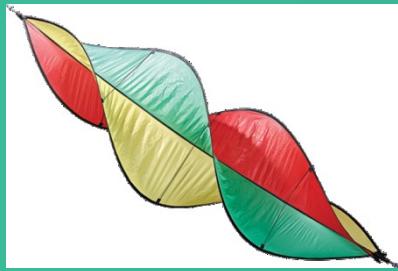


Earthquake stability of sand reclaimed areas



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')

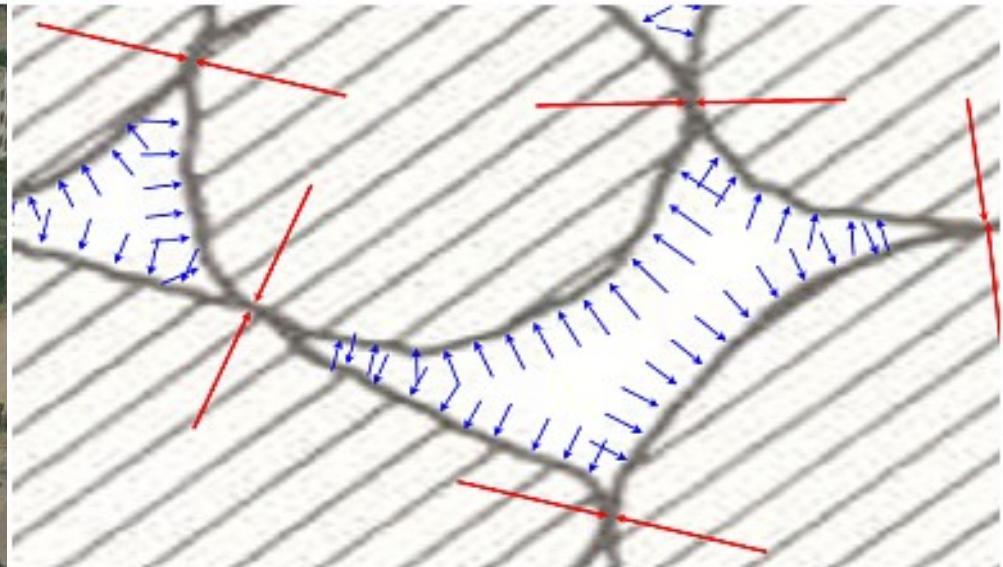
Liquefaction

- 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>



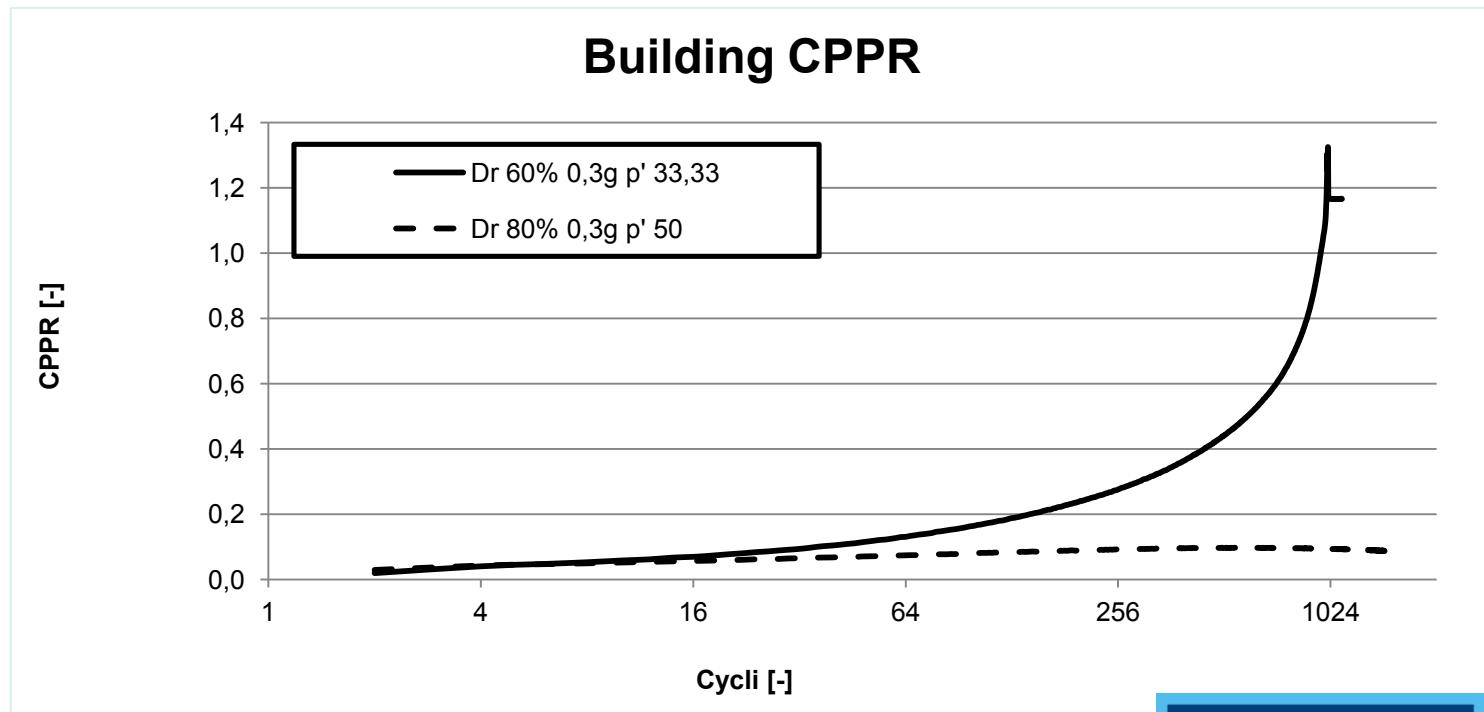
Liquefaction

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

Liquefaction

- CPPR: Cyclic Pore Pressure Ratio

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

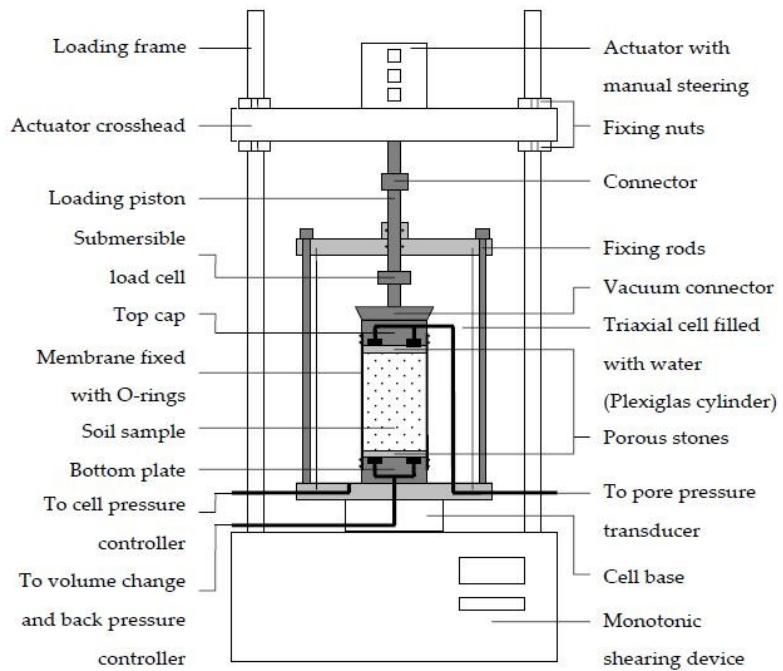


Liquefaction

- 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

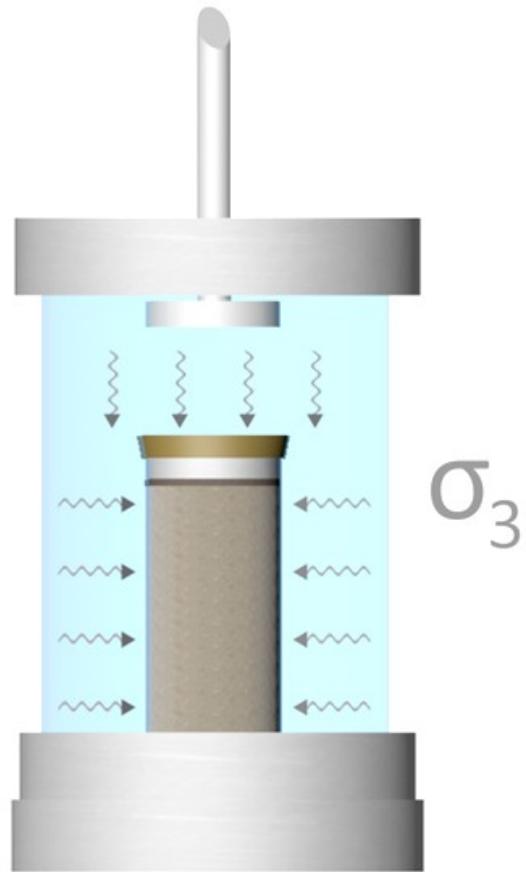
Setup

- 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
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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	D/4	D/2	D/1	D/4	D/2	D/1
