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The Application of a Combination of PVD & Stone Columns for the Treatment of Oil Tank Foundations

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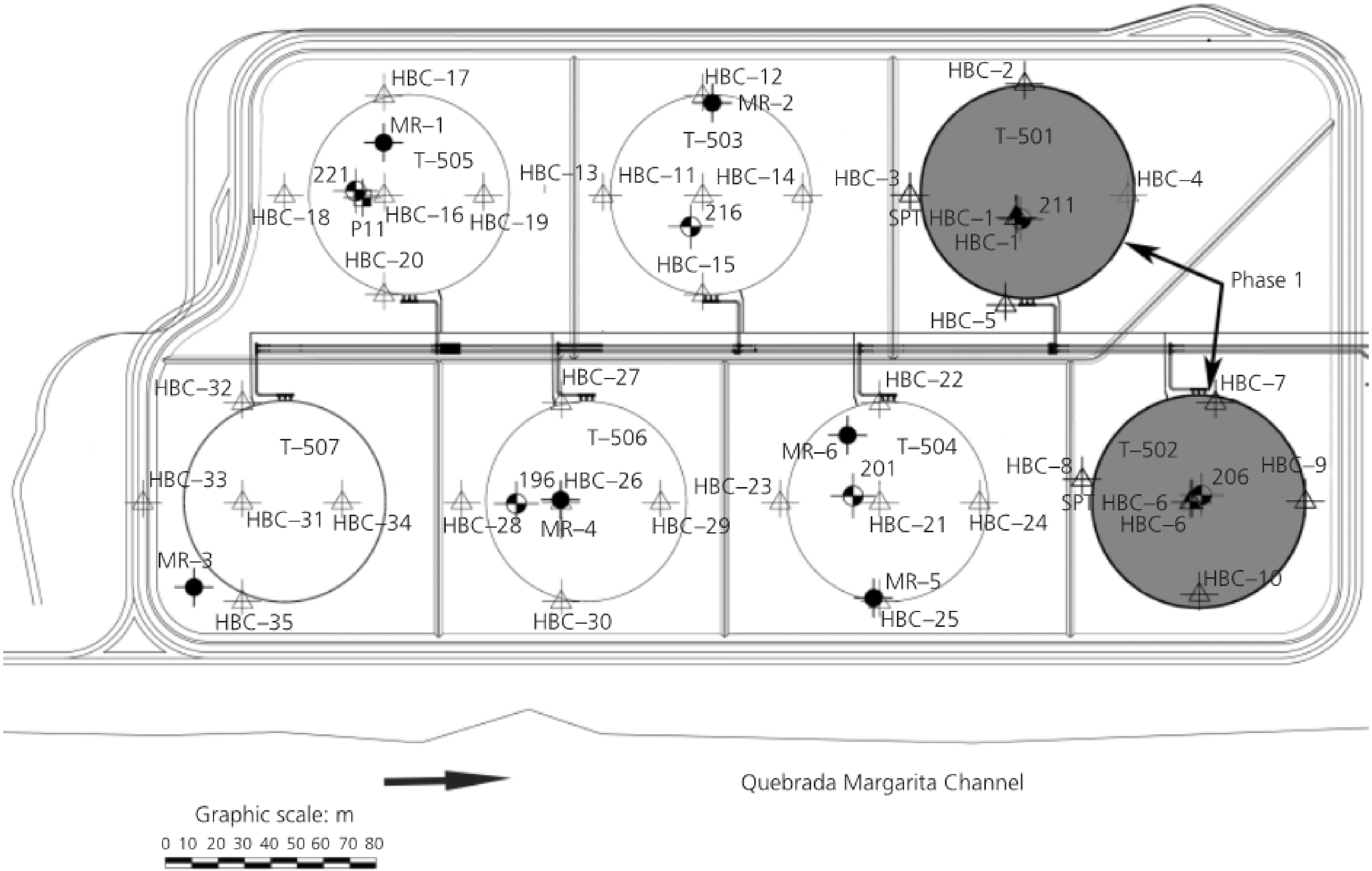
Geotechnical Specialist Contractors

Chiriqui Grande Phase II Oil Terminal Panama

- Participants
  - Owner: Petroterminal de Panamá S.A.
  - Main contractor: CBI Americas Ltd
  - Specialist geotechnical contractor: Rodio Swissboring – Grupo Rodio Kronsa (GFWA in WA)
- Construction of 5 crude oil tanks
  - Diameter = 76.2 m
  - Height = 20.4 m
  - Product storage height: 18.9 m
  - Roof system:
    - Internal :floating
    - External: cone type

