



# GROUND IMPROVEMENT

## FROM AN ENGINEERING GEOLOGICAL PERSPECTIVE

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JEROEN DIJKSTRA

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DELFT

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23-11-2018

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THIS PDF CONTAINS ONLY A SELECTION OF THE SLIDES SHOWN  
DURING THE PRESENTATION AT THE SYMPOSIUM

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DETAILS





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- 01 INTRODUCTION**
- 02 COMPACTION OMAN**
- 03 COMPACTION AUSTRALIA**



# RESUME

- 1997 – 2003 DELFT UNIVERSITY**  
Engineering geology
- 2003 – 2005 COFRA (FAMILY OWNED)**  
Assistant project manager  
Geotechnical engineer
- 2006 – 2007 CRUX ENGINEERING**  
Geotechnical engineer
- 2008 COFRA (BOSKALIS OWNED)**  
Manager geotechnical department  
Business development





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# PROJECT FROM THE PLANE





## MATERIAL



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## REQUIREMENTS



### QC-SPT REQUIREMENT

- $q_c > 10\text{MPa}$  (rolling average)
- 1m cumulative in profile is allowed  $>6\text{MPa}$  and  $< 10\text{MPa}$
- SPT  $> 18$  blows per 30cm
- Carbonate correction factor !

### LIQUEFACTION REQUIREMENT

- $M=6.5$  PGA 0.05 at bedrock 475 year

### LOAD SETTLEMENT BEHAVIOR

### MDD REQUIREMENT TOP 1.5 METERS

- 95-98% MDD

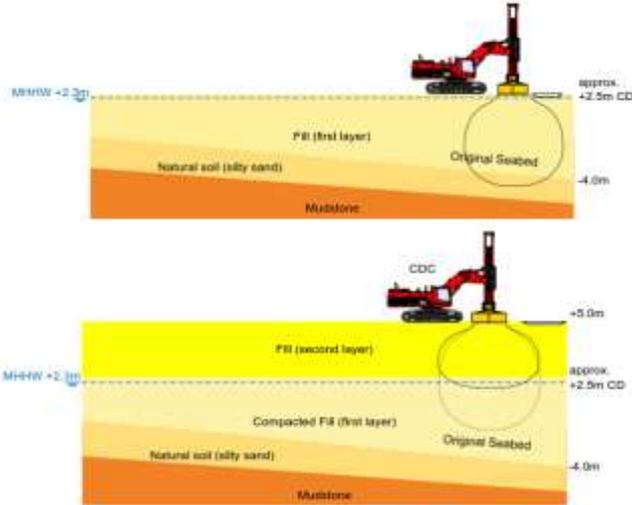
REQUIREMENT ID	LOADING	MAX. PERMISSIBLE TOTAL SETTLEMENT
1	Self-settlement of the finished reclamation with no additional load applied	75mm after 50 years
2	150kPa surcharge over a 5m x 5m at the final surface level of the reclamation	100mm after 50 years
3	150kPa uniform surcharge applied at the final surface level of the reclamation	120mm after 50 years
4	50kPa uniform surcharge applied at the final surface level of the reclamation	100mm after 50 year
5	50kPa uniform surcharge applied at the final surface level of the reclamation	100mm after 20 year
6	100kPa uniform surcharge applied at the final surface level of the reclamation	90mm after 1 year



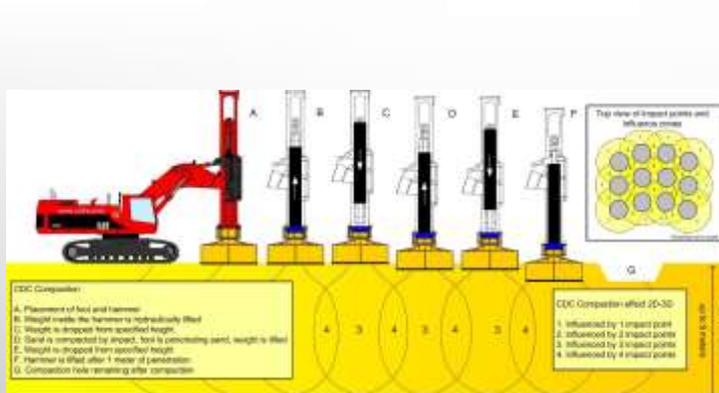
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# COMPACTION APPROACH