Kalibers	D/4	D/2	D/1	D/4	D/2	D/1	D/4	D/2	D/1
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: hoogteid ³		
Code						Code			Code		
CF	MF	FF	4,0 ± 2,4	2,8 ± 1,5	2,1 ± 0,6	I3	I6	I7	I8	I10	I18
In het geval van zanden voor dewelke de doorval door D van de aanduiding hoger is dan 90 %, mag de producent :						3,0	5,0	7,0	8,0	10,0	16,0
- 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 %;						22,0	30,0	Opgewegeerde waarde ≥ 30			
- op de leveringsbon het kaliber 0/0 aanduiden door de aanduiding van de reelle zeef D* tussen haakjes, hetzij "0/0 (D*)".						Opgewegeerde waarde ≥ 30					

EN 933-1

Vergelijk kenmerk

Vergelijk kenmerk		
Absolute volumieke massa	Gemiddelde waarde = verklareerde waarde	Tolerantie ± 100 kg/m ³
Waterabsorptie ¹⁴	Gemiddelde waarde = verklareerde 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

Verplicht voor granulaten van maritieme oorsprong ¹

EN 933-7

Bijkomend kenmerk maximaal gehalte aan scheelpdelen (%)

Code		
SA	SB	SC
20	25	30

Verplicht voor granulaten van maritieme oorsprong ¹

EN 589-309

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

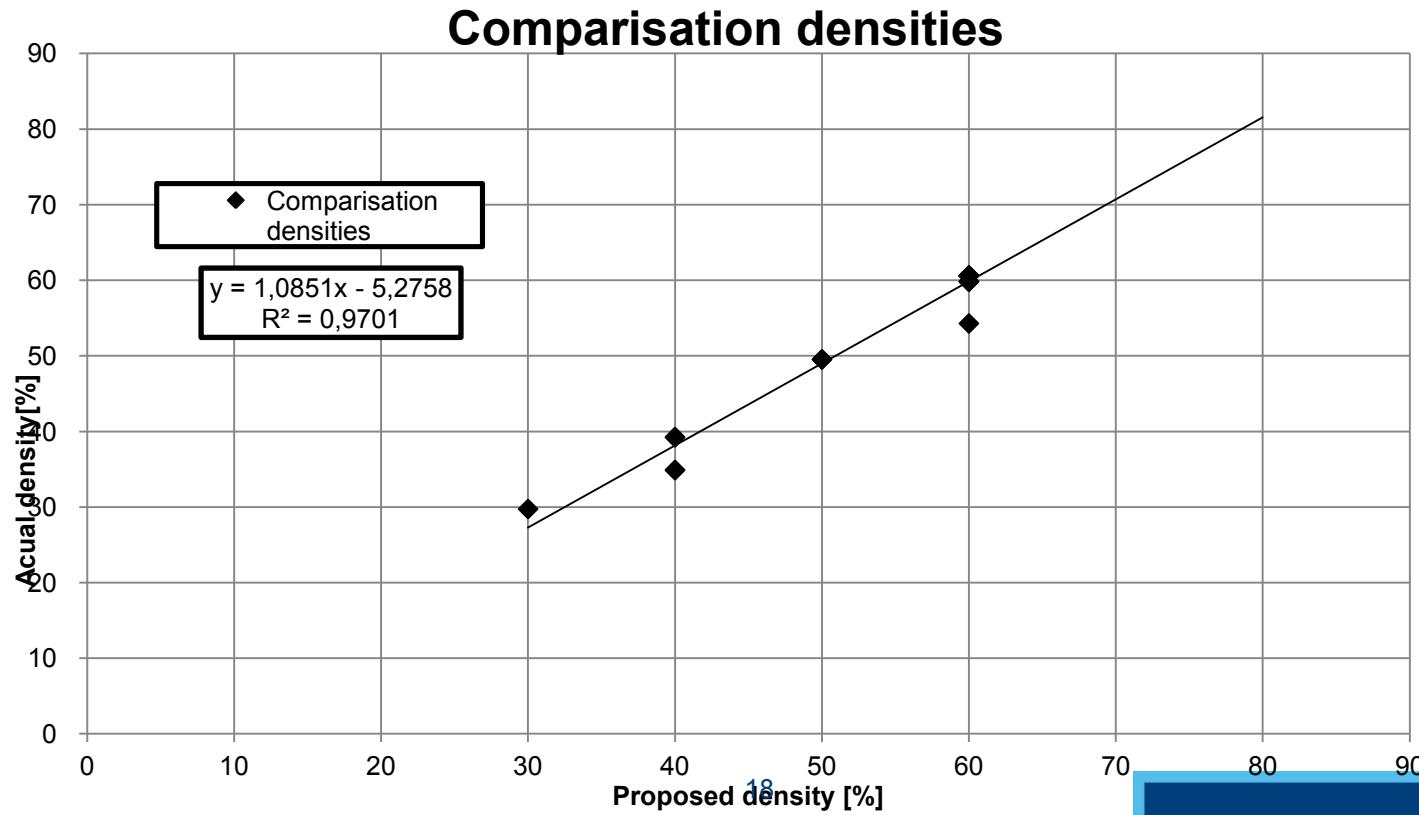
D_r [%]	γ_d [kN/m ³]	W_s [%]	$W_{20\%}$ [%]	$W_{70\%}$ [%]	n [-]	e [-]
0	13,11	36,57	7,31	25,60	0,490	0,959
10	13,36	35,16	7,03	24,61	0,480	0,922
20	13,61	33,80	6,76	23,66	0,470	0,887
30	13,87	32,49	6,50	22,74	0,460	0,852
40	14,12	31,23	6,25	21,86	0,450	0,819
50	14,37	30,01	6,00	21,00	0,440	0,787
60	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