Project Layout & Tender Stage Site Investigation



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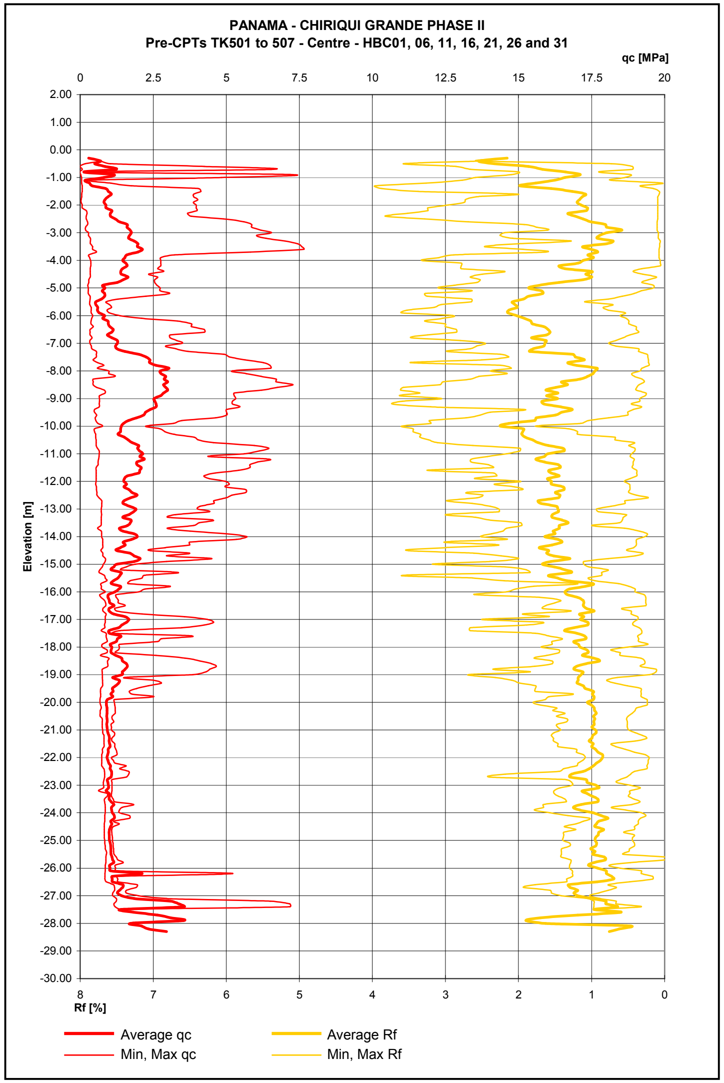
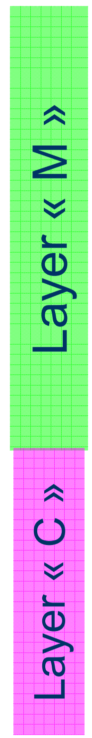
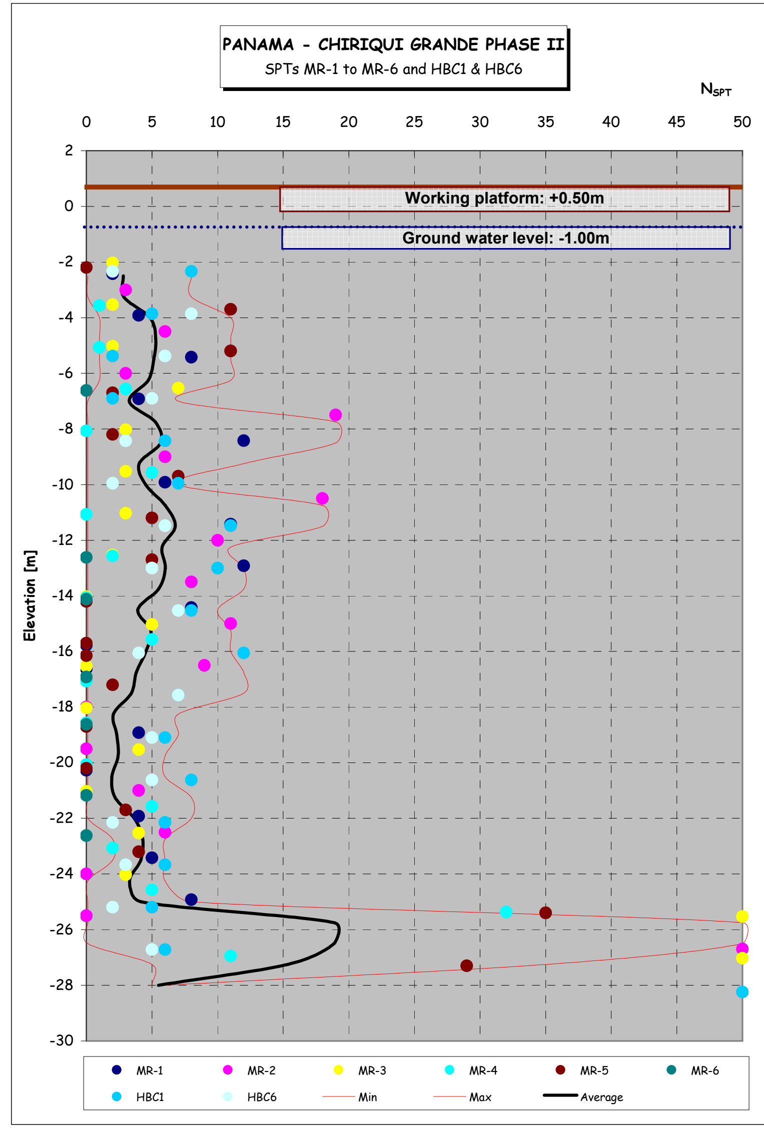
Tender Stage Site Investigation: 8 SPTs & 35 CPTs







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Design Criteria

- Ring wall foundation total settlement ≤ to 200 mm
- Centre to edge dishing settlement ≤ to 150 mm
- Out of plane settlement ≤ 10 mm in an arc distance of 24.4 m.
- Net allowable bearing ≥ 200 kPa with SF= 3

Design & Construction Approach in Phase II

- Rather than making simplistic design assumptions:
  - back analyse the results of Phase I
  - derive Phase II design
- Construction techniques same as Phase I (PVD, SC, PL) but:
  - Wet Top Feed Stone Column method rather than Dry Bottom Feed
  - PVD spacing 0.91 m (from 1.22 m in PI; i.e 80% increase in PVD)
  - PVD depth: up to 28 m
  - Stone columns spacing: 2.44 m triangular
  - Stone columns diameter: 1.06 m (replacement ratio= 17.1%)
  - Preload height: 13 to 14 m (285 kPa)
  - Preloading placement duration: 3-4 weeks
  - Preloading period from placement completion: 7-9 weeks
  - Treatment diameter/ tank: 95 m

