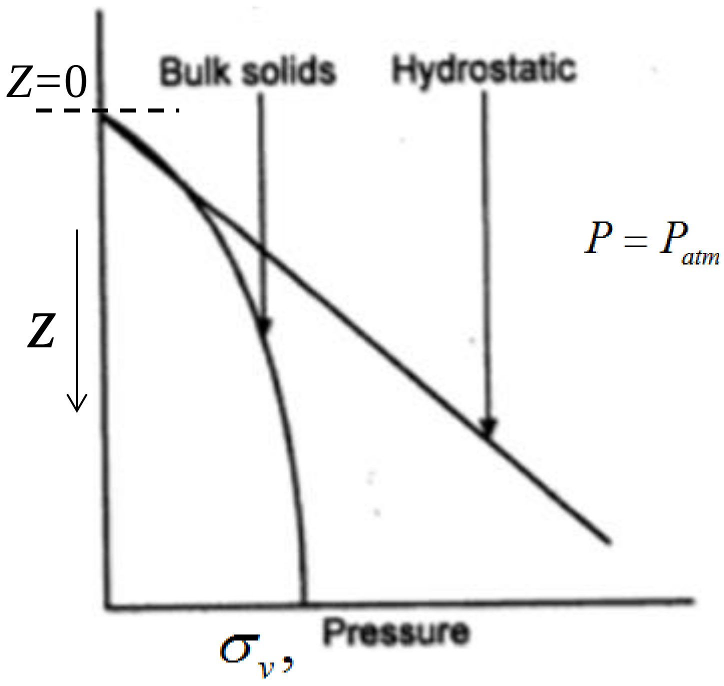
Janssen's equation

$$\boxed{\frac{d\sigma_v}{dz} = g\rho_b - \frac{\sigma_v K U \tan\varphi_x}{A}}$$

$$\int_{\sigma_{v0}}^{\sigma_v} \frac{d\sigma_v}{g\rho_b - (\sigma_v K U \tan\varphi_x / A)} = \int_0^z dz$$

$$\boxed{\sigma_v = \frac{g\,\rho_b\,A}{K\,\tan\varphi_x\,U} + \left[\sigma_{v0} - \frac{g\,\rho_b\,A}{K\,\tan\varphi_x\,U}\right] \cdot e^{\frac{-K\tan\varphi_x U z}{A}}}$$

$$\boxed{\sigma_v = \frac{g\,\rho_b A}{K\,\tan\varphi_x U} + \left[\sigma_{v0} - \frac{g\,\rho_b A}{K\,\tan\varphi_x U}\right] \cdot e^{\frac{-K\tan\varphi_x U z}{A}}} \rightarrow \boxed{L_c = \frac{A}{KU\tan\varphi_x}}$$

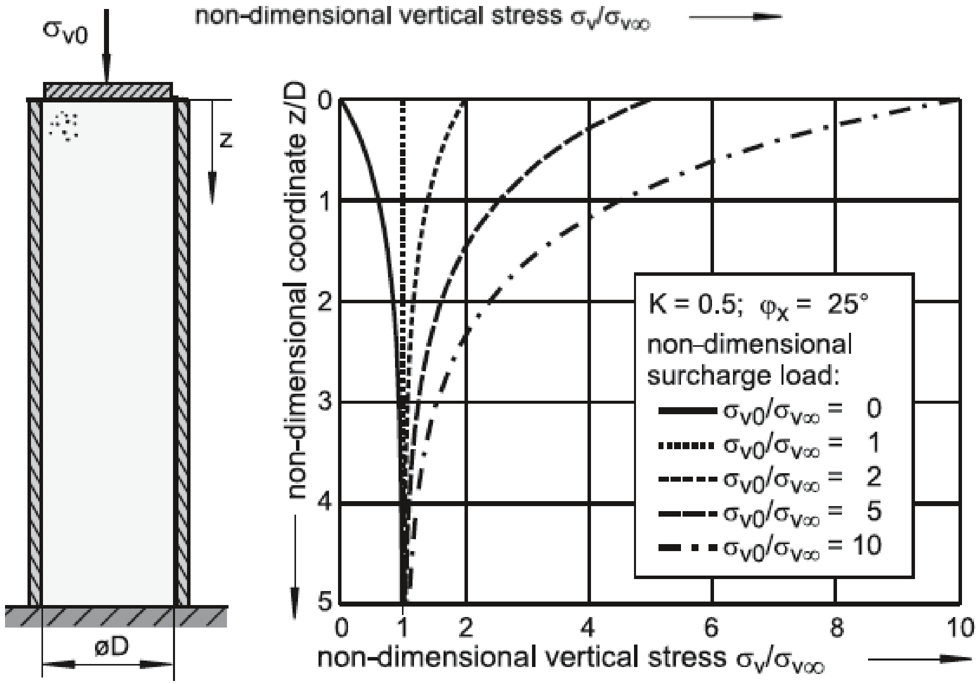


$$P = P_{atm} + \rho g h$$

$$\sigma_{v\infty} = \sigma_v(z \to \infty) = \frac{g\,\rho_b A}{K\,\tan\varphi_x U}$$

$$\boxed{\frac{\sigma_v}{\sigma_{v\infty}} = 1 + \left[\frac{\sigma_{v0}}{\sigma_{v\infty}} - 1\right] \cdot e^{-4K\tan\varphi_x \frac{z}{D}}}$$