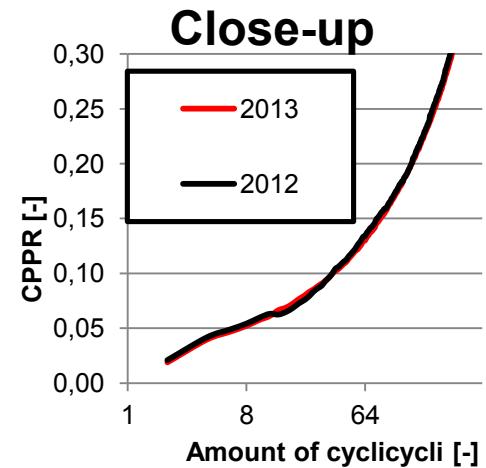
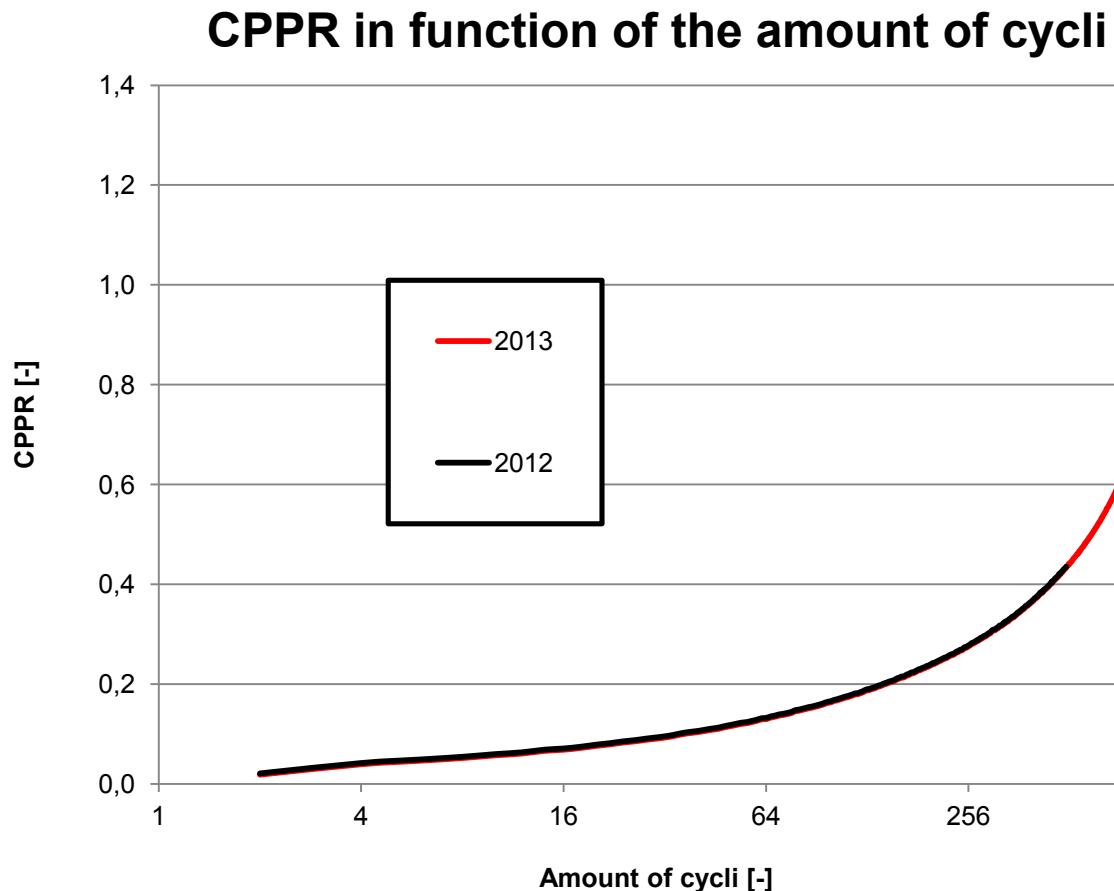
Results and processing

