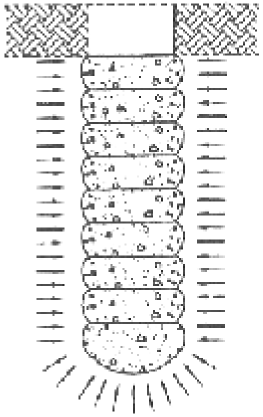
Full Scale Trial Embankment Test-Acceleration of Consolidation Using the Rammed Aggregate Pier (RAP) System



Presented by:
Emilio M. Morales, CE, MSCE, F. ASCE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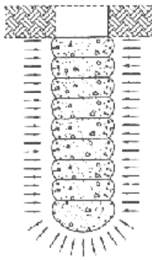
INTRODUCTION

- A full scale instrumented trial embankment test was conducted to determine and evaluate the effect/s on the acceleration of consolidation of Railway embankments using the Rammed Aggregate Pier (RAP) System on the very soft clays underlying the proposed embankments. The test site is located in the island of Luzon, the Philippines.

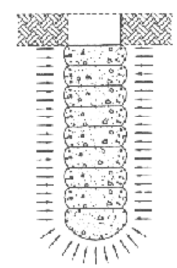
- The study was initiated to prove that consolidation time in very soft clays could be accelerated by the lateral prestressing and prestraining effects of the rammed aggregates piers on the subgrade and the enhanced drainage effect of the RAP body.

- In addition to the accelerated settlement, increased shear strength was realized for the very poor soils due to the Lateral Prestressing and lateral compression of the soils.



INTRODUCTION

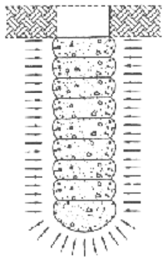
- A 5.0m high trial embankment was constructed on a Section of a 10 kilometer stretch of railway on relatively very soft marshy ground to simulate embankment loads and the impact of train loads on railway embankments of the NORTHRAIL Railway.
- The embankment was fully instrumented with settlement plates at various levels as well as Pneumatic Piezometers to determine the Porewater Pressures PWP at various stages in the installation.
- The PWP decay with time was matched against the settlement plots to confirm attainment of Full primary consolidation.



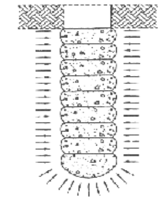
RESULTS

- The results of the settlement monitoring program revealed significant time savings could be realized during railway embankment construction if the RAP System is utilized.

- Time to full consolidation was accelerated to four (4) weeks instead of the calculated 6 to 8 months using other conventional ground improvement systems such as conventional stone columns, and soil cement columns.



TEST EMBANKMENT DESCRIPTION



- The constructed test embankment was 5.0 meters high and it was built up with naturally sloping embankment materials on three sides while the fourth face was reinforced by uniaxial geogrids to form an almost vertical face.

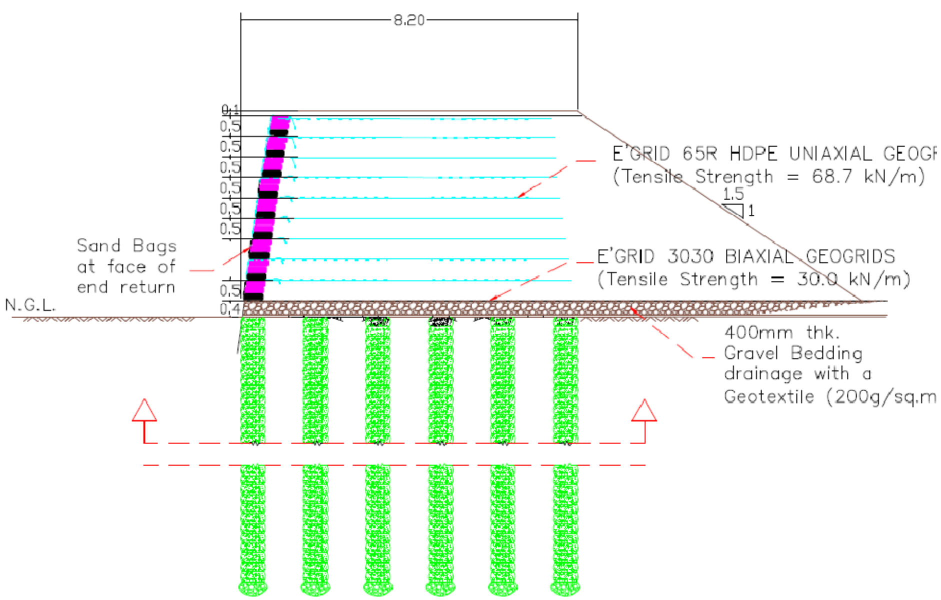
- The embankment was supported on 33 Rammed Aggregate Pier overlain by a gravel drain layer. The embankment layers on the vertical 4th face were reinforced by uniaxial geogrids at every 500 mm compacted lift. This paper outlines the procedures for the conduct of the trial embankment test. Subsurface soil investigation to establish reference soil parameters for soil compression and strength were also conducted including field vane shear testing.

- Installation of 33 *Rammed Aggregate Pier* for embankment support and to accelerate consolidation by drainage.

- Ground settlement monitoring using settlement plates installed on the natural ground line **(**NGL**)** immediately underneath the test embankment.

- Porewater pressure PWP monitoring using pneumatic piezometers.
- Monitoring of actual Groundwater table through observation wells and electric water level sensors.

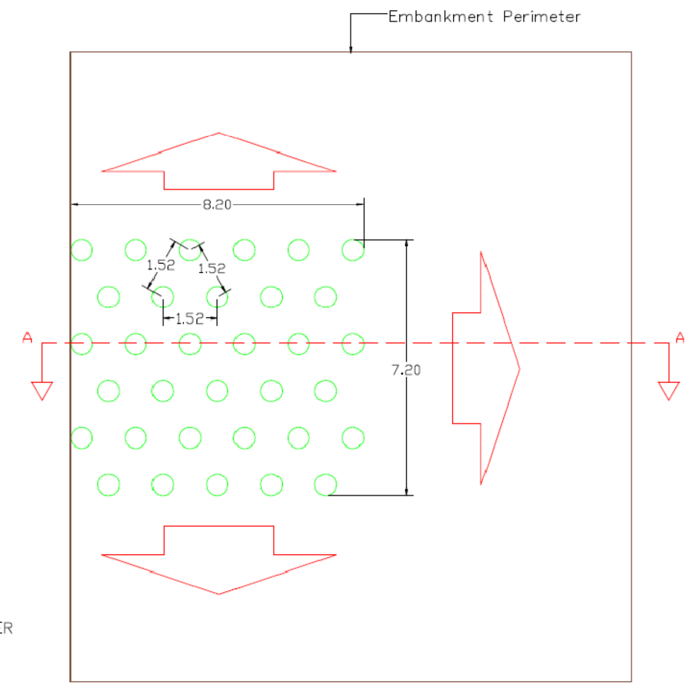
TEST EMBANKMENT LAYOUT



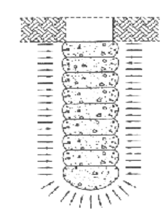
SECTION

LEGEND:

○ = IMPACT PIER

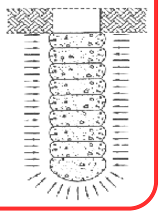


PLAN



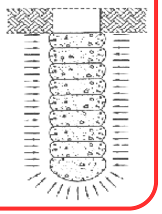
BACKGROUND OF TECHNOLOGY

The Impact® System uses vertical displacement Rammed Aggregate Pier® (RAP) elements to reinforce good to poor soils, including loose sands, silts, mixed soil layers, uncontrolled fill and soils below the ground water table.

