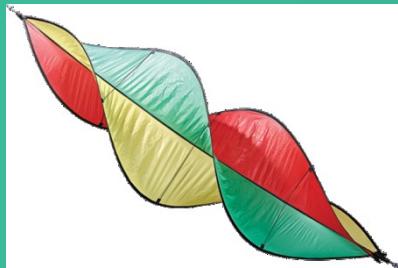


Earthquake stability of sand reclaimed areas



Experimental research through cyclic
TXA-tests

Alexander Maes
Koen Surmont



Overview

- Problem and research
- Liquefaction
- Setup
- Parameterization
- Results and processing
- Conclusions

Problem

- Liquefaction occurred by sand reclaimed areas
- Compaction till 90% of the maximal proctordensity is reached
- What is the critical relative density for liquefaction

Research

- What is the influence of:
 - Relative density (D_r)
 - Intensity of the acceleration during vibrations
 - Mean effective stress (p')

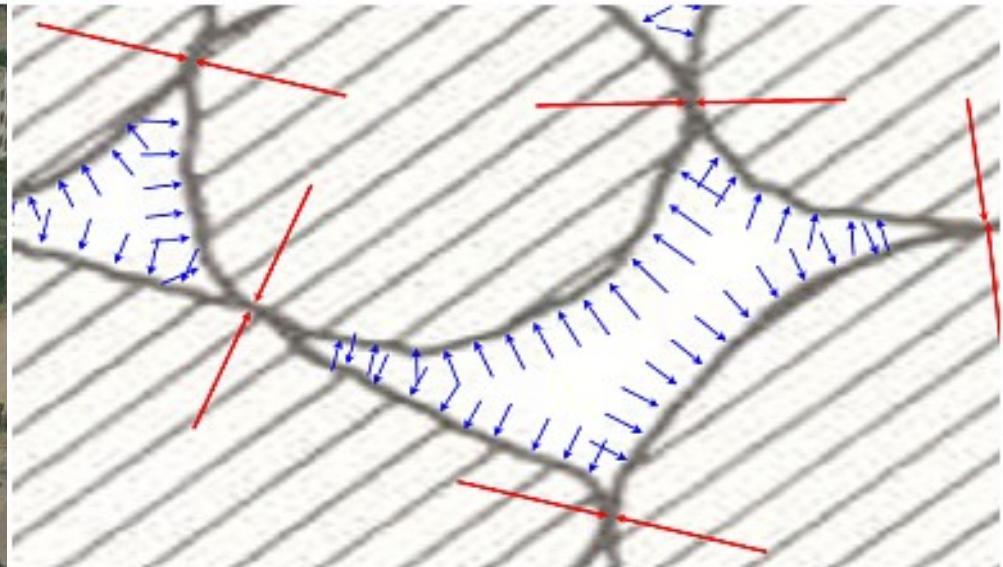
Liquefaction

- Definition:

Describes a phenomenon whereby a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake shaking or other sudden change in stress condition, causing it to behave like a liquid.

Liquefaction

- <http://www.youtube.com/watch?v=qmVYbjiNWds>



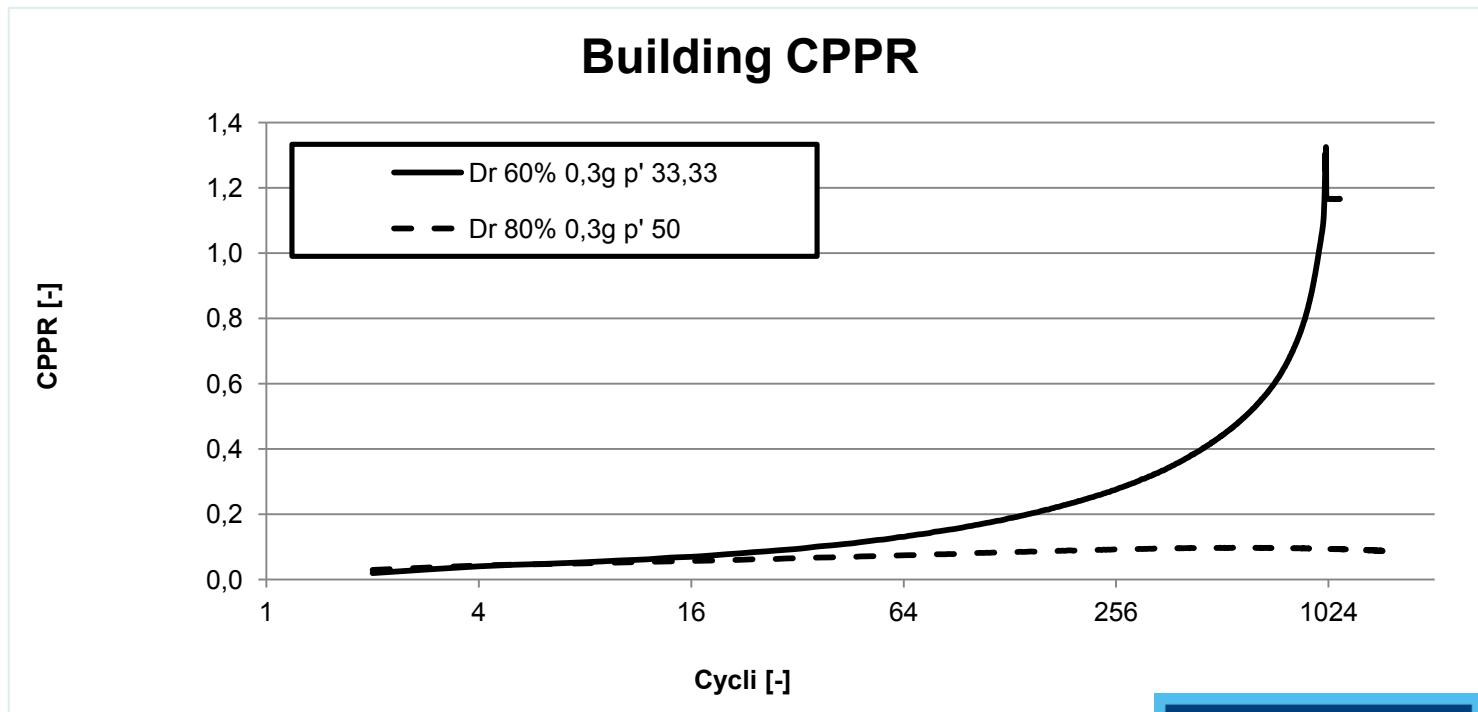
Liquefaction

- Three methods to control if liquefaction has occurred:
 - Visually
 - CPPR
 - Pore water pressure