# METHOD OF COMPACTION





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# VIBRATIONS



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## CHALLENGES

- Silty sand layer above bedrock
- Unknown carbonate correction factor at the tender stage
- Compaction level near water table



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## SILTY SAND



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# EFFECT OF PVD

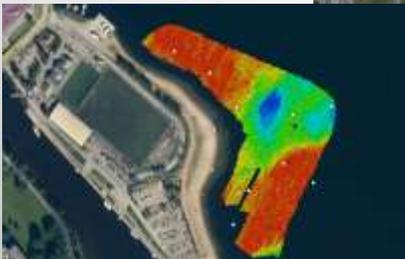


# UNFORTUNATELY – NO GPS LOGGING



Push force at specific depth

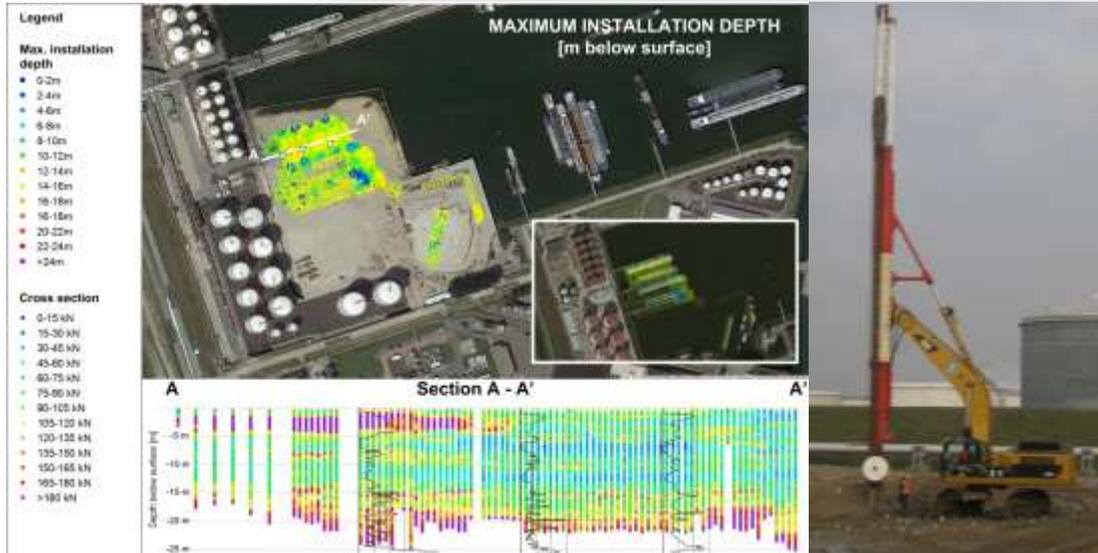
Depth map



Highly optimized drain designs



## PROFILING



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## CALCAREOUS CONTENT



- >90% calcareous ( $\text{CaCO}_3$ )
- High peak stresses cause crushing during CPT testing
  - $q_c$  calcareous <  $q_c$  silica
  - Literature shows a large spread in correction factors (1.4-2.0)
  - Correction factor depending on relative density



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# LARGE VOLUME CHANGES



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# WATER TABLE



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# COMPACTION DATA



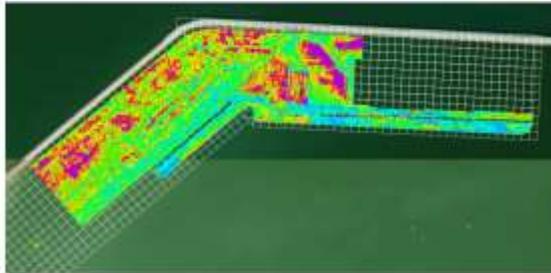
## CDC Progress Sheet

Induced settlement – Phase 1 – Pass 1

Project  
Client  
Reference  
C3118  
Author  
JSA  
Date  
12.03.2018

**Legend**

- 0-2 mm/blow
- 2-4 mm/blow
- 4-8 mm/blow
- 8-10 mm/blow
- 10-12 mm/blow
- 12-14 mm/blow
- 14-16 mm/blow
- 16-18 mm/blow
- 18-20 mm/blow
- 20-22 mm/blow
- 22-24 mm/blow
- >24 mm/blow