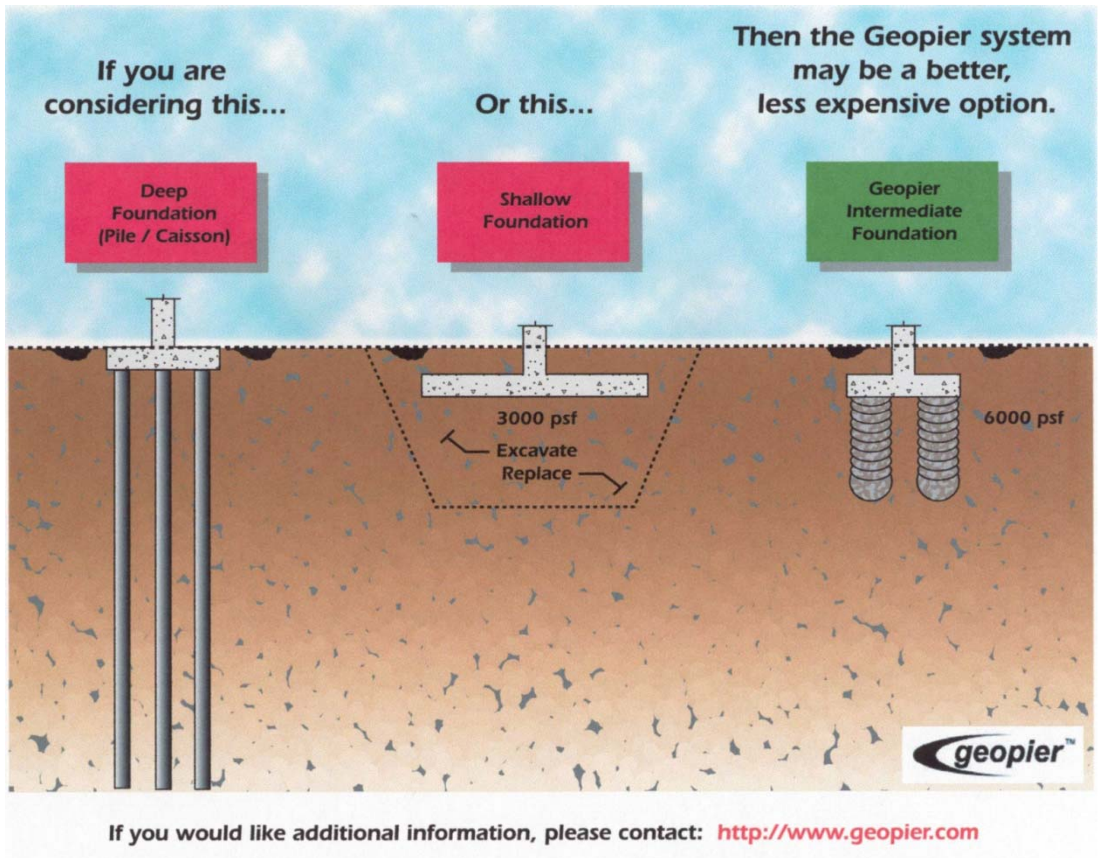


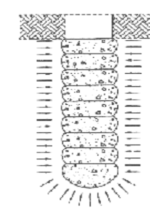
BACKGROUND OF TECHNOLOGY

- **Rammed.** Vertically ramming thin lifts of aggregate is the key to providing strength and stiffness.
- **Strength.** Vertical impact ramming results in high density and high strength RAP elements that provide superior support capacity.
- **Stiffness.** Vertical impact ramming results in high pier stiffness that provides excellent settlement control.
- **Proven.** Thousands of structures are currently supported — proven experience that ensures high levels of performance and reliability.
- **Economical.** Often results in 20% to 50% savings compared to traditional deep foundation alternatives.
- **Fast.** Rapid installation process means shorter construction