Liquefaction

- CPPR: Cyclic Pore Pressure Ratio

$$CPPR = \frac{\text{maximum excess pore pressure}}{\text{effective isotropic consolidation stress } \sigma'_{3,c}}$$

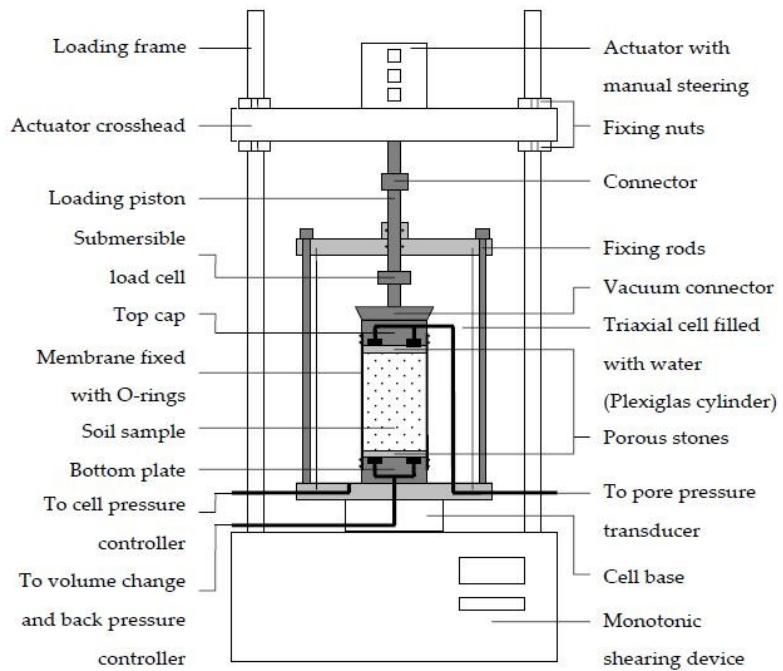


Liquefaction

- Pore water pressure
 - Measure the difference in pore water pressure during the test
 - Liquefaction degree
 - Different for every test (K_0 and p')
 - $= \frac{du}{cellpressure - backpressure}$