Ground Improvement Works


1


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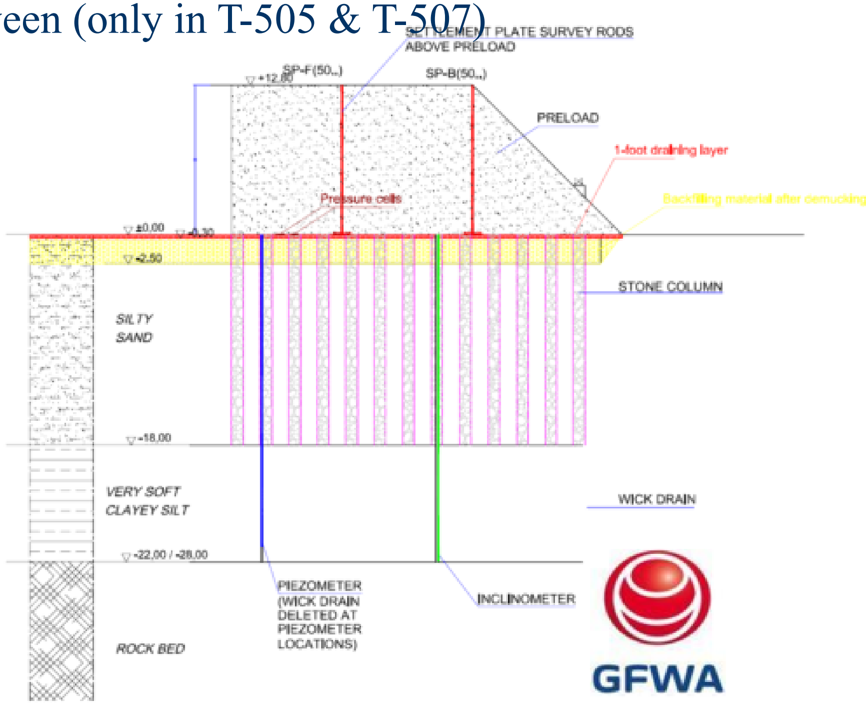
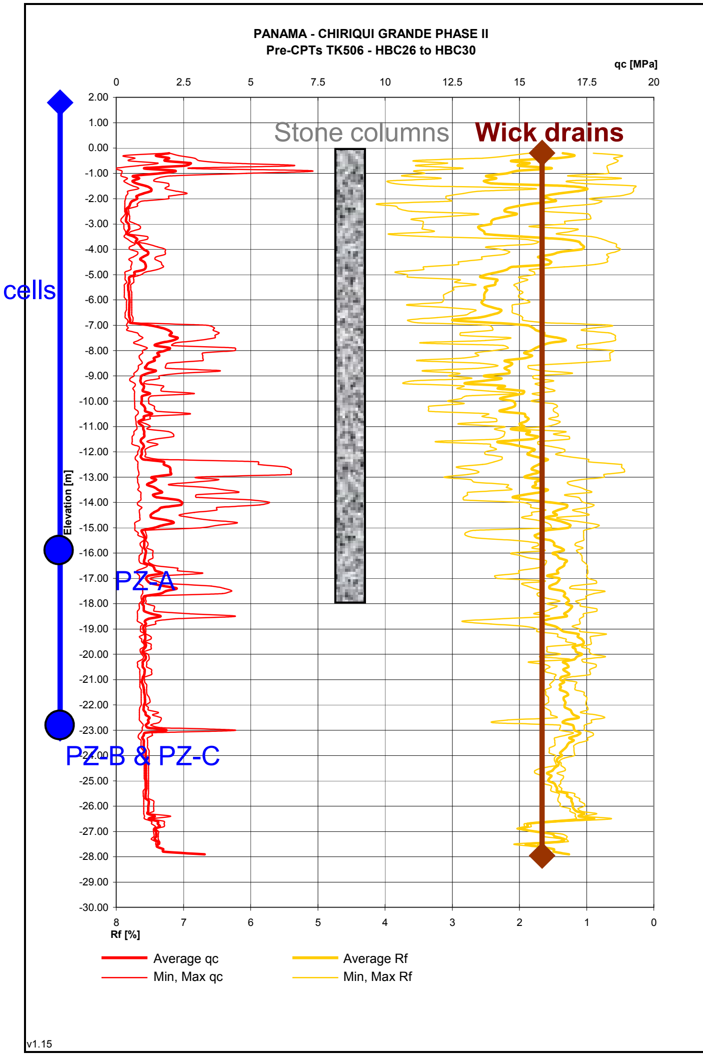
Instrumentation & Monitoring

- Each tank:
  - 8 settlement plates on shell, 1 at centre
  - 3 pore pressure transducers in line along a diameter
    - -16 m RL (PVD & SC)
    - -23 m RL (PVD only)
  - 3 Inclinometers (only in T-503 & T-505)
  - 3 total earth pressure cells located on (2) stone columns & in (1) in between (only in T-505 & T-507)