BACKGROUND OF TECHNOLOGY

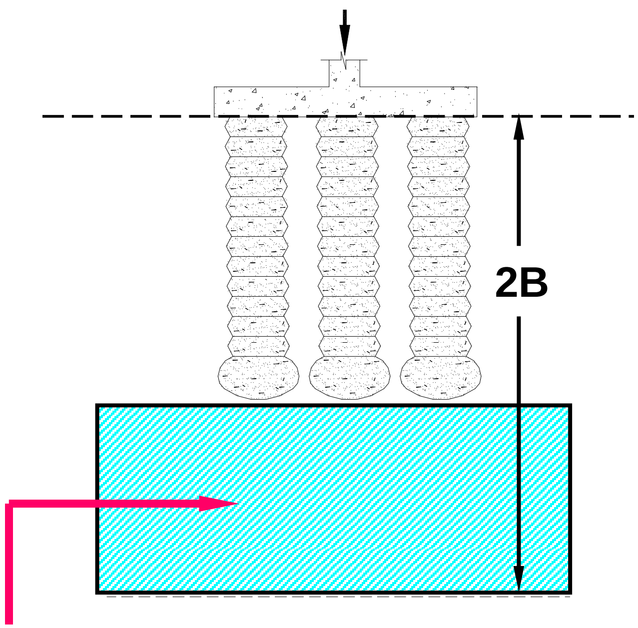


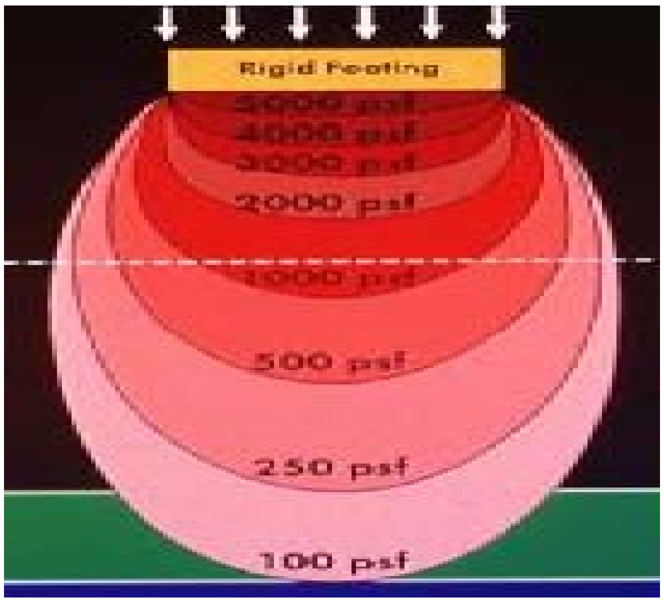


DESIGN FOR FOUNDATION SUPPORT

LOWER ZONE SETTLEMENT CONTRIBUTION

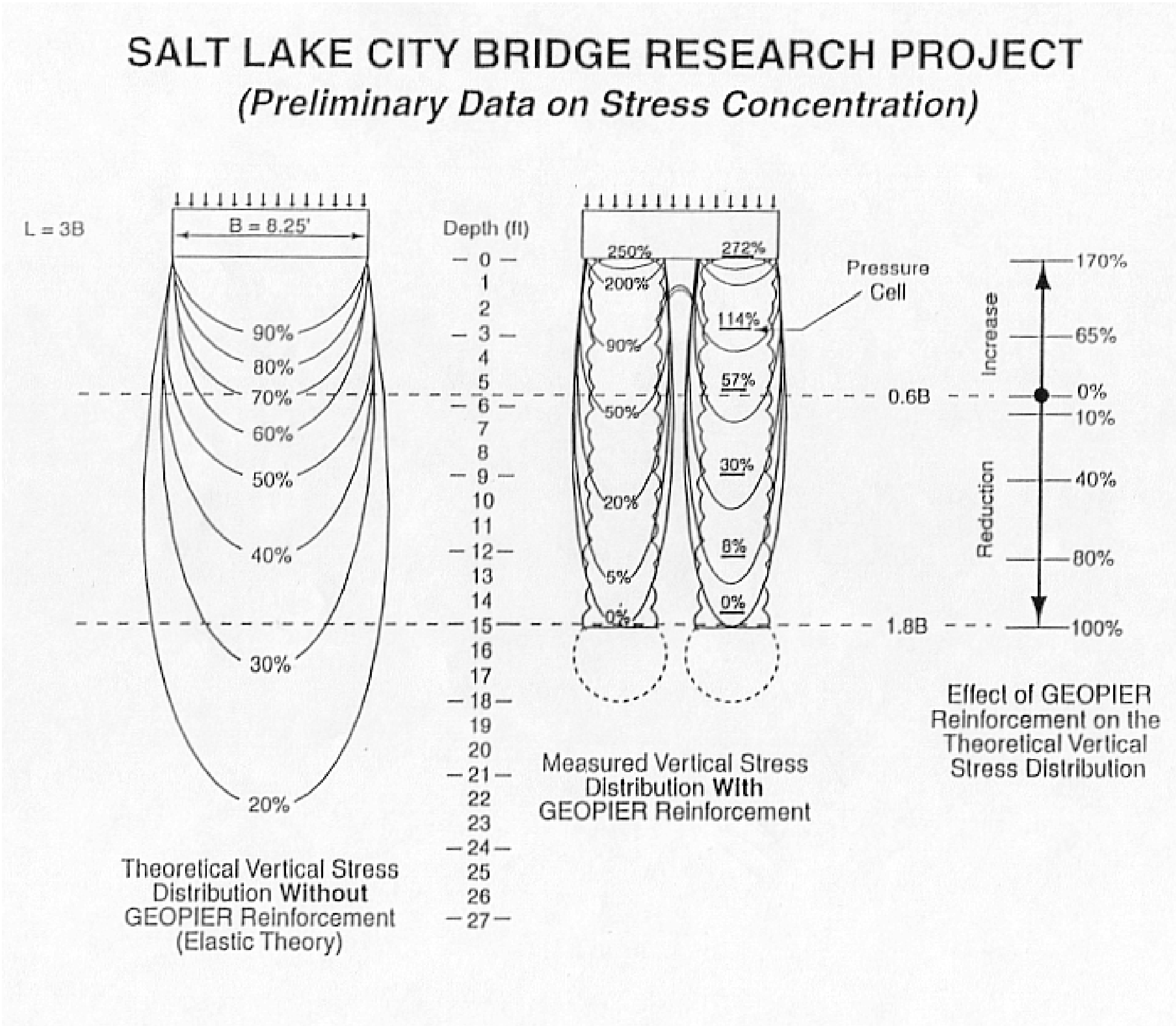
Design Goal
Control total and differential settlements within project criteria





Lower Zone settlement contribution computed using conventional geotechnical analyses

BACKGROUND OF TECHNOLOGY



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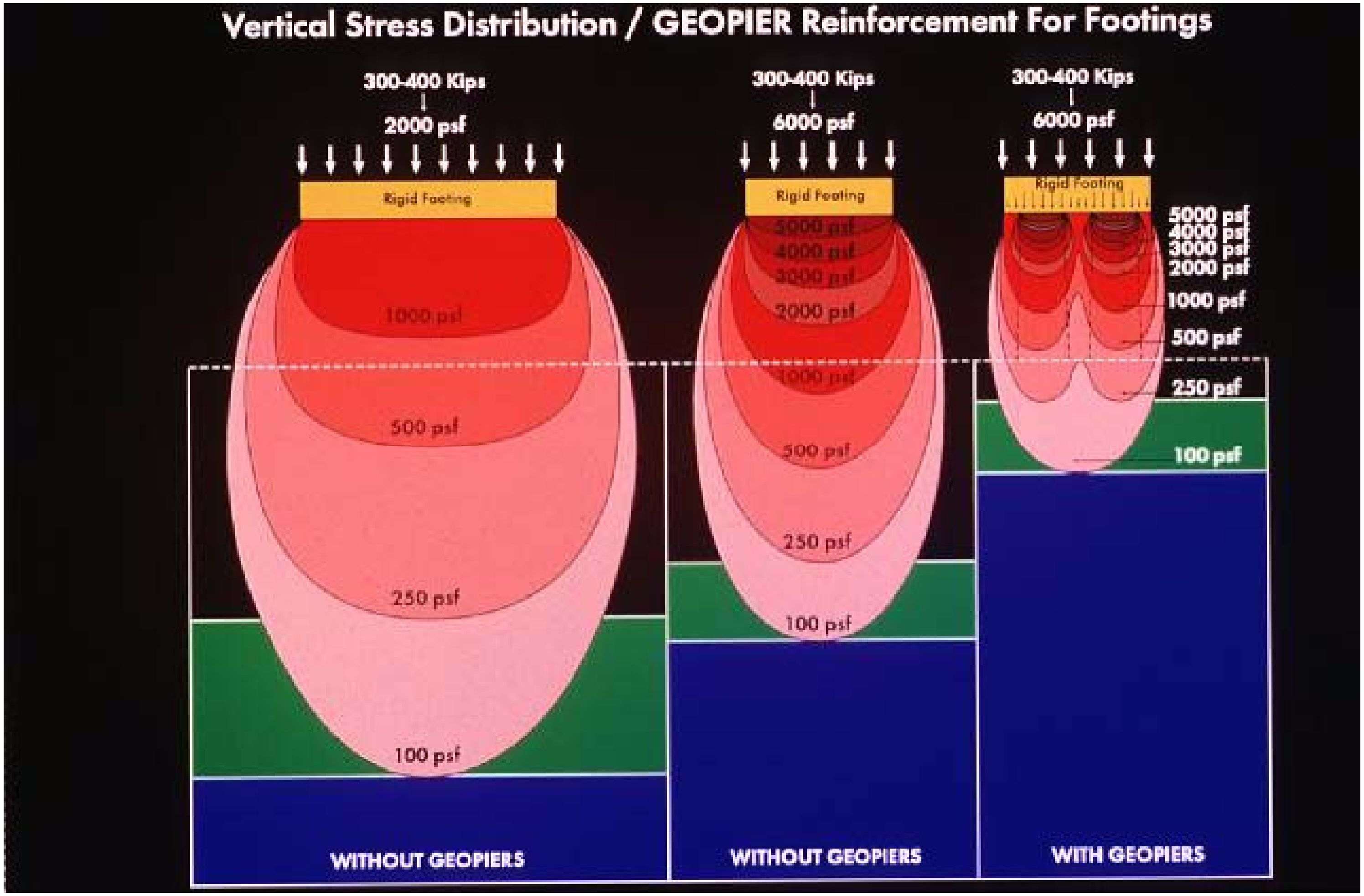