Setup

- Cyclic triaxialcell test device



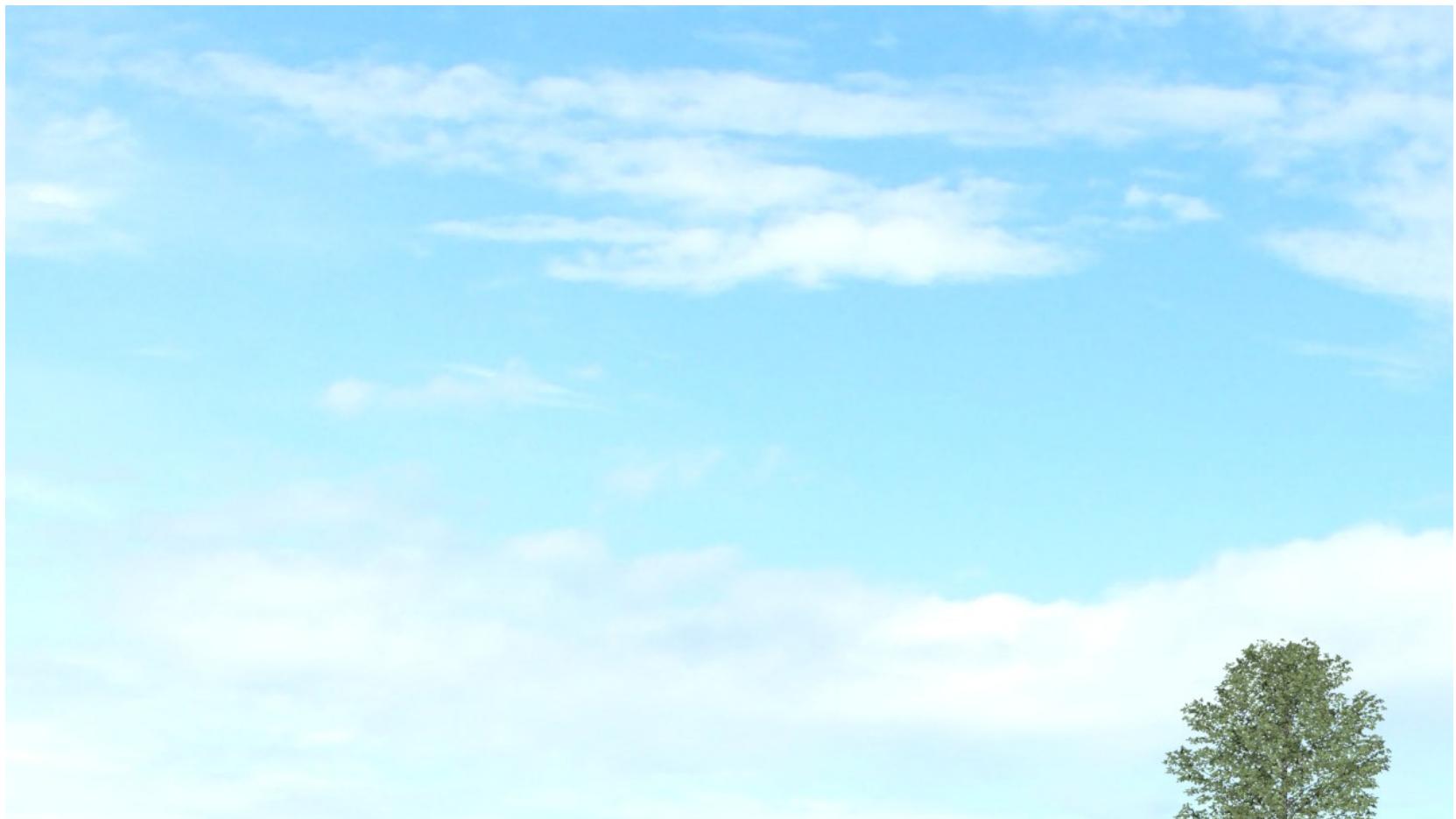
10

27

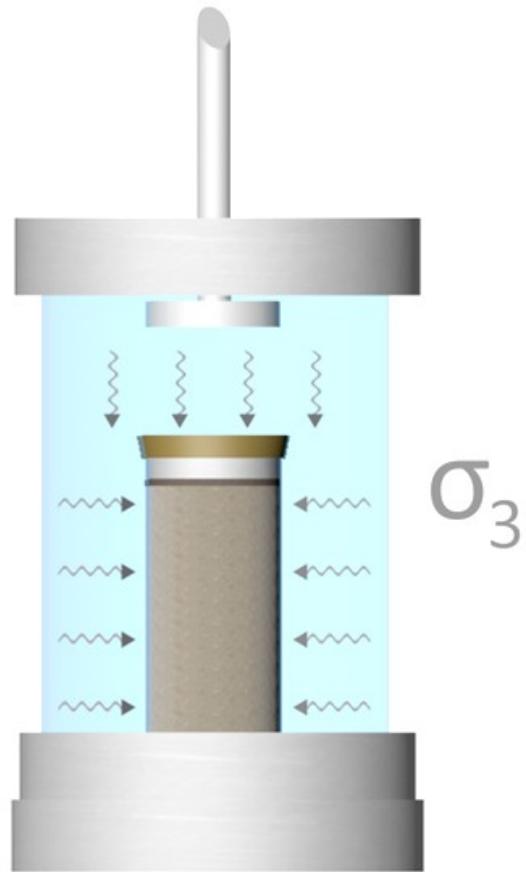
Setup

- Steps to be taken
 - Building the sample $\longrightarrow D_r(\%)$
 - Fill the TXA with water
 - Replace O₂ with CO₂
 - Fill the sample with water
 - Apply 5 kPa pressure for stability
 - Build up cell and backpressure till 105 kPa, 100 kPa
 - Isotropic consolidation
 - Anisotropic consolidation
 - Test with certain cyclic load. $\longrightarrow K_0$
 $\longrightarrow p'$
 $\longrightarrow a (\%g)$

Setup



Setup



Parameterization

- PVT 411

| Parameter | Result |
|-----------------------|---------------------------|
| Apparent density | 1336,24 kg/m ³ |
| Absolute density | 2618,35 kg/m ³ |
| Optimal water content | 15,84% |
| minimal void ratio | 0,3913 |
| Percentage of fines | 0,44% |
| Similarity degree | 0,726 |
| Mean grain diameter | 0,140 mm |
| Active grain diameter | 0,098 mm |
| Specific surface area | 76,19 |
| Lime content | 7,19% |
| BW | 0,04 |
| BW _f | 0,16 |
| Roundness | 0,25 |

Aanduiding en identificatie van zanden (D = < 4mm)

| | | | | | | | | | | |
|-------------|---------------|-----|---------|----|---|----|---|-------|-------------------------|----------|
| Voorbeeld : | Rond zand 142 | 0/1 | (0/0,5) | FF | A | I3 | a | CA SA | EK * E _{ca} 25 | gewassen |
|-------------|---------------|-----|---------|----|---|----|---|-------|-------------------------|----------|

Korrelverdeling - 1 / week - EN 933-1

| Norm | Kaliber 0/D | Categorie EN | Massapercentage doorval door de zeef van | | | | |
|----------|-------------------|-------------------|--|----------|---------|---|-----|
| | | | 2 D | 1,4 D | D | d | d/2 |
| EN 12820 | D ≤ 4 mm en d = 0 | G ₂ 95 | 100 | 95 - 100 | 85 - 99 | - | - |
| EN 13043 | D ≤ 2 mm | G ₂ 95 | 100 | - | 85 - 99 | - | - |
| EN 13242 | D ≤ 4 mm en d = 0 | G ₂ 95 | 100 | 98 - 100 | 85 - 99 | - | - |
| | | G ₃ 80 | 100 | 98 - 100 | 80 - 99 | - | - |
| EN 13139 | D/1 | - | 100 | 95 - 100 | 85 - 99 | - | - |
| | D/2 | - | 100 | 95 - 100 | 85 - 99 | - | - |
| | D/4 | - | 100 | 95 - 100 | 85 - 99 | - | - |

Veranderlijkhed van de korrelverdeling

| Code | Beperkte tolerantie | | | Gereduceerde tolerantie | | | Normale tolerantie | | |
|----------|---------------------|--------|--------|-------------------------|--------|--------|--------------------|--------|--------|
| | A | B | C | A | B | C | A | B | C |
| Kalibers | D4 | D2 | D1 | D4 | D2 | D1 | D4 | D2 | D1 |
| 4,0 mm | ± 5 % | - | - | ± 5 % | - | - | ± 5 % | - | - |
| 2,0 mm | ± 10 % | ± 5 % | - | - | ± 5 % | - | - | ± 5 % | - |
| 1,0 mm | ± 10 % | ± 10 % | ± 5 % | ± 10 % | ± 10 % | ± 5 % | ± 20 % | ± 20 % | ± 5 % |
| 0,5 mm * | | | | ± 10 % | | | | ± 20 % | |
| 0,25 mm | ± 10 % | ± 15 % | ± 15 % | ± 10 % | ± 15 % | ± 15 % | ± 20 % | ± 25 % | ± 25 % |
| 0,63 mm | ± 3 % | ± 3 % | ± 3 % | ± 3 % | ± 5 % | ± 5 % | ± 3 % | ± 5 % | ± 5 % |

Kwaliteit van de fijne deeltjes

| | Code | | |
|---|----------------------|---------------------------|----------------------|
| | A (1 week) | B (1 maand) | C (1 maand) |
| Uiterste waarden van BW | BW ≤ 1,5 | 1,5 < BW ≤ 2,5 | BW > 2,5 |
| Uiterste waarden ⁵ van BW _f | BW _f ≤ 10 | 10 < BW _f ≤ 25 | BW _f > 25 |
| Uiterste waarden van ZE | ZE ≥ 60 | ZE ≥ 50 | ZE ≥ 40 |

* BW = blauwwaarde bepaald volgens NBN EN 803-9 en gemeten op de fractie 0/2 van het zand
+ BW_f = blauwwaarde bepaald volgens NBN EN 803-9 en gemeten op de fractie 0/0,125 van het zand
+ ZE = zandequivalent bepaald volgens NBN EN 933-0 en gemeten op de fractie 0/2 van het zand