- 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

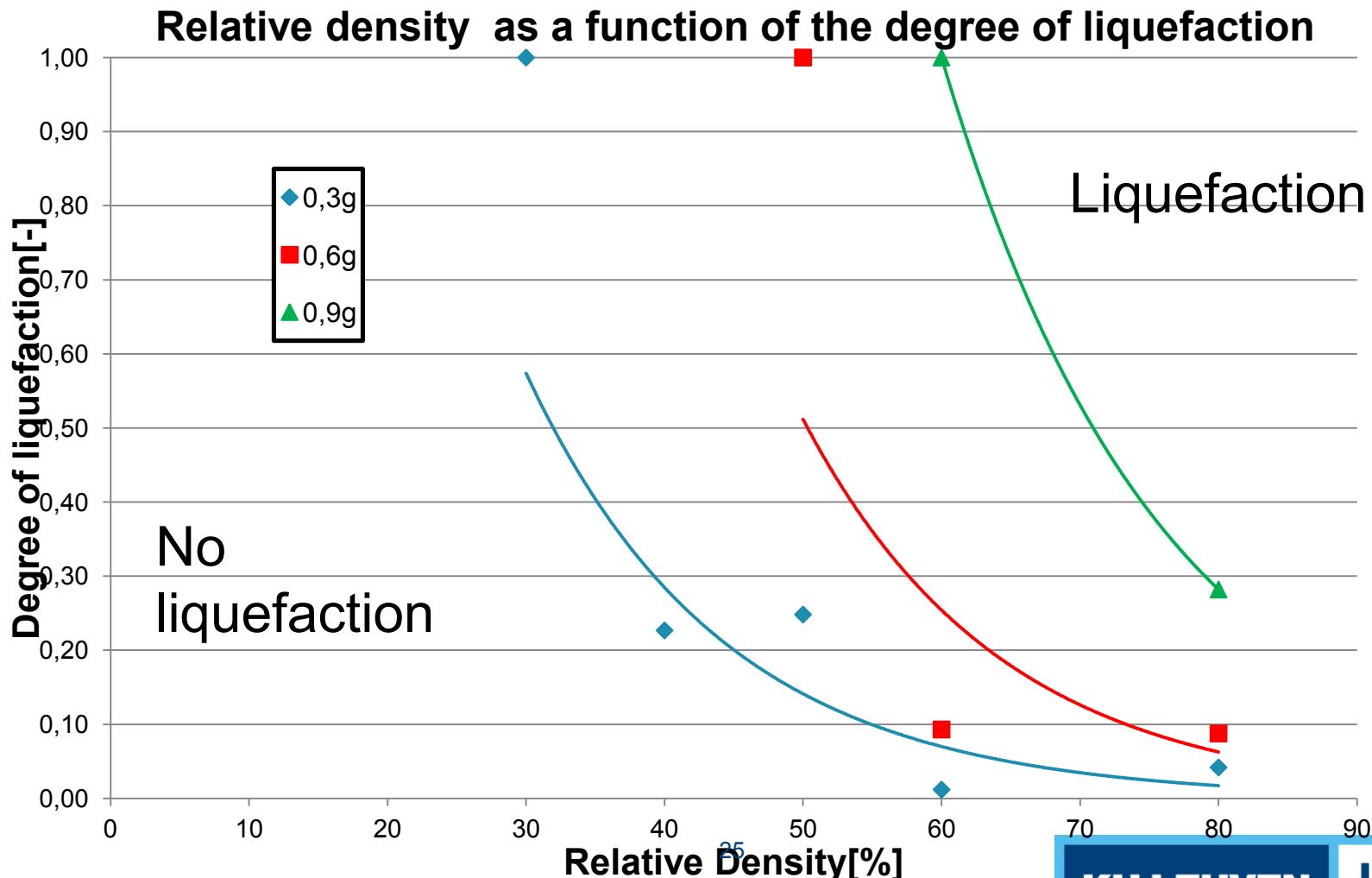
	D _r [%]	K ₀ [-]	a [m/s ²]	Frequence [Hz]	p' [kPa]	Remarks
1	30	0,82	0,3	2	50	Liquefaction at 712 cycli
2	40	0,82	0,3	2	50	No liquefaction
3	40	0,82	0,6	2	50	Liquefaction at 32 cycli
4	50	0,82	0,3	2	50	No liquefaction
5	50	0,82	0,6	2	50	Liquefaction at 6 cycli
6	60	0,82	0,3	2	50	No liquefaction
7	60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