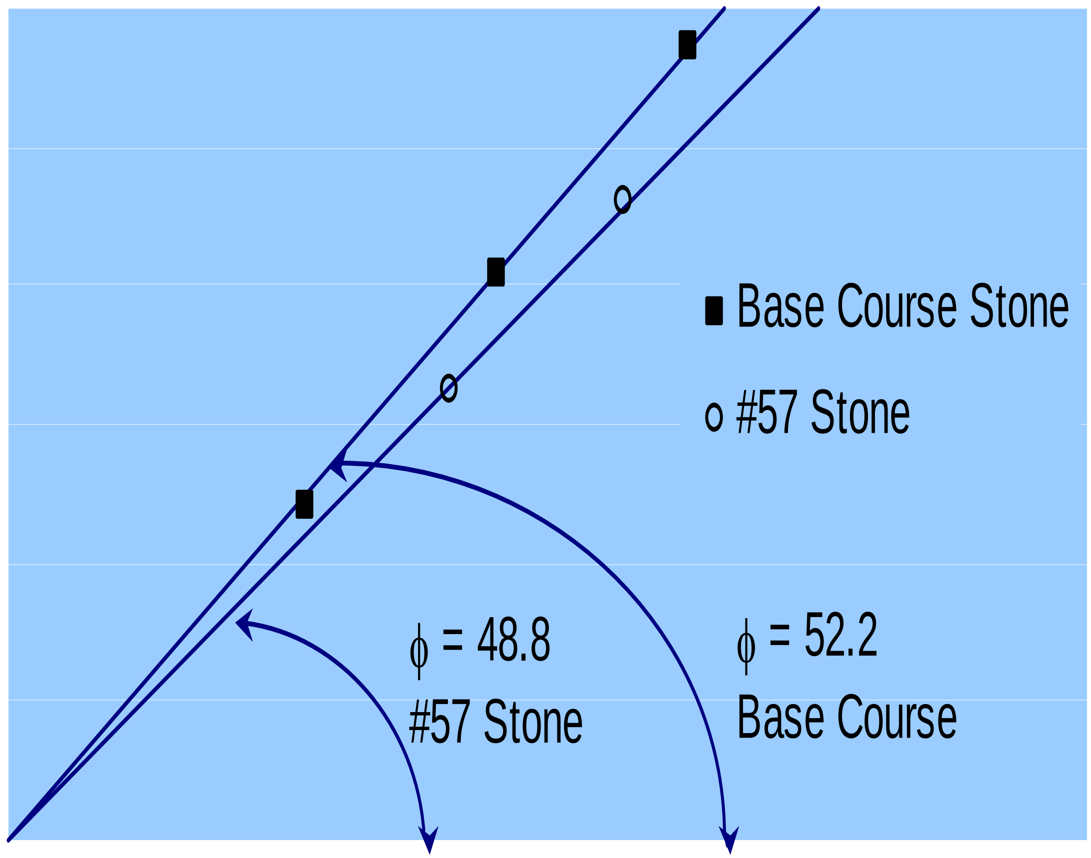
BACKGROUND OF TECHNOLOGY

Creation of stiff Rammed Aggregate Pier within matrix soils.