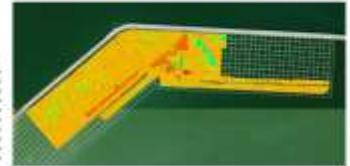
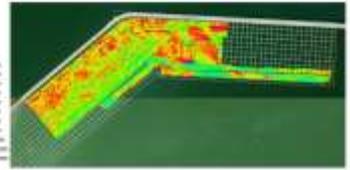
## CDC Progress Sheet

Total settlement Phase 1 - Pass 1

Project  
Client  
Reference  
C3118  
Author  
JSA  
Date  
12.03.2018

**Legend**

- 0-100mm
- 100-150mm
- 150-200mm
- 200-250mm
- 250-300mm
- 300-350mm
- 350-400mm
- 400-450mm
- 450-500mm
- 500-550mm
- 550-600mm
- 600-650mm
- 650-700mm
- 700-750mm
- 750-800mm
- 800-850mm
- 850-900mm
- 900-950mm
- 950-1000mm
- 1000-1050mm
- 1050-1100mm
- 1100-1150mm
- 1150-1200mm
- 1200-1250mm
- 1250-1300mm
- 1300-1350mm
- 1350-1400mm
- 1400-1450mm
- 1450-1500mm
- 1500-1550mm
- 1550-1600mm
- 1600-1650mm
- 1650-1700mm
- 1700-1750mm
- 1750-1800mm
- 1800-1850mm
- 1850-1900mm
- 1900-1950mm
- 1950-2000mm
- 2000-2050mm
- 2050-2100mm
- 2100-2150mm
- 2150-2200mm
- 2200-2250mm
- 2250-2300mm
- 2300-2350mm
- 2350-2400mm
- 2400-2450mm
- 2450-2500mm
- 2500-2550mm
- 2550-2600mm
- 2600-2650mm
- 2650-2700mm
- 2700-2750mm
- 2750-2800mm
- 2800-2850mm
- 2850-2900mm
- 2900-2950mm
- 2950-3000mm
- 3000-3050mm
- 3050-3100mm
- 3100-3150mm
- 3150-3200mm
- 3200-3250mm
- 3250-3300mm
- 3300-3350mm
- 3350-3400mm
- 3400-3450mm
- 3450-3500mm
- 3500-3550mm
- 3550-3600mm
- 3600-3650mm
- 3650-3700mm
- 3700-3750mm
- 3750-3800mm
- 3800-3850mm
- 3850-3900mm
- 3900-3950mm
- 3950-4000mm
- 4000-4050mm
- 4050-4100mm
- 4100-4150mm
- 4150-4200mm
- 4200-4250mm
- 4250-4300mm
- 4300-4350mm
- 4350-4400mm
- 4400-4450mm
- 4450-4500mm
- 4500-4550mm
- 4550-4600mm
- 4600-4650mm
- 4650-4700mm
- 4700-4750mm
- 4750-4800mm
- 4800-4850mm
- 4850-4900mm
- 4900-4950mm
- 4950-5000mm
- 5000-5050mm
- 5050-5100mm
- 5100-5150mm
- 5150-5200mm
- 5200-5250mm
- 5250-5300mm
- 5300-5350mm
- 5350-5400mm
- 5400-5450mm
- 5450-5500mm
- 5500-5550mm
- 5550-5600mm
- 5600-5650mm
- 5650-5700mm
- 5700-5750mm
- 5750-5800mm
- 5800-5850mm
- 5850-5900mm
- 5900-5950mm
- 5950-6000mm
- 6000-6050mm
- 6050-6100mm
- 6100-6150mm
- 6150-6200mm
- 6200-6250mm
- 6250-6300mm
- 6300-6350mm
- 6350-6400mm
- 6400-6450mm
- 6450-6500mm
- 6500-6550mm
- 6550-6600mm
- 6600-6650mm
- 6650-6700mm
- 6700-6750mm
- 6750-6800mm
- 6800-6850mm
- 6850-6900mm
- 6900-6950mm
- 6950-7000mm
- 7000-7050mm
- 7050-7100mm
- 7100-7150mm
- 7150-7200mm
- 7200-7250mm
- 7250-7300mm
- 7300-7350mm
- 7350-7400mm
- 7400-7450mm
- 7450-7500mm
- 7500-7550mm
- 7550-7600mm
- 7600-7650mm
- 7650-7700mm
- 7700-7750mm
- 7750-7800mm
- 7800-7850mm
- 7850-7900mm
- 7900-7950mm
- 7950-8000mm
- 8000-8050mm
- 8050-8100mm
- 8100-8150mm
- 8150-8200mm
- 8200-8250mm
- 8250-8300mm
- 8300-8350mm
- 8350-8400mm
- 8400-8450mm
- 8450-8500mm
- 8500-8550mm
- 8550-8600mm
- 8600-8650mm
- 8650-8700mm
- 8700-8750mm
- 8750-8800mm
- 8800-8850mm
- 8850-8900mm
- 8900-8950mm
- 8950-9000mm
- 9000-9050mm
- 9050-9100mm
- 9100-9150mm
- 9150-9200mm
- 9200-9250mm
- 9250-9300mm
- 9300-9350mm
- 9350-9400mm
- 9400-9450mm
- 9450-9500mm
- 9500-9550mm
- 9550-9600mm
- 9600-9650mm
- 9650-9700mm
- 9700-9750mm
- 9750-9800mm
- 9800-9850mm
- 9850-9900mm
- 9900-9950mm
- 9950-10000mm