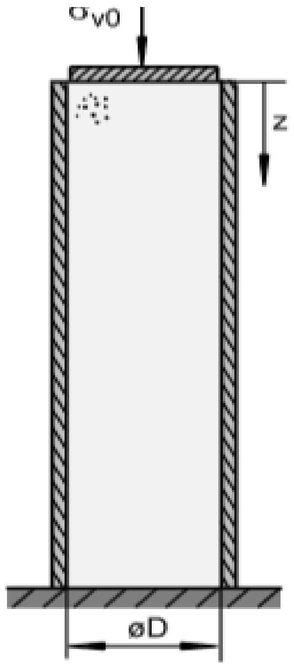
$$\sigma_{v0} = 0 \longrightarrow \sigma_v = \sigma_{v\infty}\left(1 - e^{-(KU\tan\varphi_x)z/A}\right)$$



Application of Janssen's equation

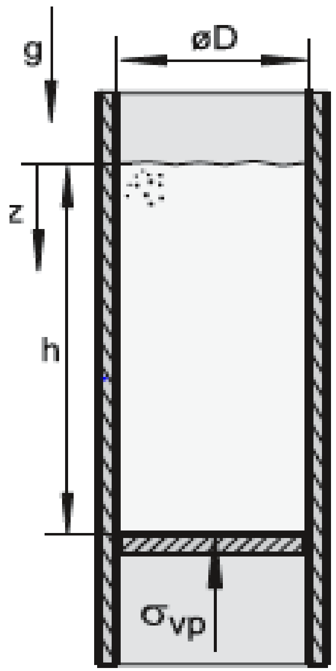
Example 1 (by group 1)

Consider that the wall of the cylindrical silo (shown in figure below) is made of a material, which can bear the maximum normal stress up to 4.4kPa. Assume that the only possible source of damage of wall is the horizontal normal stress exerted by the bulk solid on the wall (and not due to the frictional forces/shear stress present between bulk-solid and wall). There is no surcharge stress, $\sigma_{v0}=0$. Calculate the maximum height allowed for the silo to avoid any damage to silo-wall.



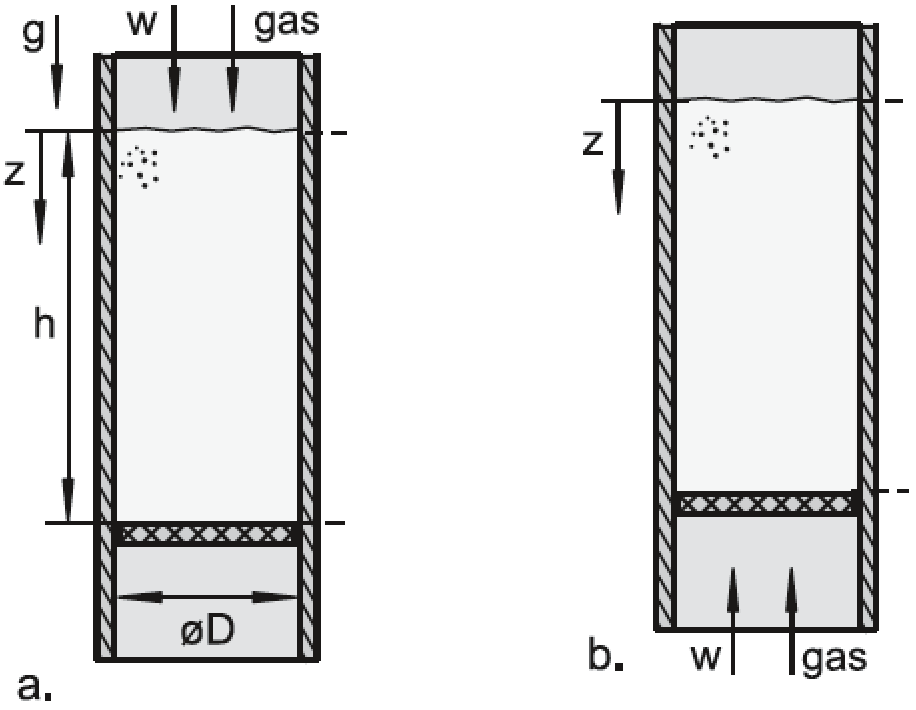
Example 2 (by group 2)

Consider a case wherein a column of bulk solid should be pushed upwards in a vertical channel, the wall shear stress on bulk solids then start acting downwards. Find out the expression for stress as a function of depth.



Example 3 (by group 3)

If a gas flows through a stationary packing of bulk solid, the stresses in the bulk solid are influenced by the pressure gradient. This effect can be taken into account for a setup as shown in figure below by adding pressure gradient, dp/dz.



$$A\sigma_v + g\,\rho_b A\,dz - \left(\frac{dp}{dz}\right)A\,dz = A(\sigma_v + d\sigma_v) + \tau_w U\,dz$$

Summary

- Within a cylindrical section of a silo, both vertical and horizontal normal stress are increasing function of depth, and saturates to a maximum value and very large depth.

$$\boxed{\sigma_v = \frac{g\,\rho_b A}{K\ \tan\varphi_x U} + \left[\sigma_{v0} - \frac{g\,\rho_b A}{K\ \tan\varphi_x U}\right] \cdot e^{\frac{-K \tan\varphi_x U z}{A}}}$$

- The frictional forces applied by wall on material is very crucial, which makes bulk solids different than liquids.

- The above expression works fine in practical sense, however more rigorous derivations are available with less assumption.

Next Class: Stress distribution in Hopper

Hoppers