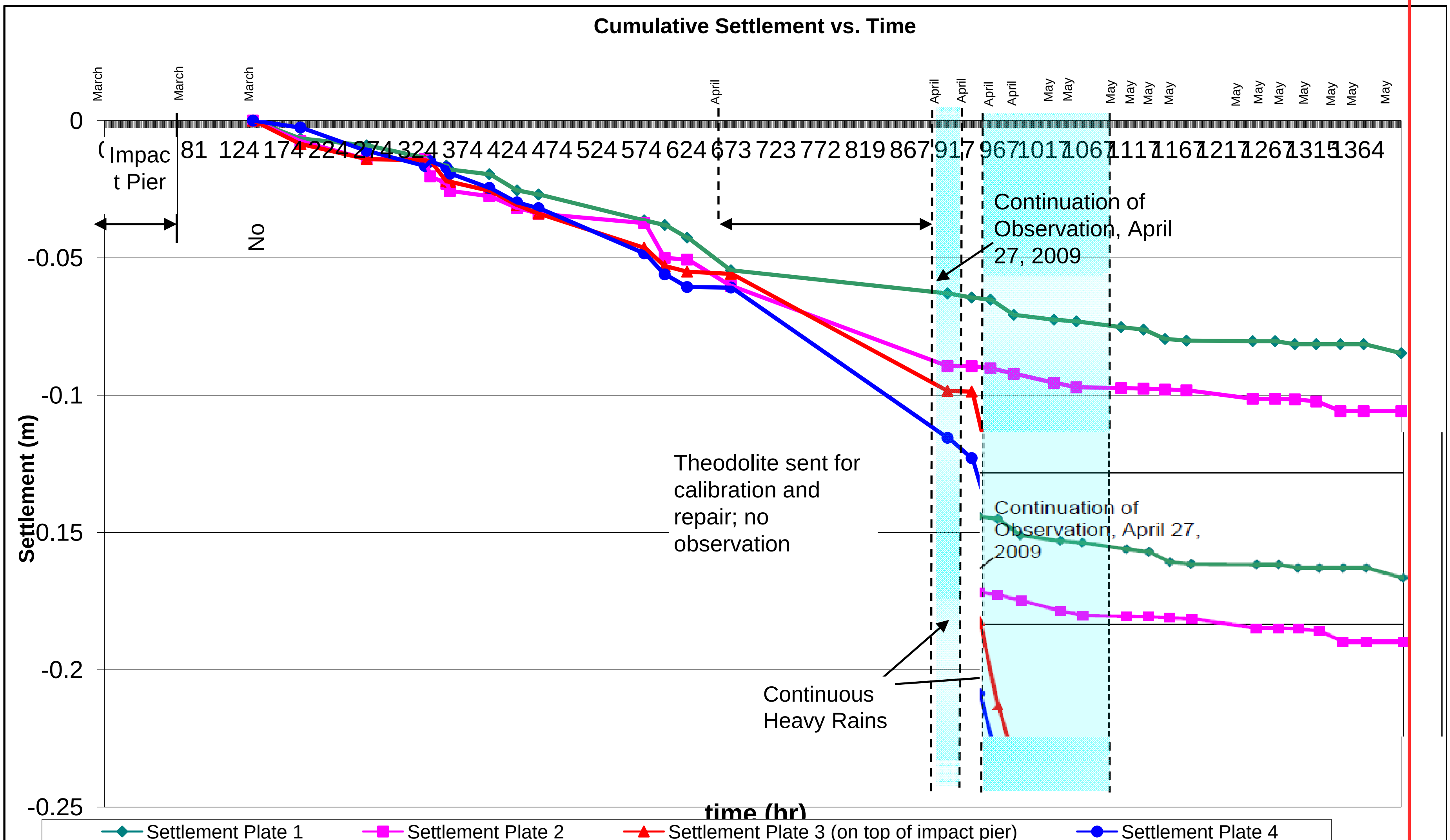
Undulated shape

Efficient transfer of load in perimeter

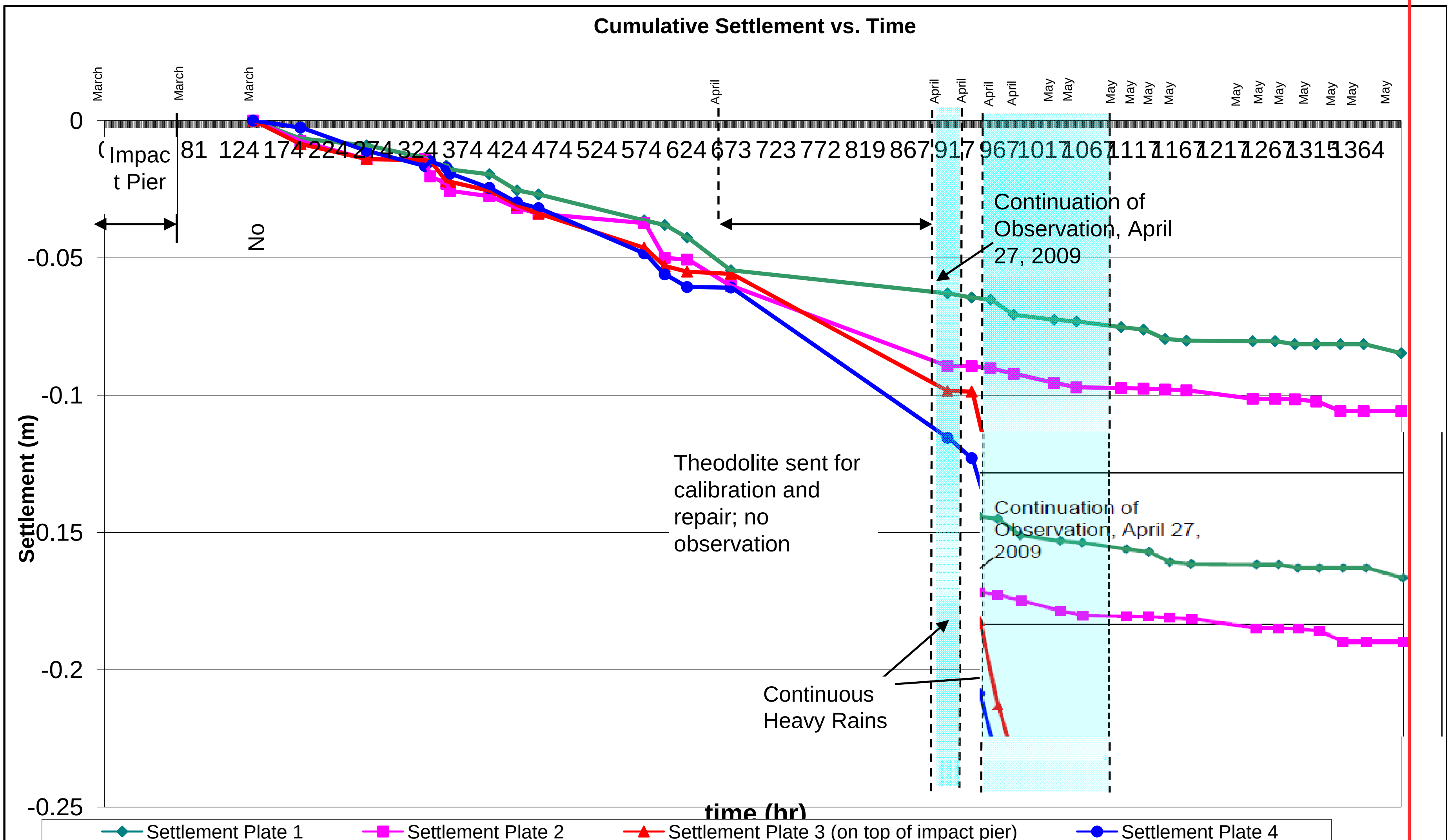
BACKGROUND OF TECHNOLOGY



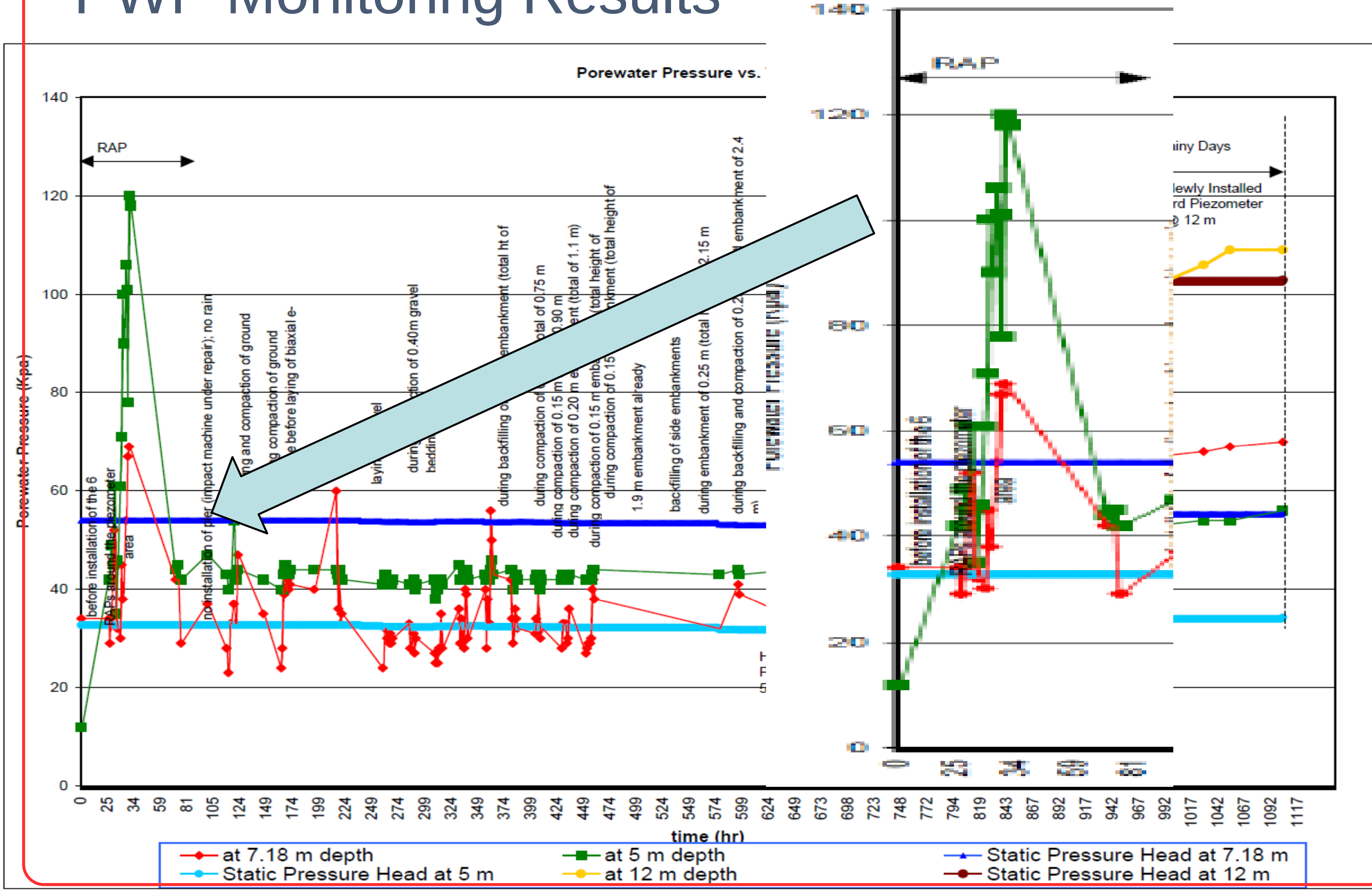
Settlement Plot



Settlement Plot



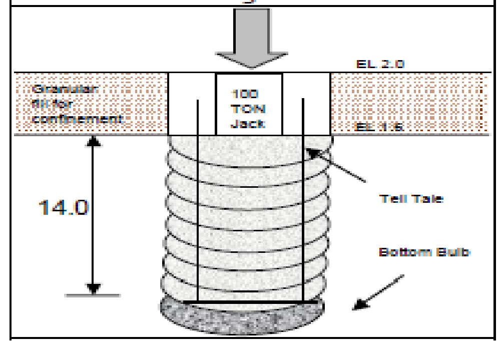
PWP Monitoring Results

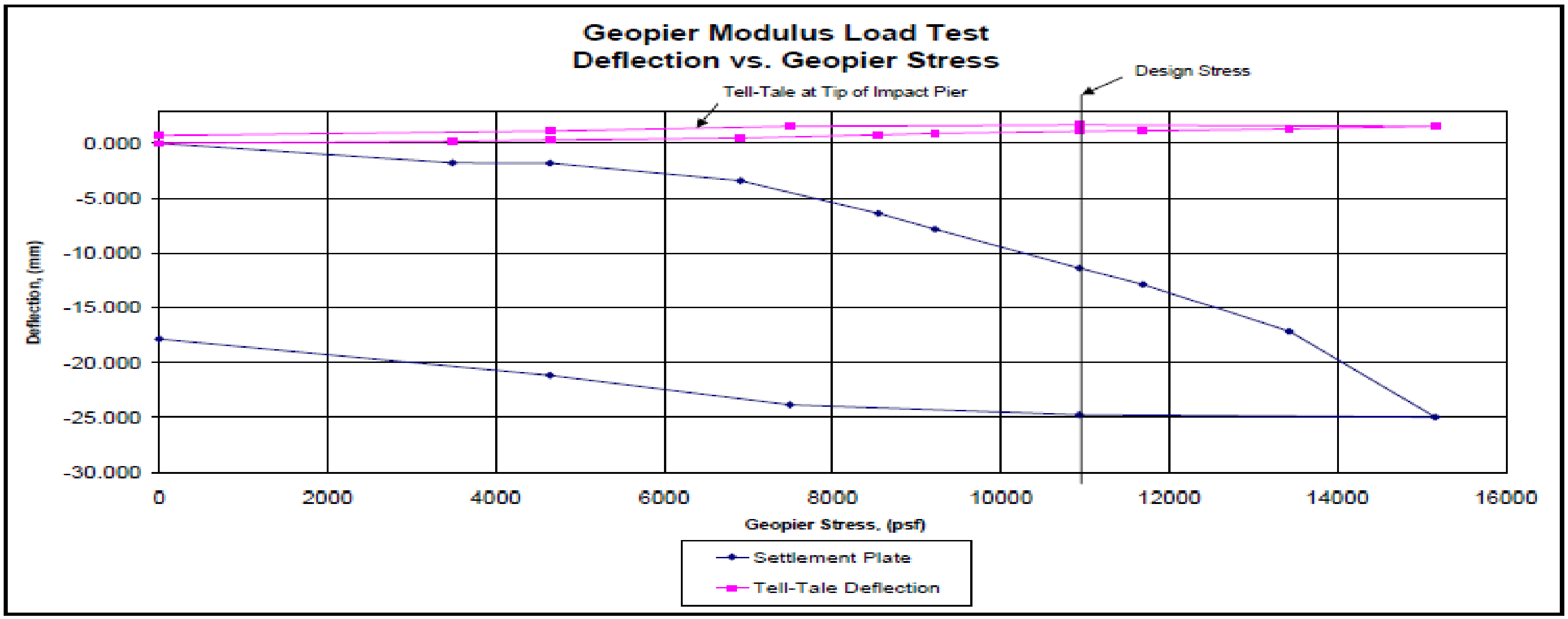


Modulus Load Test Results on Rammed Aggregate Pier

Ram Load, (Lbs)	Applied Stress, (psf)	Percent Design Stress	Total Deflection, (mm)	Tell-Tale Deflection, (mm)	Geopier Modulus, (pci)
-	0	0%	0.000	0.000	
10,944.00	3485	36%	-1.780	0.1725	345
14,592.00	4645	49%	-1.816	0.29	451
20,111.00	6907	72%	-3.405	0.482	358
25,630.00	8544	89%	-6.374	0.7555	236
28,352.00	9216	97%	-7.830	0.9125	208
33,796.00	10935	115%	-11.363	1.0825	170
36,518.00	11685	122%	-12.838	1.1445	161
41,965.00	13425	141%	-17.150	1.293	138
47,412.00	15163	159%	-24.961	1.5375	107
33,796.00	10935	115%	-24.761	1.68	78
22,871.00	7493	78%	-23.854	1.5325	55
14,592.00	4645	49%	-21.183	1.103	39
-	0	0%	-17.866	0.705	0

Diagram





Embankment Test Loads

- The actual test embankment load was built to 5.0 meters high, utilizing soils with $\mathbf{g}_{\mathbf{s}\text{oil}}$ = 18.07 kN/m^{3,} which is higher than the actual maximum design height of 3.5 meters for the actual railway embankment sections. The purpose of this overloading is to evaluate the performance of the Rammed Aggregate Pier *b*eyond the actual load demand and demonstrate the high capacity of the RAP®. This was replicated in a load test which simulated the weight of the 5.0 meter high embankment plus 50% overload.