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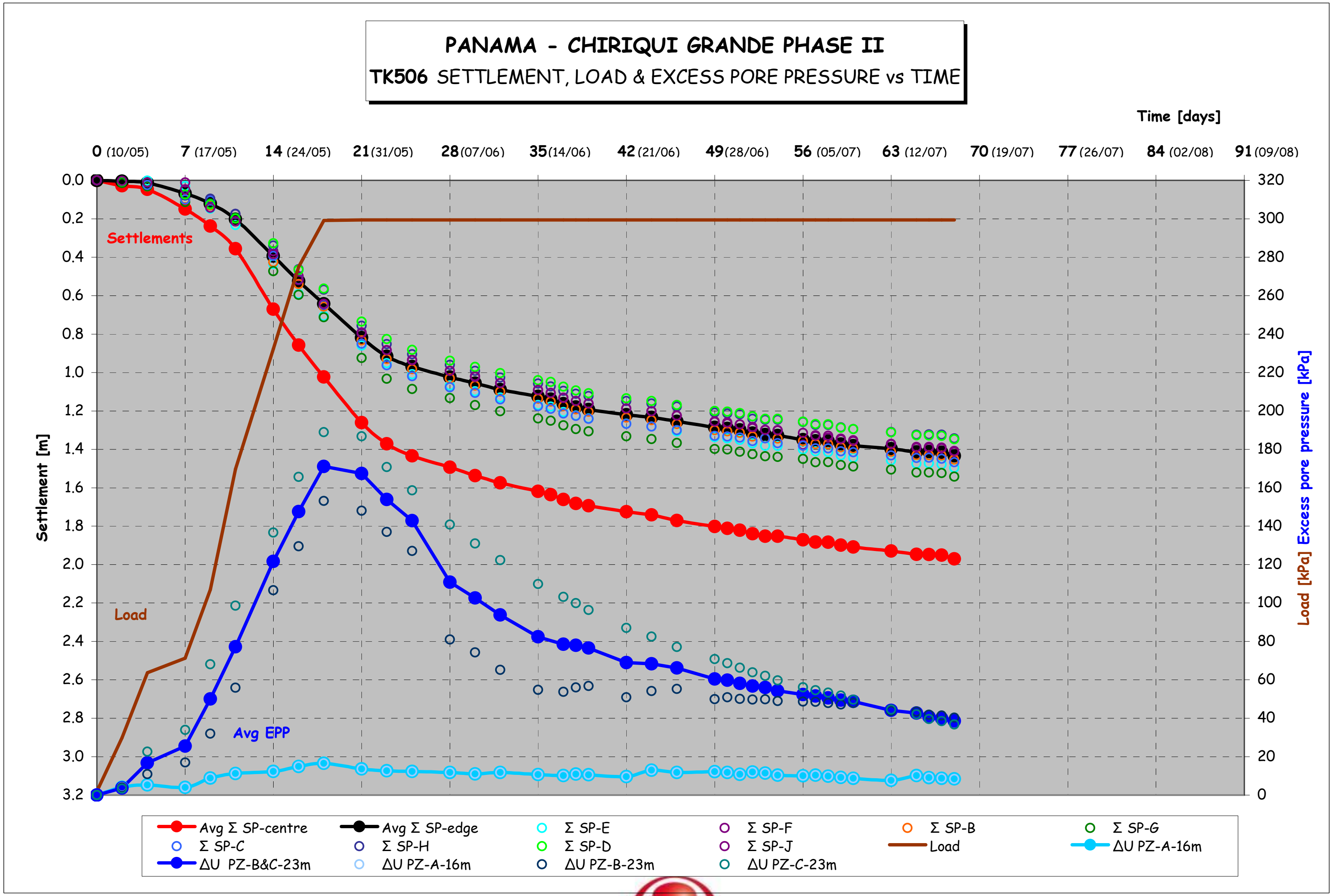
Tank 506: Preloading settlement & EPP monitoring



Elevation -23m (zone with wicks drain only)

Average Excess Pore Pressure of Pz-B and C in kPa

Elevation -16m (Zone with stone columns & wick drains)

Average Excess Pore Pressure of Pz-A in kPa ➔No clogging efffect

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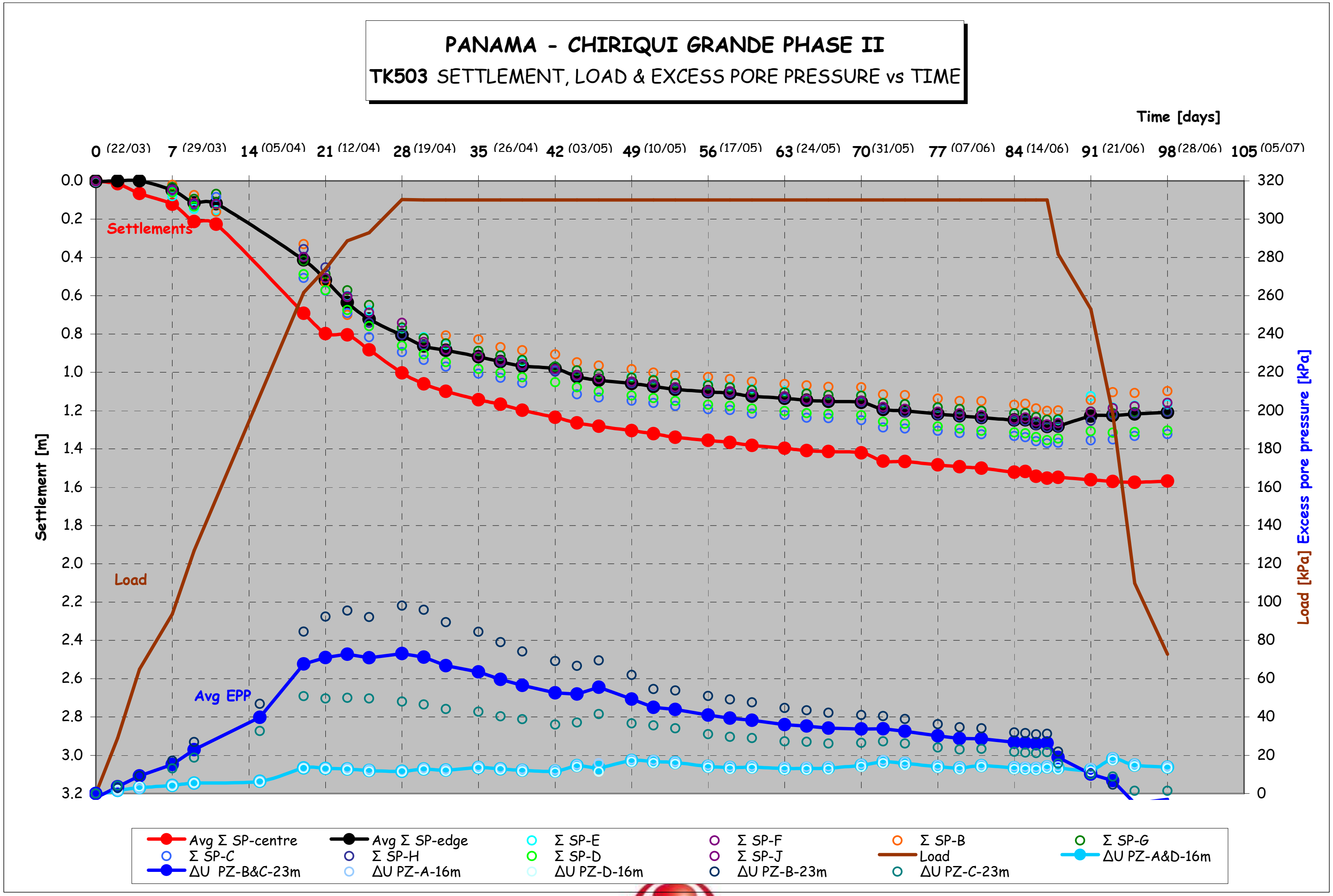
Tank 503: Preloading settlement & EPP monitoring