Fijnheid - 1/week

| Fijnheidsmodulus | | | Aanvullende aanduiding | | | Maximaal gehalte aan fijne deeltjes | | | Bijkomend kenmerk: hoogtegrad* | | |
|---|----|----|------------------------|-----------|-----------|-------------------------------------|--|--|--------------------------------|--|--|
| Code | | | | | | Code | | | Code | | |
| CF | MF | FF | 4,0 ± 2,4 | 2,8 ± 1,5 | 2,1 ± 0,6 | | | | | | |
| In het geval van zanden voor dewelke de doorval door D van de aanduiding hoger is dan 90 %, mag de producent : | | | | | | | | | | | |
| - de grootste zeef D* van de reeks R20 (ISO 965) bepalen, gekozen uit de volgende zeven: 3,15 ; 2,51 ; 2,11 ; 0,5 ; 0,315 ; 0,25 ; 0,125 mm waaroor de doorval begrepen is tussen 85 en 99 %; | | | | | | | | | | | |
| - op de leveringsbon het kaliber 0/0 aanduiden door de aanduiding van de reelle zeef D* tussen haakjes, hetzij "0/0 (D*)". | | | | | | | | | | | |
| De fijnheidsmodulus wordt berekend als de som van de cumulatieve massapercentages op de volgende zeven: 4 - 2 - 1 - 0,5 - 0,25 et 0,125 mm, en gedeeld door 100. | | | | | | | | | | | |
| B [nog B; EN 10450] | | | | | | | | | | | |

Vergelijk kenmerk *

| Absolute volumetrische massa | Gemiddelde waarde = verklaarde waarde | | | Tolerantie ± 100 kg/m ³ |
|------------------------------|---------------------------------------|--------------------|--|------------------------------------|
| | | | | |
| Waterabsorptie ¹⁴ | Gemiddelde waarde = verklaarde waarde | Tolerantie ± 1,0 % | | |
| | NBN EN 1097-4, 59 | | | |

Bijkomend kenmerk maximaal gehalte aan chloorkorten (%)

| Code | | |
|------|------|------|
| CA | CB | CC |
| 0,01 | 0,06 | 0,10 |

Bijkomend kenmerk maximaal gehalte aan scheelpdelen (%)

| Code | | |
|------|----|----|
| SA | SB | SC |
| 20 | 25 | 30 |

Bijkomend kenmerk In functie van de PSV van de moederrots

| Code | |
|--|------|
| PA | PB |
| ≥ 50 | < 50 |
| PSV : polish stone value = verneerde polijstingscoëfficiënt | |
| EN 1097-4 | |

Parametrization

- Result

0/2 FF A f3 a SA

- With : **0/2** : The caliber of the sand in accordance with the grain size distribution
- FF** : Sand with a fineness modulus between 2,1 and 0,6
0,6
- A** : designation for uniform grain distribution
- F3** : Maximal 3% of fine particles
- a** : Methylene blue value BW < 1,5
- SA** : Maximum lime content of 20%

Parametrization

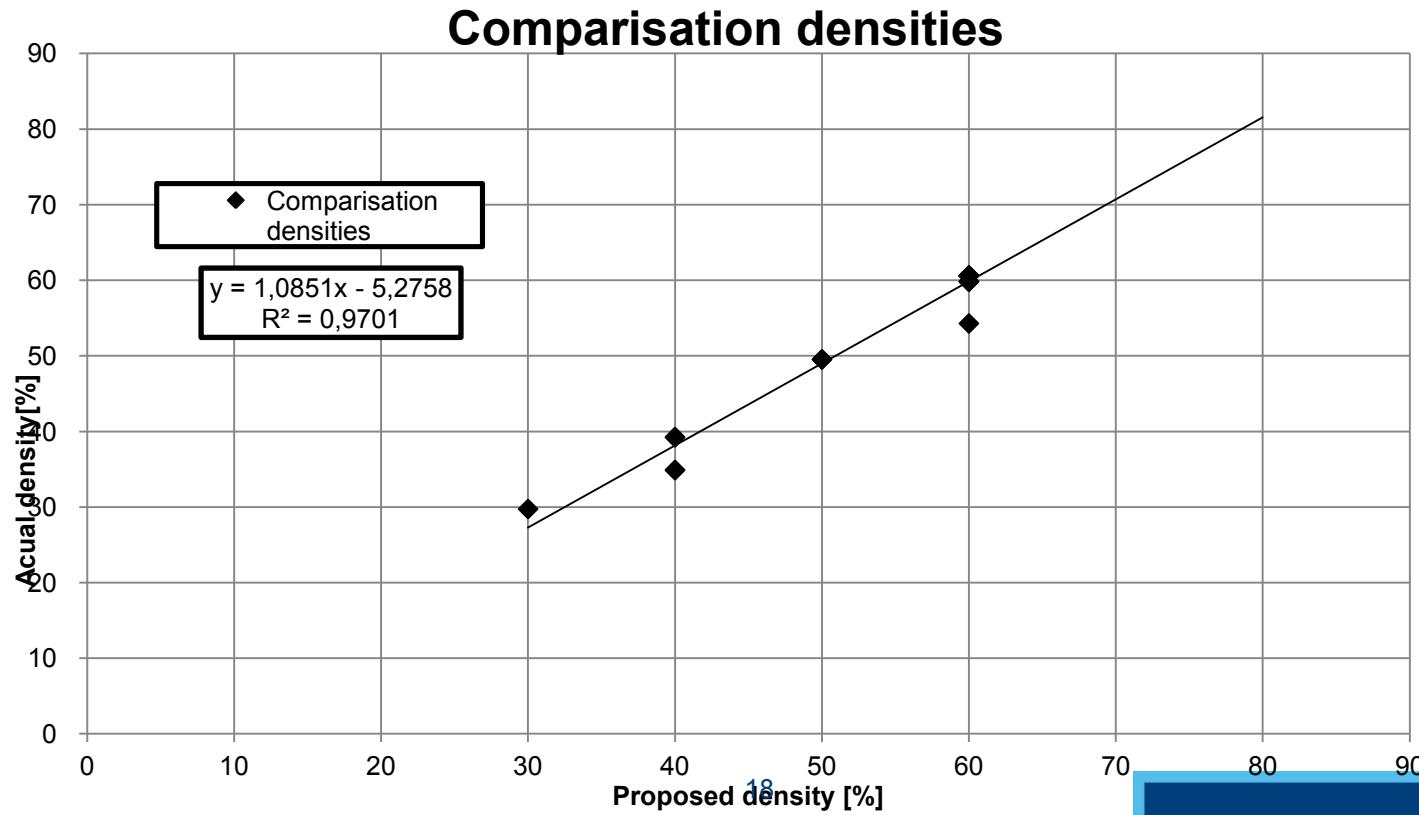
| D_r [%] | γ_d [kN/m ³] | W_s [%] | $W_{20\%}$ [%] | $W_{70\%}$ [%] | n [-] | e [-] |
|-----------|---------------------------------|-----------|----------------|----------------|-------|-------|
| 0 | 13,11 | 36,57 | 7,31 | 25,60 | 0,490 | 0,959 |
| 10 | 13,36 | 35,16 | 7,03 | 24,61 | 0,480 | 0,922 |
| 20 | 13,61 | 33,80 | 6,76 | 23,66 | 0,470 | 0,887 |
| 30 | 13,87 | 32,49 | 6,50 | 22,74 | 0,460 | 0,852 |
| 40 | 14,12 | 31,23 | 6,25 | 21,86 | 0,450 | 0,819 |
| 50 | 14,37 | 30,01 | 6,00 | 21,00 | 0,440 | 0,787 |
| 60 | 14,62 | 28,83 | 5,77 | 20,18 | 0,431 | 0,756 |
| 70 | 14,88 | 27,69 | 5,54 | 19,38 | 0,421 | 0,727 |
| 80 | 15,13 | 26,59 | 5,32 | 18,62 | 0,411 | 0,698 |
| 90 | 15,38 | 25,53 | 5,11 | 17,87 | 0,401 | 0,670 |
| 100 | 15,64 | 24,50 | 4,90 | 17,15 | 0,391 | 0,643 |

