Stress distribution inside a powder bed: does Janssen’s model applicable locally in a granular medium
Agnès Duri-Bechemilh, Sandra Mandato, Bernard Cuq, Thierry Ruiz

To cite this version:
Agnès Duri-Bechemilh, Sandra Mandato, Bernard Cuq, Thierry Ruiz. Stress distribution inside a powder bed: does Janssen’s model applicable locally in a granular medium. 7. World Congress on Particle Technology (WCPT7), May 2014, Pekin, China. hal-01606814

HAL Id: hal-01606814
https://hal.science/hal-01606814
Submitted on 3 Jun 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution - ShareAlike 4.0 International License
Stress distribution inside a powder bed: does Janssen’s model applicable locally in a granular medium?

Sandra Mandato, Agnès Duri*, Bernard Cuq and Thierry Ruiz

UMR IATE
http://umr-iate.cirad.fr/
2 Place Pierre Viala - 34000 Montpellier – FRANCE

*duri@supagro.inra.fr

21th May 2014
Motivation

What is the local stress distribution in an ensiled granular media?
Motivation

What is the local stress distribution in an ensiled granular media?

Applications:
- Stability of silos
- Initial state before powder flowing (mixing processing...)

What is the local stress distribution in an ensiled granular media?
The well-known Janssen’s experiment (1895)

Weight measurement at the bottom of a cylindrical grain column
Weight measurement at the bottom of a cylindrical grain column

From a certain height of bed, any powder addition does not make any variation of mass weighed at the bottom
Pressure at the bottom of a cylindrical grain column

3 hypotheses:
- Lateral uniformity of the vertical stress (layer model)
- The horizontal stress is proportional to the vertical stress
- Slipping at the wall (Coulomb criterion)
Janssen’s model

Pressure at the bottom of a cylindrical grain column

3 hypotheses:
- Lateral uniformity of the vertical stress (layer model)
- The horizontal stress is proportional to the vertical stress
- Slipping at the wall (Coulomb criterion)

\[ P = \rho g \lambda (1 - e^{-h/\lambda}) \]

\[ \lambda = \frac{D}{4\mu K} \]

Hydrostatic pressure \( \rho gh \)

Weight deflection into lateral sides of the column
Janssen’s model?

**Stakes**

- Height of grain in the column: $h$
- Vertical stress: $\sigma_{zz}(z)$
- at the bottom
Profile of the local vertical stress in an ensiled granular media? Effect of the particle size?
Janssen’s model?

Stakes

Method

Rheological device

Janssen’s experiment: large probe

Measurement of the vertical stress
at the bottom of the cell

$0 < z \leq 14 \text{ cm}$ (height of the bed)
Janssen’s model?

Stakes

Method

2D rheological device

Local experiment: small probe

Measurement of the vertical stress in the granular bed

$0 < x \leq 4 \text{ cm} \quad \& \quad 0 < z \leq 14 \text{ cm}$ (position in the bed)

2D-cartography of the local vertical stress
A range of 5 wheat-based powders: native and agglomerated particles

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>$d_{50} , (\mu m)$</th>
<th>dsp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine semolina</td>
<td>210</td>
<td>1.53</td>
</tr>
<tr>
<td>Medium semolina</td>
<td>300</td>
<td>1.46</td>
</tr>
<tr>
<td>Fine couscous</td>
<td>680</td>
<td>0.95</td>
</tr>
<tr>
<td>Medium couscous</td>
<td>950</td>
<td>0.54</td>
</tr>
<tr>
<td>Large couscous</td>
<td>1100</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Native powder: durum wheat semolina (pasta, noodle, couscous...)

Effect of the size and the structure on the local vertical stress profiles
Janssen’s profile:

- Deviation from the hydrostatic profile
- \( \lambda = 23 \text{ cm} \)

**Screening** of the weight by the lateral sides of the cell.
Janssen & local vertical stress profiles in the center of the cell

Results

Local approach - x=0

Local profile ≠ Janssen’s profile
Janssen’s model?  
Stakes  
Material and method  
Results

Janssen & local vertical stress profiles in the center of the cell

**Vertical stress (kPa)**

<table>
<thead>
<tr>
<th>Vertical stress (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
</tr>
</tbody>
</table>