# OPTICAL ILLUSION



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# AUSTRALIA 2011-2012



# CALCAREOUS MATERIAL





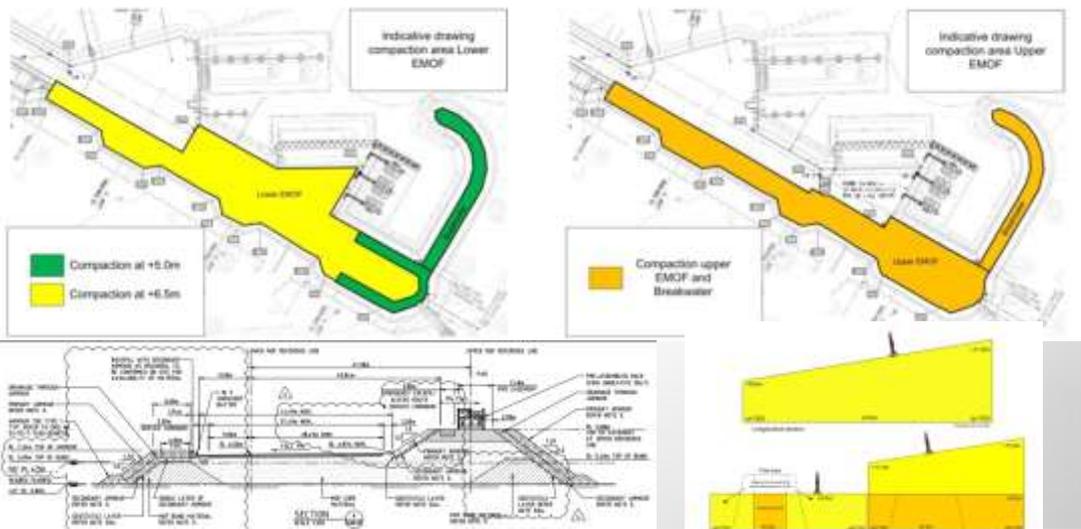
# REQUIREMENTS

Target values compaction

- E-modulus from +2.0m till +6.5m: 60 MPa (breakwater and slope area up to +5.0m)
- E-modulus from +6.5m and above: 100MPa (breakwater and slope area up from +5.0m)