Installation Equipment

Theoretical Settlement Calculations

PROJECT: Phillipines Rail Corridor
NO: P08-API-00011 Pilot Test Program
DATE: 5/12/2009
ENGINEER: CHW
Station: Pilot Test Program

ΔP	2050	psf	(16.4 ft tall embankment)
γsoil	125	pcf	
Dgw	16	ft	
Beq	50.0	ft	
Area Piers	3.14	ft2	
Ra	0.13		5' o.c. Spacing
Ep		ksf	

Zstress 2.0
square
Center

Layer	Soil Type	Esoil ksf	Ep ksf	Ecomp ksf	$C_{\varepsilon r}$	$C_{\varepsilon c}$	OCP ksf	Thickness ft	z ft	σ'v psf	z/Beq	I_c	ΔP psf	$S_{(Center)}$ in
1	Impact	10	1000	135	N/A	N/A	N/A	8	4	500	0.08	1.00	2050	1.46
2	Impact	10	1000	135	N/A	N/A	N/A	8.4	12.2	1525	0.24	0.90	1845	1.38
3	Impact	10	500	72	N/A	N/A	N/A	9.8	21.3	2332	0.43	0.60	1230	2.02
4	Impact	10	250	40	N/A	N/A	N/A	10	31.2	2952	0.62	0.40	820	2.45
5	Impact	10	250	40	N/A	N/A	N/A	11	41.7	3609	0.83	0.30	615	2.02
6	Impact	10	250	40	N/A	N/A	N/A	3	48.7	4047	0.97	0.25	512.5	0.46
7	Clay	60		N/A	0.03	N/A	3000	10	55.2	4454	1.10	0.20	410	0.14
8	Clay	80		N/A	0.03	N/A	3000	10	65.2	5080	1.30	0.15	307.5	0.09
				N/A										

70.2	feet
21.4	meters

	UZ (in) =	9.8
	LZ (in) =	0.2
	Total (in) =	10.0
Post Construction	UZ (in) =	1.0
	LZ (in) =	0.0
	Total (in) =	1.0

GROUNDWATER AND POREWATER PRESSURE MONITORING

- The porewater pressure (PWP) monitoring was started immediately upon installation of the pneumatic pressure transducers on 20 March, 2009 and prior to installation of the *Rammed Aggregate Pier* elements. The static groundwater table was likewise monitored using depth gages and an electric water level.

PWP Observations

- There is a rapid rise in PWP to a maximum of 120 kPa at depth (-) 5.0 meters during the 1st RAP installation up to t=38 hours. This elevated PWP from the hydrostatic level reading of 32 kPa to 120 kPa, i.e. by an additional 88 kPa, is due to the lateral prestressing effect of the Rammed Aggregate Pier installation on the surrounding saturated soils. Rapid decay of the elevated PWP to near static groundwater table is observed at time= 60 hours or approximately two days (48 hrs) after post installation of the Rammed Aggregate Pier

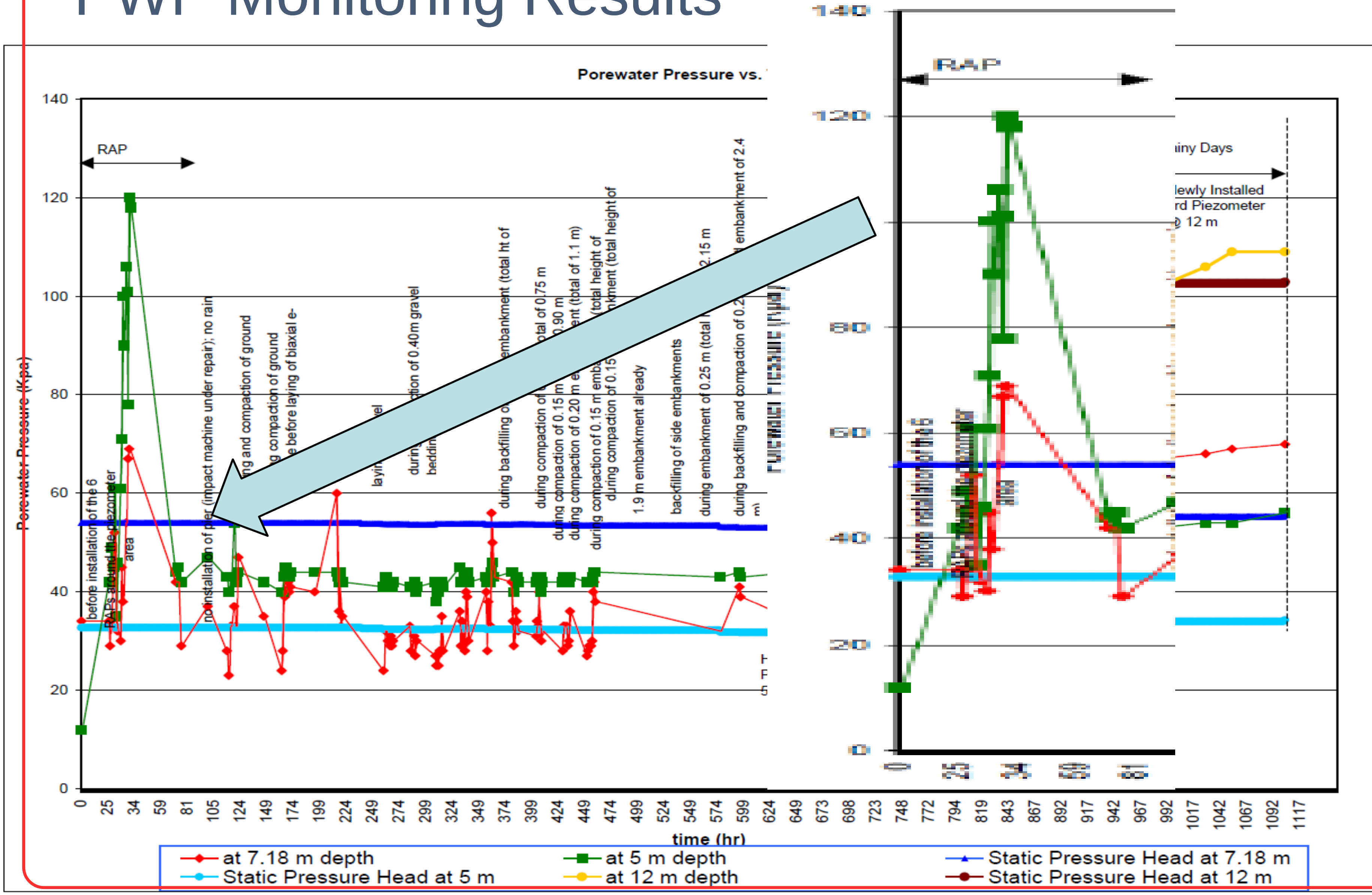
- An elevation in PWP readings was also observed during a 7 day period of heavy rainfall from April 23rd 2009 to May 5th 2009.

- PWP pressure dissipation soon after the end of the continuous heavy rainfall period was observed, slowly returning the PWP to near static ground water levels on June 30th 2009.