Results and processing

- 3 sets
 - Set 1: Getting familiar with the setup – validation
 - Set 2: Vary the relative density (D_r)
 - Set 3: Building the cyclic loads (%g)

Results and processing

- Density
 - Actual density ≈ proposed density



18

Results and processing

- When does liquefaction occur
 - Visually
 - CPPR-value > 1
 - Pore water pressure
- New method
 - Axial deformation

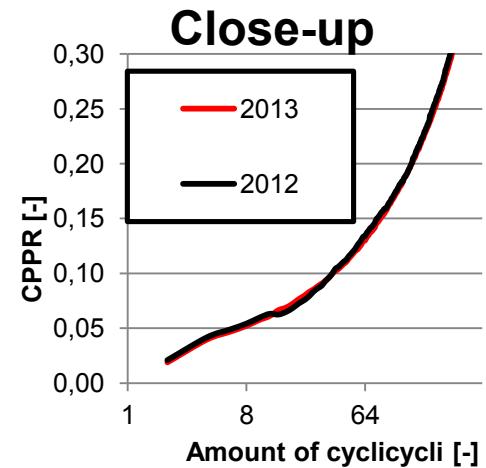
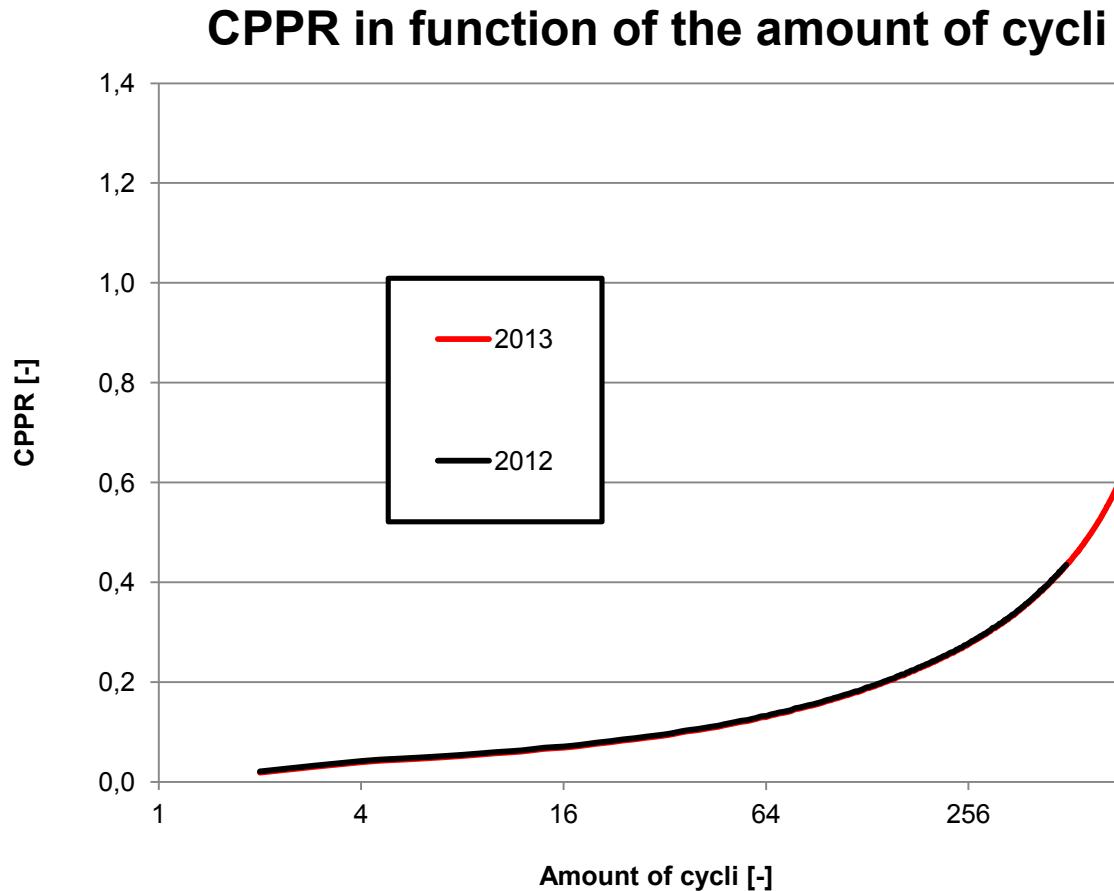
Results and processing

- Set 0: Boundary conditions
 - Relative density (D_r) = 60%
 - Frequency = 2 Hz
 - K-value = 0,74
 - Acceleration (a) = 0,3g
 - Mean effective stress (p') = 33,33 kPa
 - Amount of cycles = 1500

Results and processing

- Set 0: Comparisation
 - Test Tournoy & Popeye: 500 cycli
 - No liquefaction
 - Test Maes & Surmont: 1500 cycli
 - Liquefaction after 998 cycli
 - The values correspond to eachother