**Semolina height/Depth of the probe (cm)**

- **Zone I**: \( \lambda_h \approx 4 \text{ cm} \)
- **Zone II**: \( \lambda_h \approx 4 \text{ cm} \) and \( \lambda_b \approx 2 \text{ cm} \)
- **Zone III**: \( \lambda_b \approx 2 \text{ cm} \)

Local approach - \( x=0 \)
**Janssen & local vertical stress profiles in the center of the cell**

**Results**

**Material and method**

- **Janssen’s model?**
- **Stakes**
- **Janssen & local vertical stress**
- **profiles in the center of the cell**

**Local approach - x=0**

- **3 zones**
- **2 characteristic lengths:**
  - $\lambda_h \approx 4 \text{ cm}$ and $\lambda_b \approx 2 \text{ cm}$
- **Janssen** value at the bottom of the cell!
Janssen & local vertical stress profiles in the center of the cell

**Results**

- **Material and method**
  - Janssen’s model?
  - Semolina height/Depth of the probe (cm)
  - Vertical stress (kPa)

**Graphs**

- Zone I
  - \( \lambda_h \approx 4 \text{ cm} \)
  - 3 zones
  - 2 characteristic lengths: \( \lambda_h \approx 4 \text{ cm} \) and \( \lambda_b \approx 2 \text{ cm} \)
  - Janssen value at the bottom of the cell!

- Zone II

- Zone III
  - \( \lambda_b \approx 2 \text{ cm} \)

**Local approach - x=0**
Local vertical stress profiles in horizontal plane

Zone I: Lateral uniformity of the vertical stress
Zone II & III: Lateral inhomogeneity of the vertical stress
⇒ Janssen’s hypothesis not checked for semolina
2D iso-stress cartography

Vertical Stress (kPa)

Surface

Bottom
Results

Material and method

2D iso-stress cartography

Vertical Stress (kPa)

Janssen’s model?

Stakes

Surface

Hydrostatic

Network percolation

Stress screening

Janssen - Bottom
2D iso-stress cartography

- **Vertical Stress (kPa)**

- **Results**

  - **Material and method**
    - Janssen’s model?
    - Stakes
  - **Stress screening**
    - Janssen - Bottom
  - **Network percolation**
  - **Hydrostatic**

- **Surface**

- **x, z**

- **Stress screening**

- **Vertical Stress (kPa)**
  - 0 to 1.8
2D iso-stress cartography

Vertically Stress (kPa)

<table>
<thead>
<tr>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material and method</td>
</tr>
<tr>
<td>Stakes</td>
</tr>
<tr>
<td>Janssen’s model?</td>
</tr>
</tbody>
</table>

Hydrostatic

Network percolation

Stress screening

Janssen - Bottom

Surface

Stress screening
The bottom is a side as an other...
Particle size effect?

Results

Material and method

Janssen’s model?

Stakes

Verticle Stress (kPa)

Depth of the probe (cm)

Particle size does not affect:
- Shape of the profile
- Characteristic lengths

Particle size

\( d_{50} = 210 \mu m \)

\( d_{50} = 680 \mu m \)

\( d_{50} = 950 \mu m \)

\( d_{50} = 1100 \mu m \)

\( \lambda_h \approx 4 \text{ cm} \)

\( \lambda_b \approx 2 \text{ cm} \)
Particle size effect?

- **Vertical stress (kPa)**
- Depth of the probe (cm)

### Results

**Material and method**

- Janssen’s model?
- Stakes

**Particle size affects:**

- **Intensity** of the local vertical stress

---

- $d_{50} = 210 \mu m$
- $d_{50} = 300 \mu m$
- $d_{50} = 680 \mu m$
- $d_{50} = 950 \mu m$
- $d_{50} = 1110 \mu m$

- $\lambda_h \approx 4 \text{ cm}$
- $\lambda_b \approx 2 \text{ cm}$
Conclusions

A Generic device implementation for measuring 2D-cartography of the vertical stress in ensiled granular powders.

A Non-equivalence between global and local vertical stress measurements except at the bottom of the cell (semolina).

A Particle size affects the intensity of the local vertical stress but not the shape of the vertical stress profile and the characteristic lengths.
Stress distribution inside powder bed: does Janssen’s model applicable locally in a granular medium?

Sandra Mandato, Agnès Duri*, Bernard Cuq and Thierry Ruiz

UMR IATE
http://umr-iate.cirad.fr/
2 Place Pierre Viala - 34000 Montpellier – FRANCE

* duri@supagro.inra.fr

21th May 2014