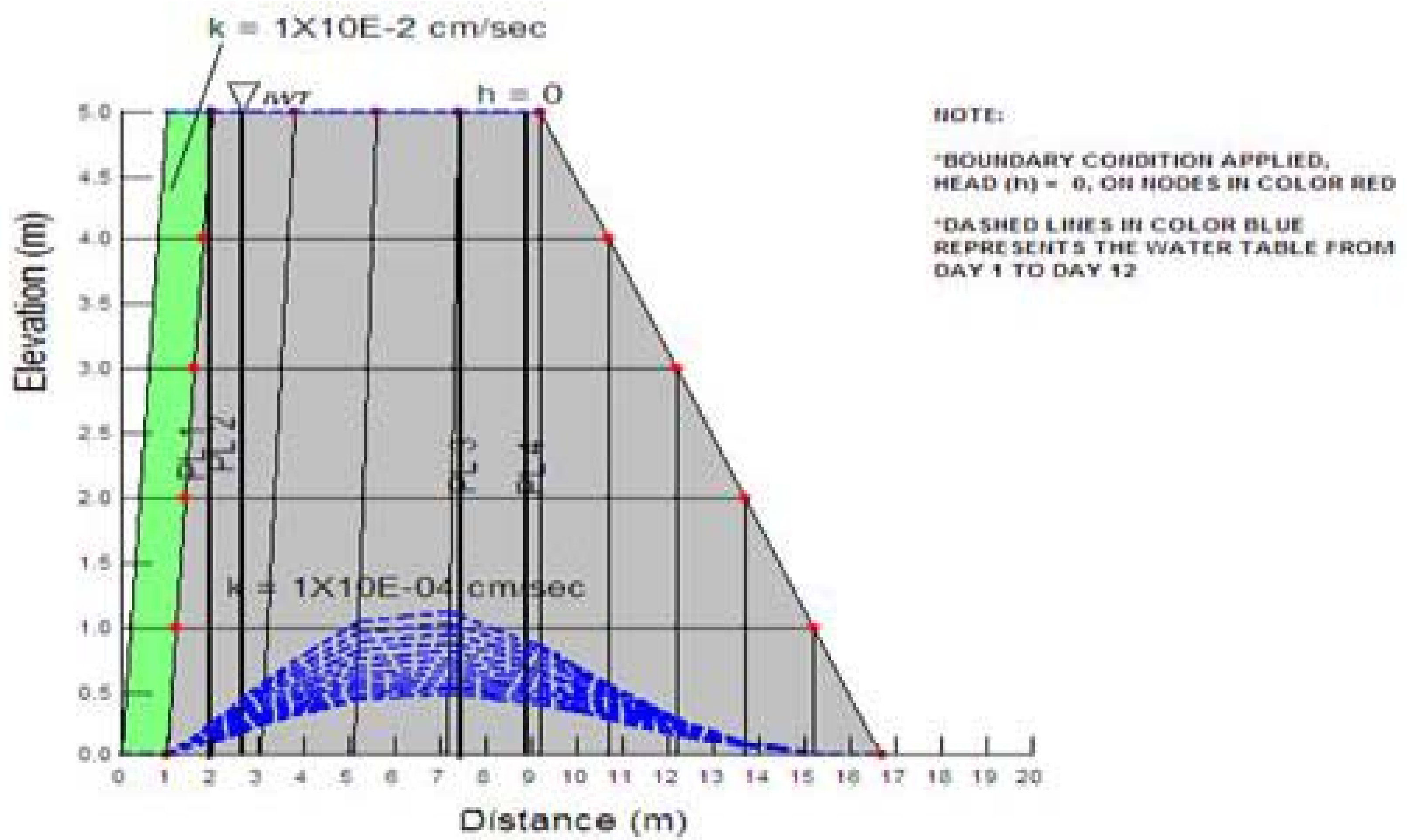
- The results of the Porewater PWP monitoring clearly illustrates the drainage enhancing effects of the Rammed Aggregate Pier (RAP) on the stabilizing the ground by virtue of the initial lateral prestressing effects which raises the existing pore pressure PWP and subsequently promotes rapid drainage through the highly permeable gravel columns acting as chimney drains.

- In addition, the PWP record also demonstrated the sensitivity of the readings to rainwater infiltration and saturation from the embankment as well as the resulting increased loading and subsequent settlement due to saturation of the embankment from the prolonged and 7 days rainfall (from April 30th to May 5th, 2009 with a two day interruption).

PWP Monitoring Results



PWP Decay with Time in Embankment



RESULTS OF SETTLEMENT MONITORING

- Four settlement plates were installed at the level of the natural ground line (NGL) prior to the laying of the embankment fill material.

- Three (3) permanent benchmarks were laid on very stable ground in a triangular layout to ensure the robustness of the horizontal and vertical controls and allow checking and recovery of measurements in case of errors in any observation.

- The settlements were observed using a laser total station and were recorded on a daily basis until completion of the test works approximately five (5) weeks from completion of embankment works.

The Details of the Load Test

- Maximum Test Load = 21.5 Metric Tons *(47.4 kips)*
- Duration of test = 7 Hours
- Maximum stress at top of RAP = 726.0 kPa *(15,163 psf)*
- Deflection of top of RAP at design stress of 9,549 psf = 8.516mm » 0.335 inch
- Maximum Deflection top of RAP at Maximum Stress of 15,163 psf = 24.96 mm » 0.98 inch

SUMMARY AND CONCLUSIONS

- The results of the trial embankment tests have satisfactorily demonstrated the effectiveness of the Rammed Aggregate Pier RAP system in accelerating primary consolidation settlements and also reducing the measured total settlement of the improved ground.

- The main objective of attaining almost primary consolidation (U_{90}) in 4 to 6 weeks was successfully achieved in 4.7 weeks. This fact, corroborated by settlement observations, and porewater pressure monitoring records, was witnessed by NORTHRAIL project personnel.

SUMMARY AND CONCLUSIONS

- The completed trial embankment monitoring results revealed the following as follows:
- Attainment of primary settlement consolidation U_{90} was achieved in maximum of less than 5 weeks after construction completion of the 5.0 m high test embankment.
- The overall total settlement recorded as a result of the weight of the 5.0 meter embankment was reduced vs. the theoretically estimated settlement, due to the strengthening effect of the composite ground by the inclusion of the high stiffness columnar gravel piles and the precompression imposed upon the surrounding matrix soils.
- Rapid drainage of pore water due to the installation method of the Rammed Aggregate Pier RAP system. This causes lateral prestressing of the matrix soil forcing the water through the highly permeable gravel columns and also triggering settlement initiation even prior to embankment construction.
- As a result of all this, stabilization of the composite ground was successfully achieved.

SUMMARY AND CONCLUSIONS

- The PWP monitoring records have demonstrated the beneficial prestressing effect of the Rammed Aggregate Pier RAP system installation on the surrounding matrix soils which causes a rapid elevation of the PWP followed by a rapid decay as well as the very efficient drainage provided by the RAP acting as chimney drains.

- The observed settlements are corroborated by the PWP records and the rainfall records. These records showed that embankment saturation due to continuous rainfall for 7 days has resulted in an increase in embankment loads and an increase in settlements in the vicinity of PL3 & PL4.

Questions are welcome.

Thank you for your interest.

Presented by:

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contact info here if presenter chooses

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