Results and processing



Results and processing

- Set 1: Overview tests

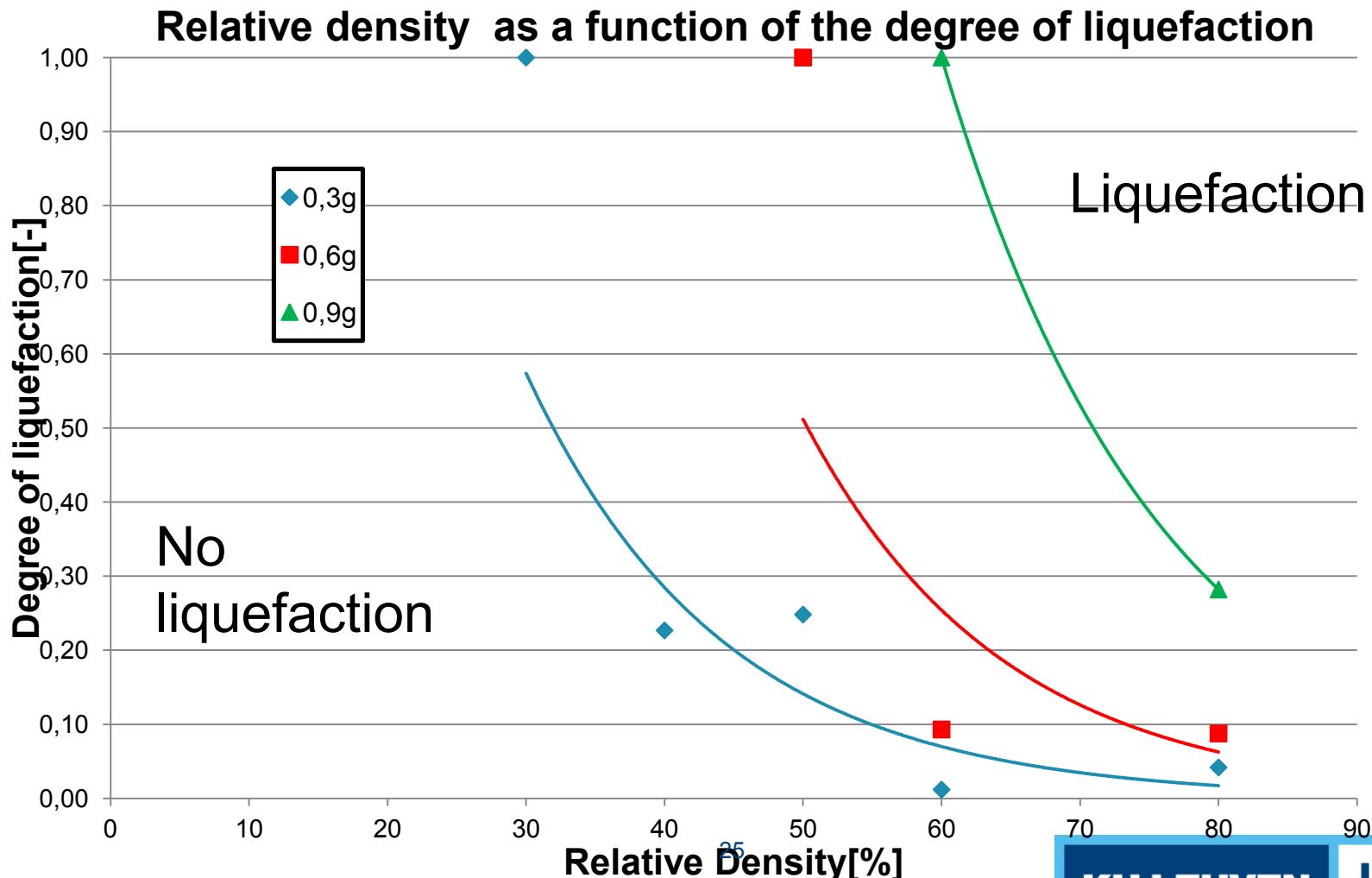
| | D _r [%] | K ₀ [-] | a [m/s ²] | Frequence [Hz] | p' [kPa] | Remarks |
|----|--------------------|--------------------|-----------------------|----------------|----------|----------------------------|
| 1 | 30 | 0,82 | 0,3 | 2 | 50 | Liquefaction at 712 cycli |
| 2 | 40 | 0,82 | 0,3 | 2 | 50 | No liquefaction |
| 3 | 40 | 0,82 | 0,6 | 2 | 50 | Liquefaction at 32 cycli |
| 4 | 50 | 0,82 | 0,3 | 2 | 50 | No liquefaction |
| 5 | 50 | 0,82 | 0,6 | 2 | 50 | Liquefaction at 6 cycli |
| 6 | 60 | 0,82 | 0,3 | 2 | 50 | No liquefaction |
| 7 | 60 | 0,82 | 0,6 | 2 | 50 | No liquefaction |
| 8 | 60 | 0,82 | 0,9 | 2 | 50 | Liquefaction at 1350 cycli |
| 9 | 80 | 0,82 | 0,3 | 2 | 50 | No liquefaction |
| 10 | 80 | 0,82 | 0,6 | 2 | 50 | No liquefaction |
| 11 | 80 | 0,82 | 0,9 | 2 | 50 | No liquefaction |

Results and processing

- Set 1: Overview results

| | LIQUEFACTION - CYCLI | | | NO LIQUEFACTION |
|----|----------------------|--------|---------------|-------------------------|
| | CPPR [-] | DU [-] | PORE/CELL [-] | LIQUEFACTION DEGREE [%] |
| 1 | 712 | 712 | 712 | |
| 2 | | | | 22,22 |
| 3 | 32 | 30 | 32 | |
| 4 | | | | 24,91 |
| 5 | 6 | 6 | 6 | |
| 6 | | | | 1,2 |
| 7 | | | | 9,45 |
| 8 | 1350 | 1350 | 1350 | |
| 9 | | | | 4,18 |
| 10 | | | | 8,77 |
| 11 | | | | 28,24 |