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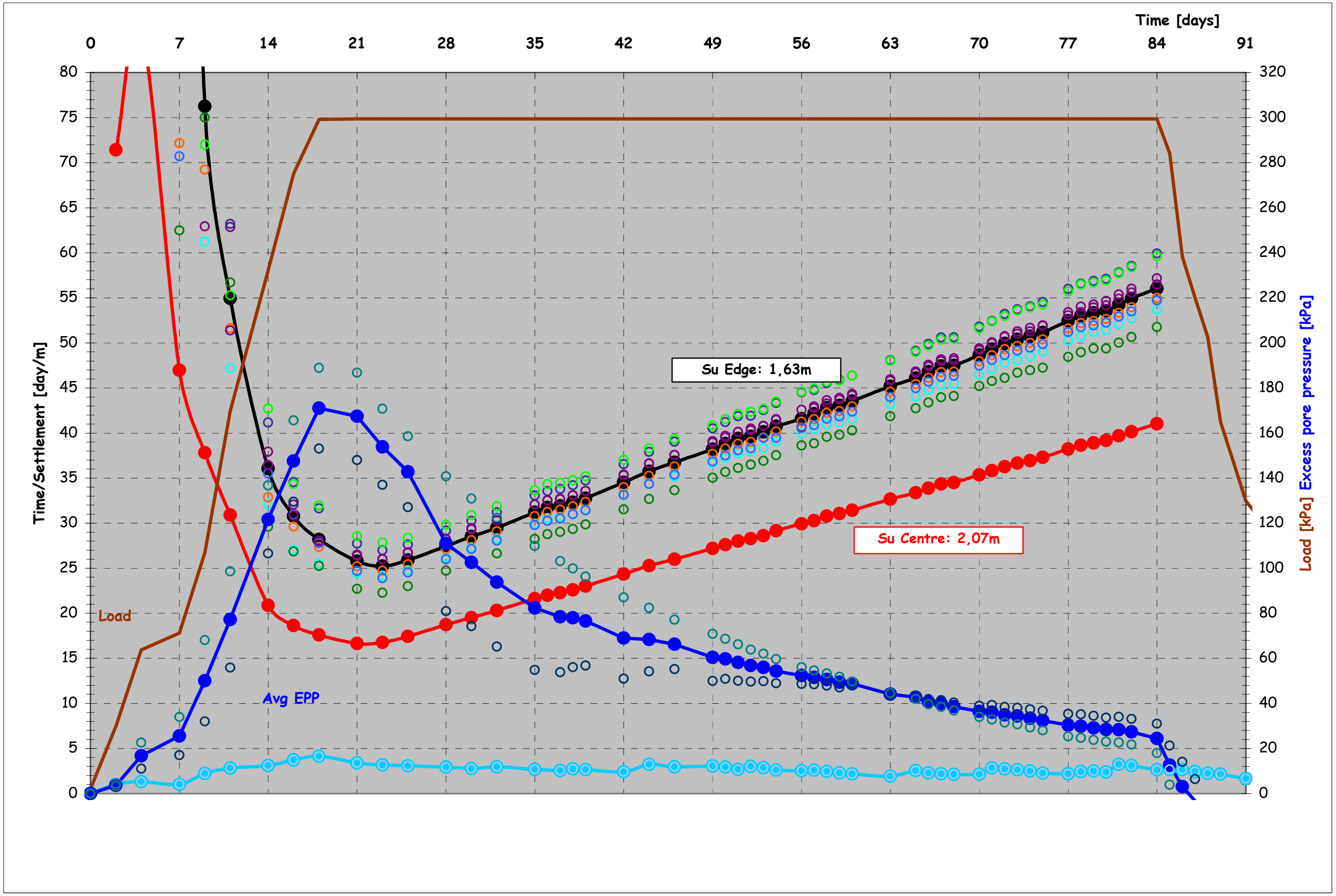
Tank 506: Hyperbolic Analysis



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Tentative Back Analysis & Creep Prediction

Tank #		503	504	505	506	507	Averages
Geometry	Treatment base elevation (m)	-27.0	-26.5	-27.0	-27.0	-26.5	-26.8
	Demucking base elevation (m)	-3.5	-4.0	-3.5	-4.0	-6.2	-4.2
Preload intensity		310 kPa	292 kPa	286 kPa	300 kPa	294 kPa	296.4
Primary consolidation prediction	Oedometric + lateral under preload (ult.settlements hyperbolic method)	1.63	1.97	1.92	2.07	1.74	1.86
Settlements	Settlement at end of preloading (centre)	1.55	1.78	1.77	2.05	1.62	1.75
	Settlement at end of preloading (edge)	1.28	1.32	1.24	1.50	1.33	1.33
	Settlement ratio (edge/centre)	0.83	0.74	0.70	0.73	0.82	0.76
	Time elapsed since installation of half of the preload	76 days	70 days	61 days	73 days	71 days	70 days
Degree of consolidation achieved	From settlements	95%	90%	92%	99%	91%	94%
	From pore pressures	96%	96%	90%	91%	90%	93%

- Less settlements for T-503 due to better ground conditions
- Settlements at the edges: 70 - 83% settlements at the centre
- Degree of consolidation: 90 - 96% (settlement or excess pore water pressure)