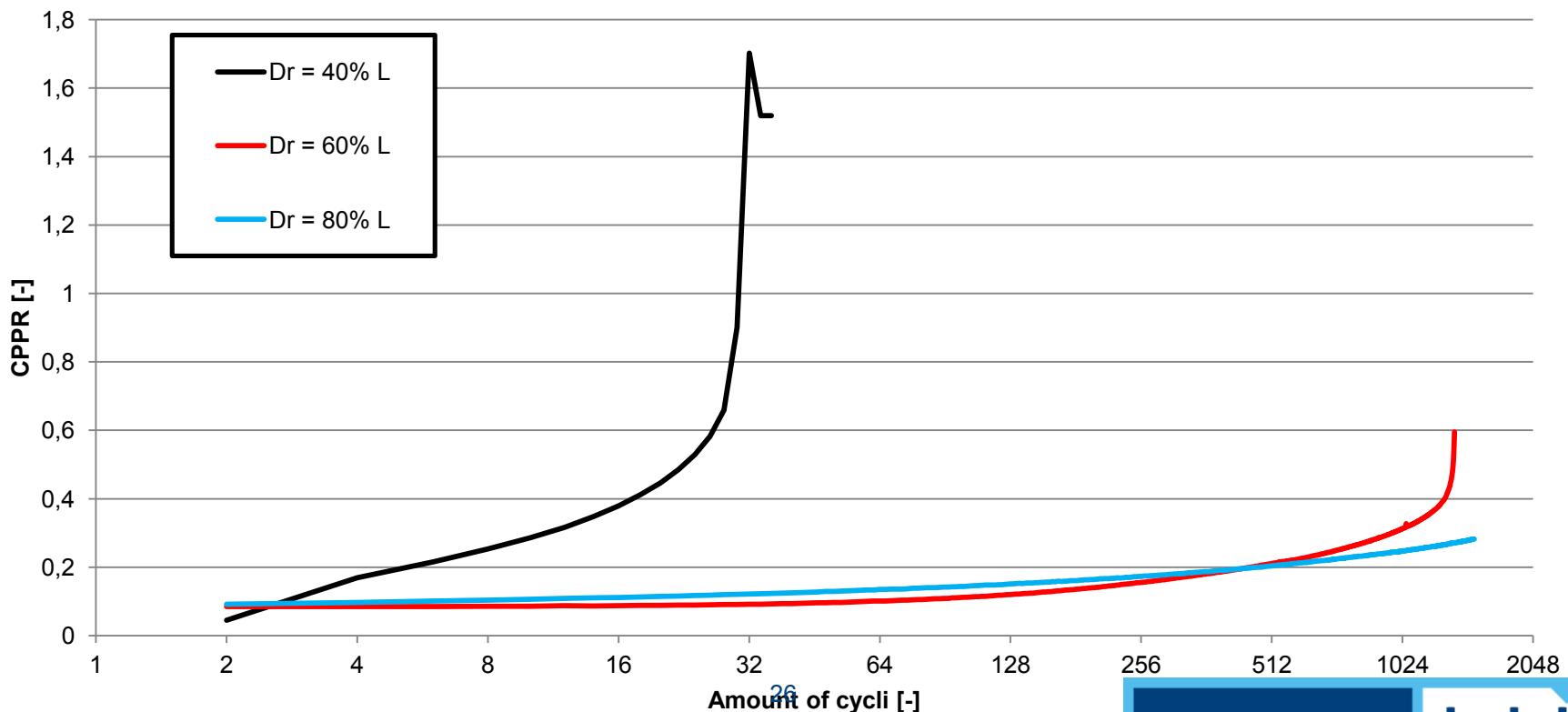
Results and processing



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