# COMPACTION APPROACH

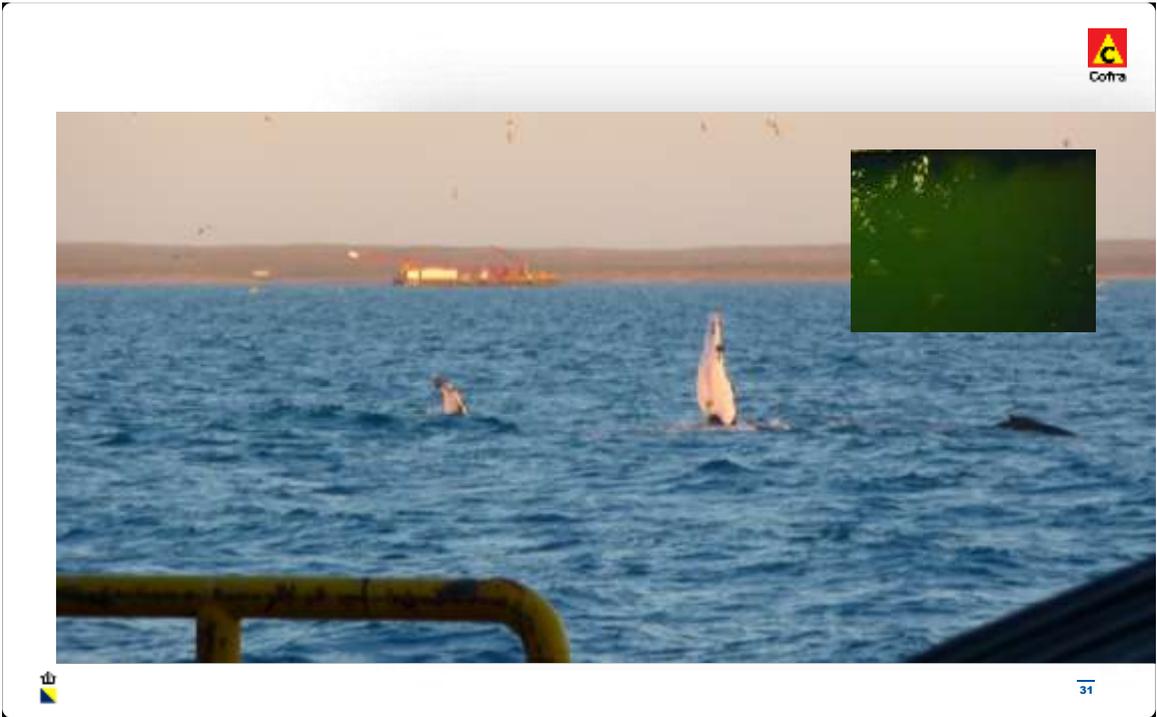




# CHALLENGES

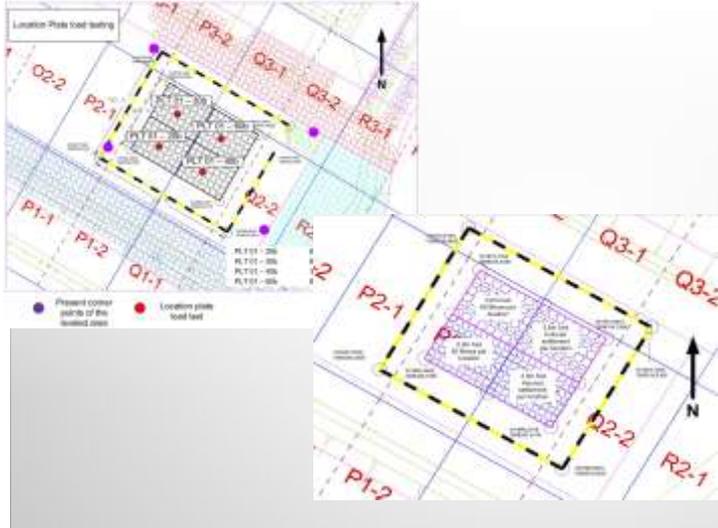
- Remote location with no land based accommodation
- Class A nature reserve
- Material – how to test
- Time pressure