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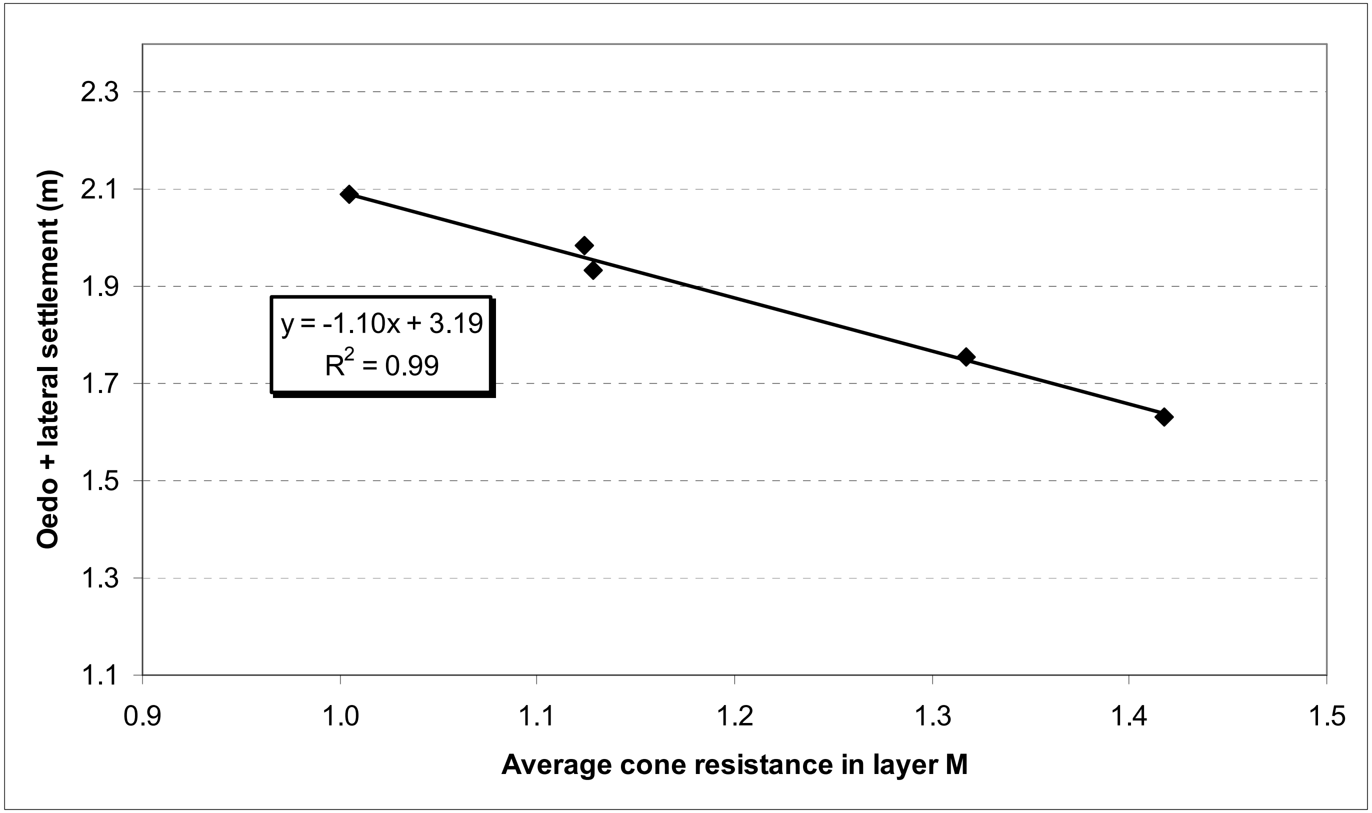
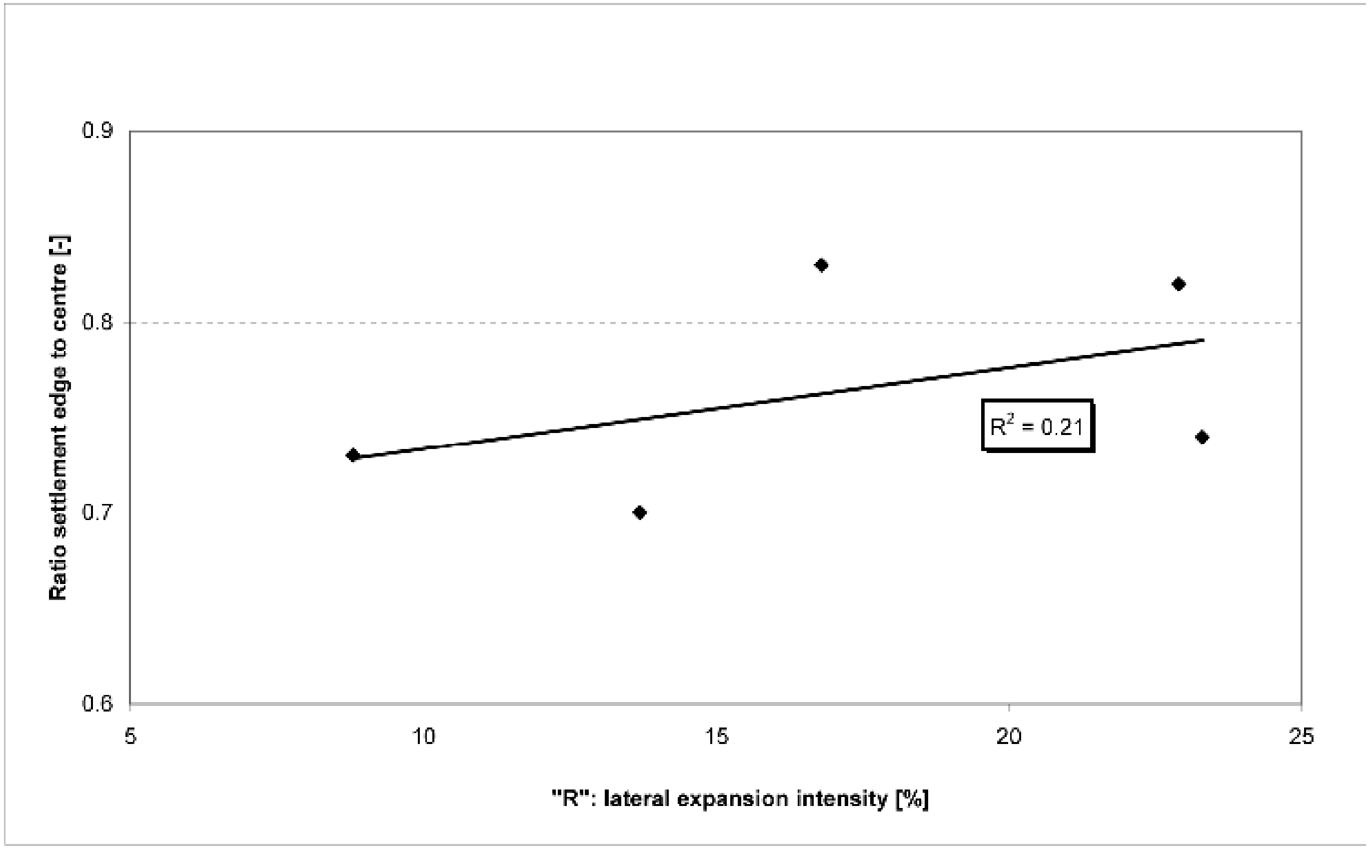
Back Analysis