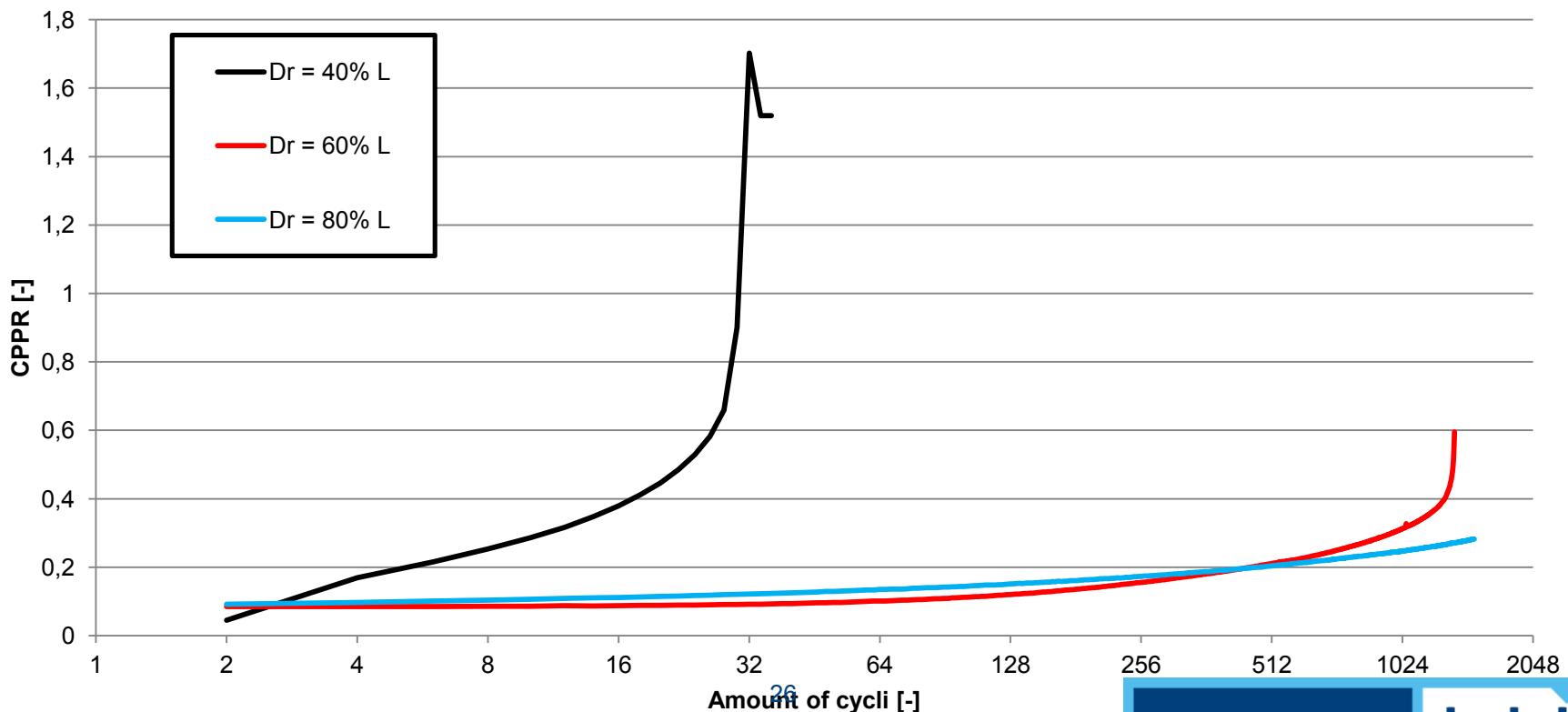
Results and processing



Results and processing

- Set 1: Results

CPPR in function of the amount of cycli for different relative densities



Results and processing

- Set 2: overview tests

| | D _r [%] | K ₀ [-] | a [m/s ²] | Frequence [Hz] | p' [kPa] | Remarks |
|---|--------------------|--------------------|-----------------------|----------------|----------|---------------------------|
| 1 | 60 | 0,82 | 0,1 | 2 | 50 | No liquefaction |
| 2 | 60 | 0,82 | 0,2 | 2 | 50 | No liquefaction |
| 3 | 60 | 0,82 | 0,3 | 2 | 50 | No liquefaction |
| 4 | 60 | 0,82 | 0,4 | 2 | 50 | No liquefaction |
| 5 | 60 | 0,82 | 0,5 | 2 | 50 | No liquefaction |
| 6 | 60 | 0,82 | 0,6 | 2 | 50 | No liquefaction |
| 7 | 60 | 0,82 | 0,7 | 2 | 50 | No liquefaction |
| 8 | 60 | 0,82 | 0,8 | 2 | 50 | Liquefaction at 898 cycli |
| 9 | 60 | 0,82 | 0,9 | 2 | 50 | Liquefaction at 12 cycli |