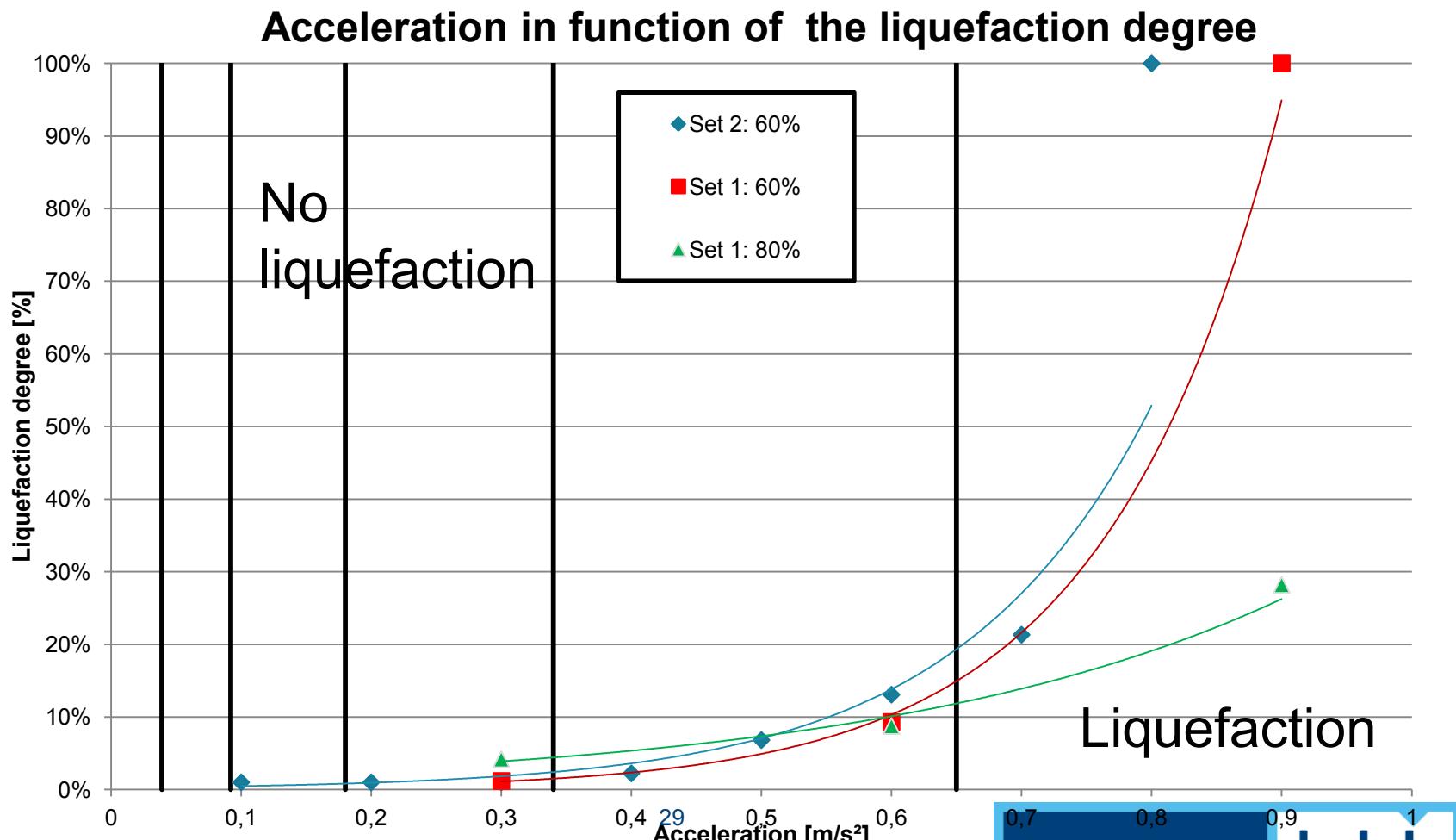
Results and processing

- 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	