The sandier and the stiffer the upper layer, the smaller the overall settlements (the soft layer “C” was relatively homogeneous)



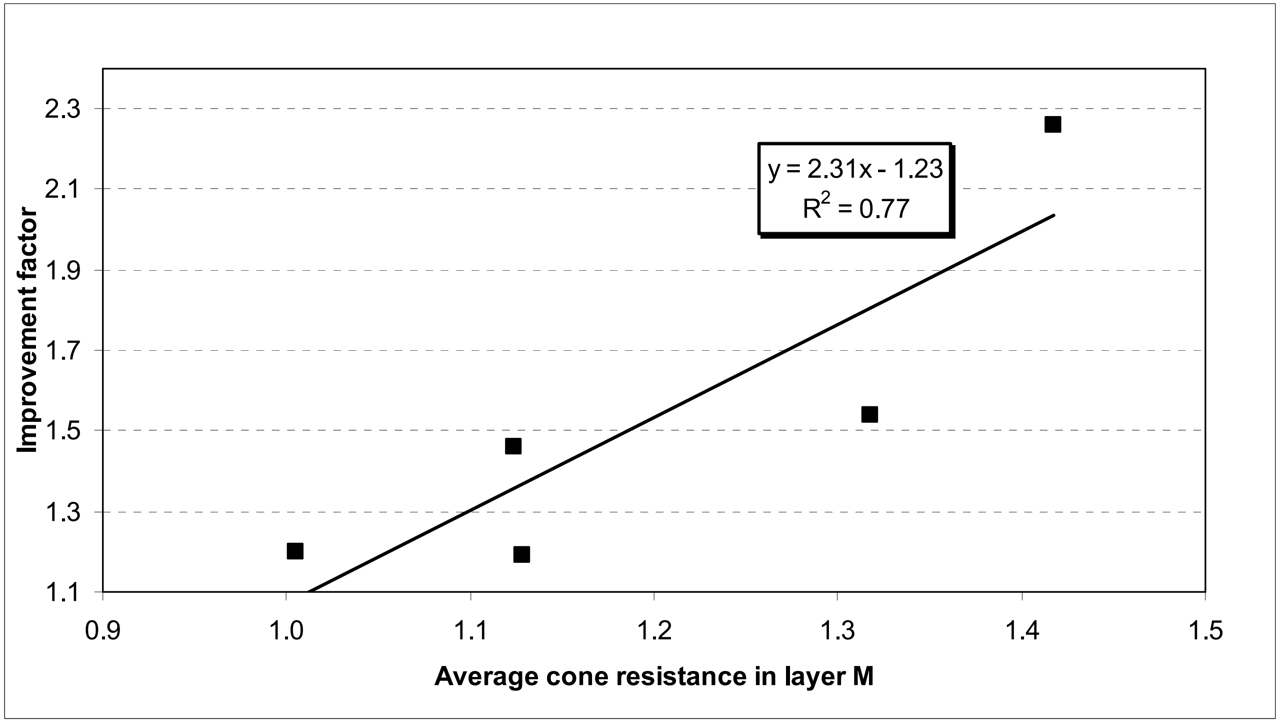
Back Analysis

The ratio of edge to centre settlements increases with the lateral expansion intensity “R”



Back Analysis

The sandier the upper layer, the larger the improvement of the virgin ground around the stone columns (20% at T-505 and T-506 to 126% at T-503)