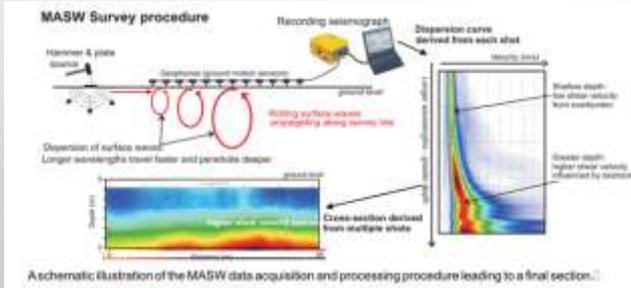


# TRIAL



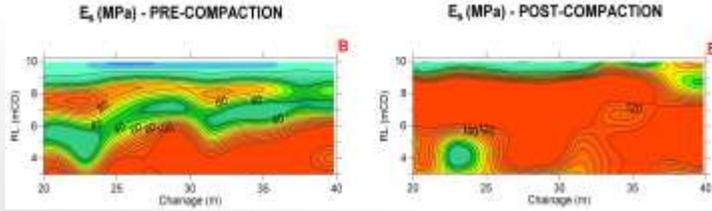
# TESTING

- Material too coarse for SPT and CPT testing
- Plate load testing
- MASW (multichannel analyses of shear wave) testing





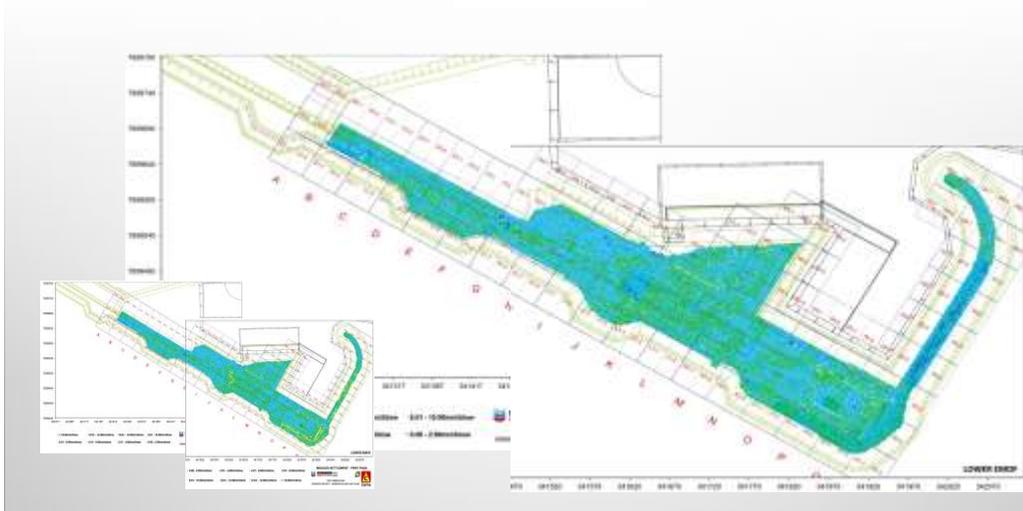
# COMPACTION RESULTS





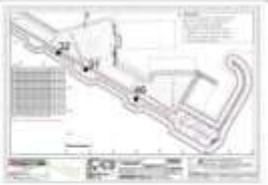


# FINAL INDUCED AFTER SECOND PASS



# HANDOVER CRITERIA: PLATE LOAD

PLT test ID	Date	Northing	Easting
PLT #31 - PMDF S1 - Final	20-12-2011	7689582.25	581389.88
PLT #32 - PMDF S1 - Final	21-02-2012	7689656.33	581265.10
PLT #46 - HLF South - Final	31-05-2012	7689462.40	341601.78



PLT test ID	Compliant	E-modulus [Mpa]						Stress [kPa]					
		1	2	3	4	5	6	1	2	3	4	5	6
PLT #31 - PMDF S1 - Final	Yes	169	162	151	145	155	168	54	102	205	308	405	508
PLT #32 - PMDF S1 - Final	Yes	194	127	123	139	151	173	54	102	205	308	406	519
PLT #46 - HLF South - Final	Yes	157	123	122	120	123	126	56	104	211	315	406	515





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