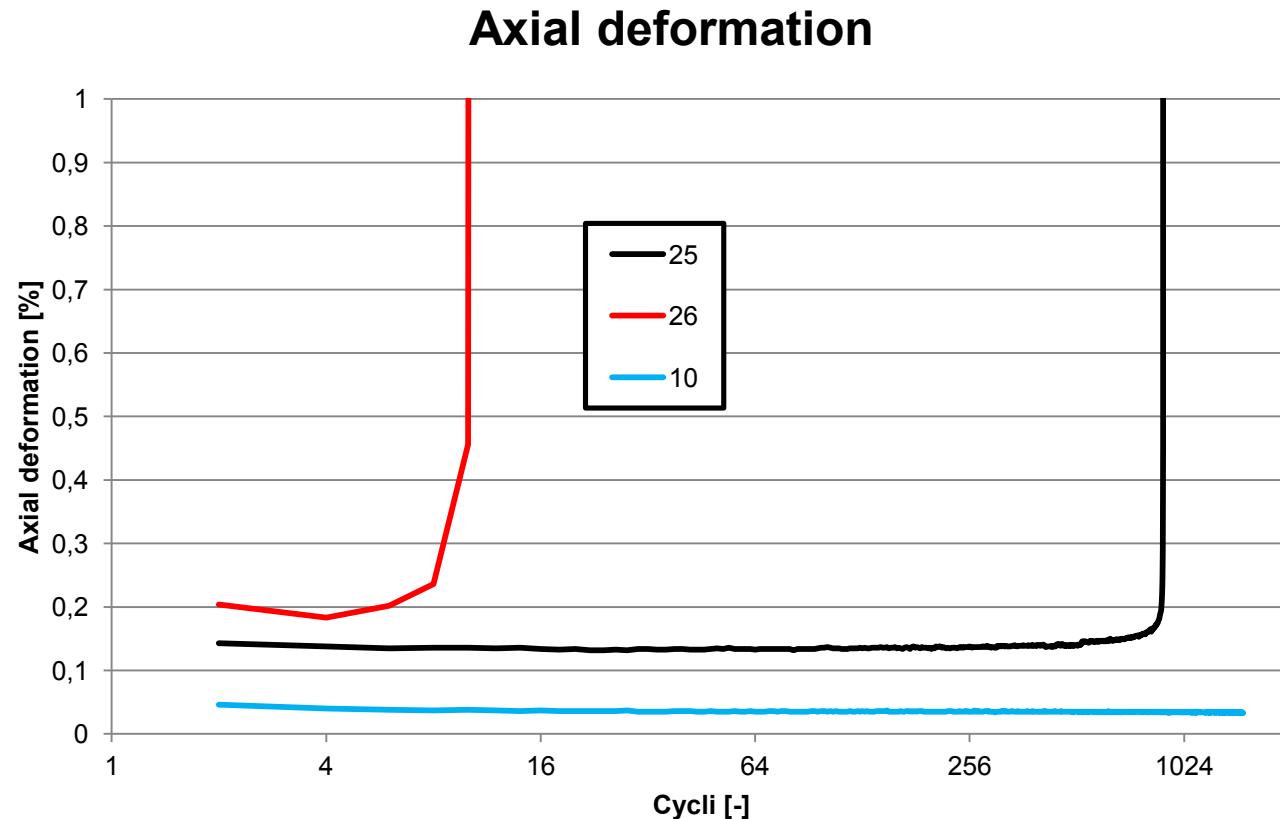
Results and processing

- 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?