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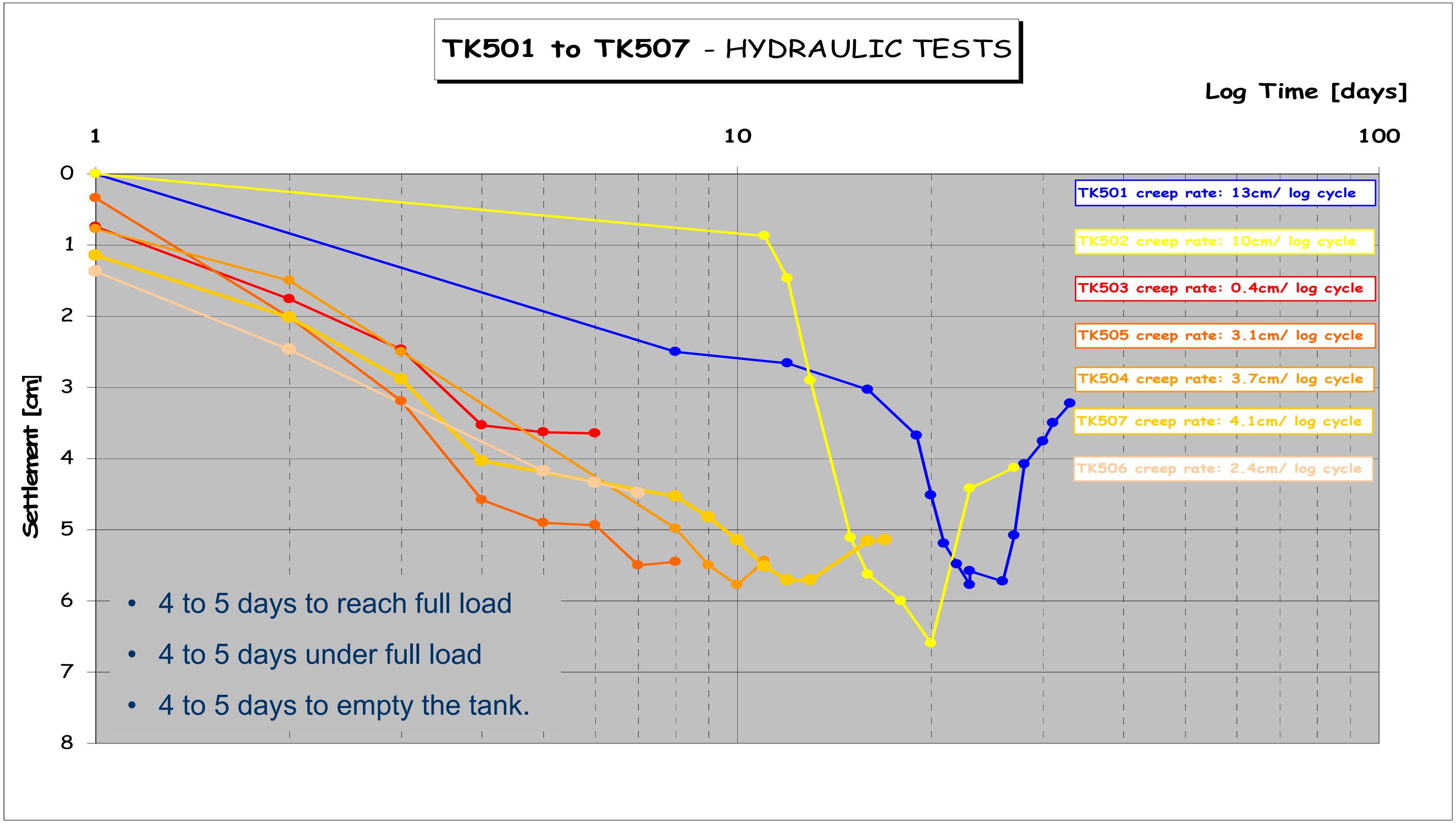
Estimated Future Settlements



Estimated re-compression + 50 year creep settlements: 16 - 20 cm in centre of tanks

Estimated dishing settlements ≤ 6 cm

Estimated re-compression during hydrotest: 4 to 5 cm

Actual settlement during: 3.5 to 5.7 cm

Aerial View of Site

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Reference

Ground Improvement
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Ground improvement efficiency and back-analysis of settlements

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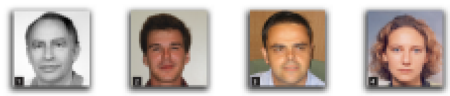

The ground improvement works carried out for the construction of five oil tanks at the Chiriqui Grande Phase II Oil Terminal, Chiriqui Grande, Panama, and their results are presented herein. The site is underlain by some 28 m of loose/soft, poorly graded, silty sands to clayey sands and silts. Ground improvement was used to provide the required bearing capacity and reduce the expected total and differential settlements. To fulfil the technical specifications, two ground improvement techniques were used in association with preloading: wick drains to full depth of the soft layers and stone columns in the upper 18 m. Stone columns are commonly installed as partial replacement to improve a soft ground, increasing its bearing capacity and accelerating its primary consolidation. Wick drains are used to accelerate the consolidation of soft clayey soils. Particular emphasis was given to the behaviour of the treated ground under the preloading fill: a back-analysis was carried out on measured settlements and pore pressures; the improvement of the ground and the degrees of consolidation achieved at the end of the preloading are highlighted; some correlations were derived and they provide an interpretation of the overall behaviour of the improved ground; estimates of the settlements for the short and long term are presented, the short term being that of the hydrotest and the long term being the design life of the oil terminal. They are based on results of preloading for their primary consolidation part, and on reasonable assumptions for their long-term creep (secondary consolidation) part. The estimates are compared to the actual hydrotest survey results.

Notation

A	tributary area of a stone column
A_c	cross-section of a stone column
a	inclusion factor $= A_c/A$
C_c	compression index
$C_c/(1 + e_0)$	compression ratio
C_r	swelling/recompression index
$C_r/(1 + e_0)$	recompression ratio
C_α	secondary compression index
$C_\alpha/(1 + e_0)$	secondary compression ratio
c_h	horizontal coefficient of consolidation
c_v	vertical coefficient of consolidation
E_{column}	Young's modulus of the compacted stone column material
E_{soil}	Young's modulus of the ground
e_0	void ratio
f_s	static cone penetration sleeve friction ratio
N_{SPT}	standard penetration test blow count
n	settlement improvement factor $= s_{untreated}/s_{treated}$
q_c	static cone penetration resistance
R	lateral expansion intensity
$s_{treated}$	settlement of ground treated with stone columns
$s_{untreated}$	settlement of ground without stone columns
T_v	time factor for vertical consolidation
U	degree of consolidation
w_n	natural water content
γ_b	bulk density
γ_s	specific gravity

1. Introduction

This paper describes the ground improvement works carried out for the construction of five oil tanks at the Chiriqui Grande Phase II Oil Terminal, Chiriqui Grande, Panama, and their results.

The project is located on the Atlantic Ocean (Laguna de Chiriqui), immediately to the north of the Margarita Channel. The five tanks (No. 503–507) form phase 2 of the project. Each tank is 78·2 m diameter, 20·4 m high and is used as crude oil

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Debats, J. M., Scharff, G., Balderas, J. & Melentijevic, S. (2013) Ground Improvement Efficiency and Back-Analysis of Settlements. *Ground Improvement,* 166, 3, 138-154.

Thank You

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