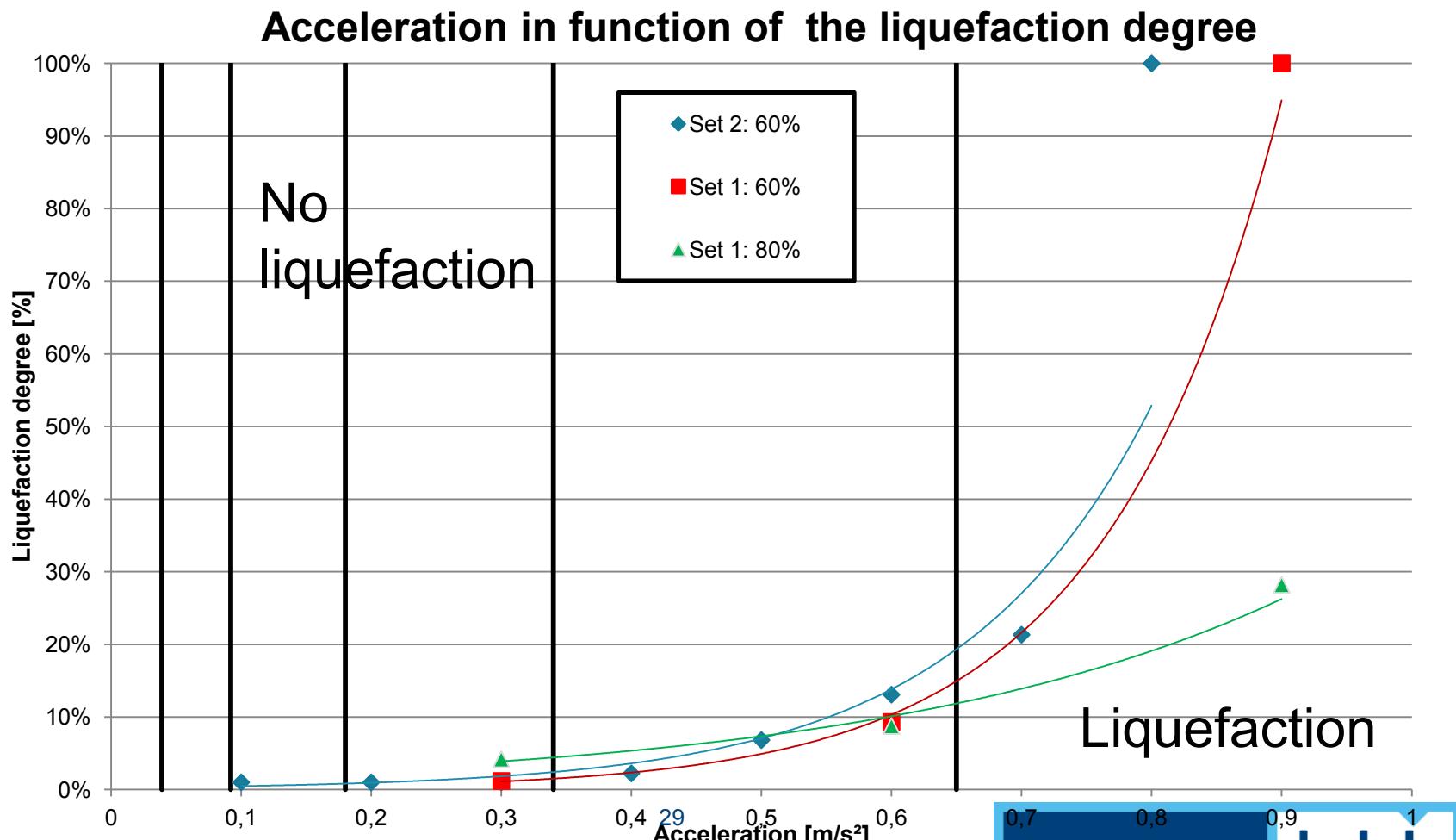
Results and processing

- Set 2: overview results

| | LIQUEFACTION - CYCLI | | | NO LIQUEFACTION |
|---|----------------------|--------|---------------|-------------------------|
| | CPPR [-] | DU [-] | PORE/CELL [-] | LIQUEFACTION DEGREE [%] |
| 1 | | | | ≈ 0 |
| 2 | | | | ≈ 0 |
| 3 | | | | ≈ 0 |
| 4 | | | | 2,18 |
| 5 | | | | 6,65 |
| 6 | | | | 12,76 |
| 7 | | | | 20,18 |
| 8 | 898 | 898 | 898 | |
| 9 | 12 | 12 | 12 | |

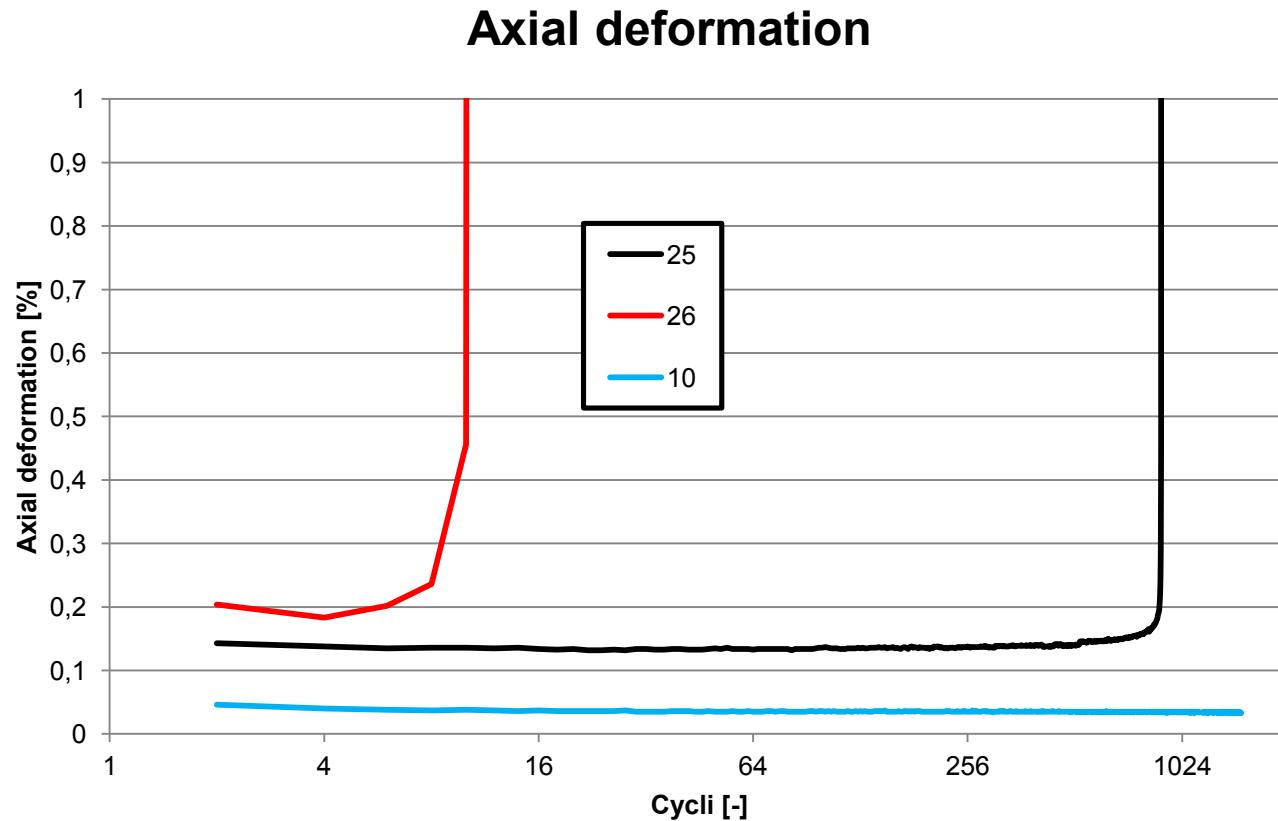
Results and processing

- Set 2: results



Results and processing

- Axial deformation



Results and processing

- Axial deformation
 - No liquefaction = maximal deformation = 0,1427%
 - Liquefaction = minimal deformation = 3,4403%

Conclusion

- Axial deformation has a threshold value
- How higher the K₀-value, how faster liquefaction will occur
- How higher the relative density, how slower liquefaction will occur
- How higher the acceleration, how faster liquefaction occurs

Questions?