University of Colorado, Boulder
Dobroslav Znidarčić, Professor Emeritus
Department of Civil, Environmental, and Architectural Engineering

College of Engineering and Applied Science
428 UCB, Engineering Center, Room OT 649
Boulder, CO 80309-0428

Telephone: 303.492.7577
Fax: 303.492.7317
e-mail: Dobroslav.Znidarcic@colorado.edu

Dobroslav Znidarčić

Seepage Induced Consolidation Test results for slurry samples for the Gasco Sediments project

Prepared for:

Anchor QEA, LLC
1201 3rd Avenue, Suite 2600
Seattle, WA 98101-1847

February 25, 2020

Introduction

This report presents the results of the consolidation testing for slurry samples for the Gasco Sediments project.

We received the samples in the form of slurries and process water. The samples had following designations:

Sample	Specific gravity
PDI-107SPT-00-04-190923	2.65
PDI-113SPT-06-16-191011	2.73
PDI-114SPT-7.5-12.5-191008	2.66
PDI-118SPT-4.5-15-191014	2.53

The specific gravity values listed in the table were also provided and used in all the calculations.

The samples had the following initial water contents, solids contents and the corresponding void ratios:

Sample	Water content	Solids content	Void ratio
PDI-107SPT-00-04-190923	75.3%	57.0%	1.996
PDI-113SPT-06-16-191011	47.1%	68.0%	1.285
PDI-114SPT-7.5-12.5-191008	66.0%	60.2%	1.755
PDI-118SPT-4.5-15-191014	69.9%	58.8%	1.769

The samples had relatively stiff consistency, unsuitable for SIC testing. The samples were thoroughly mixed and additional site water was added to each sample to achieve suitable consistency for SIC testing. The following water contents, solids contents and corresponding void ratios were obtained:

Sample	Water content	Solids content	Void ratio
PDI-107SPT-00-04-190923	178.0%	36.0%	4.716
PDI-113SPT-06-16-191011	62.5%	61.6%	1.705
PDI-114SPT-7.5-12.5-191008	144.1%	41.0%	3.832
PDI-118SPT-4.5-15-191014	176.2%	36.2%	4.458

The samples were then placed into the testing cells for seepage induced consolidation and step loading tests.

Seepage induced consolidation test

The Seepage Induced Consolidation Tests (SICT) and the step loading tests were performed on the samples. The SICT and analysis procedures are described in the attachment to this report.

Material Characteristics

The void ratio corresponding to zero effective stress was measured and the following values were obtained for the samples:

Sample	Void ratio @ σ'=0
PDI-107SPT-00-04-190923	4.583
PDI-113SPT-06-16-191011	1.486
PDI-114SPT-7.5-12.5-191008	3.564
PDI-118SPT-4.5-15-191014	4.458

The test results are presented in Tables 1 through 6 and in Figures 1 through 8.

The model parameters A, B, Z, C and D in Tables define the compressibility and hydraulic conductivity relationships given by the following expressions, and presented in the figures

Compressibility $e = A\,(\sigma' + Z)^B$

Hydraulic Conductivity $k = C\,e^D$

where **e** is the void ratio and **k** is the hydraulic conductivity. The values for the parameters A, Z and C depend on the system of units and are given for SI units.

Table 1 – Consolidation model parameters (SI units)

Sample	A	B	Z(kPa)	C(m/day)	D
PDI-107SPT-00-04-190923	2.90	-0.142	0.039	$2.33*10^{-5}$	5.05
PDI-113SPT-06-16-191011	1.30	-0.109	0.284	$5.08*10^{-4}$	3.74
PDI-114SPT-7.5-12.5-191008	2.46	-0.128	0.055	$3.62*10^{-5}$	3.91
PDI-118SPT-4.5-15-191014	2.76	-0.152	0.043	$1.27*10^{-5}$	4.11

Since the samples were tested at increased water contents, the obtained parameters are modified to account for the lower in situ values. This is accomplished by changing the parameter Z. The modified values are presented in Table 2 and should be used for settlement analyses of undisturbed materials in the field.

Table 2 – Consolidation model parameters for in situ conditions (SI units)

Sample	A	B	Z(kPa)	C(m/day)	D
PDI-107SPT-00-04-190923	2.90	-0.142	13.90	$2.33*10^{-5}$	5.05
PDI-113SPT-06-16-191011	1.30	-0.109	1.07	$5.08*10^{-4}$	3.74
PDI-114SPT-7.5-12.5-191008	2.46	-0.128	14.25	$3.62*10^{-5}$	3.91
PDI-118SPT-4.5-15-191014	2.76	-0.152	18.50	$1.27*10^{-5}$	4.11

Table 3 – SICTA and Step Loading Results for Tailing Sample PDI-107SPT-00-04-190923 (SI units)

SICTA		Input		Results	
Unit weight of water		9.81		A	2.898
Specific gravity		2.65		B	-0.142
Initial height		0.0430696		Z	0.039
Void ratio @ 0		4.583399			
Top effective stress		0.1		C	2.33E-05
Darcian velocity		6.60E-03		D	5.047
Final height		0.0346858			
Bottom effective stress		0.4030493		Final calculated	
				Height	Bottom effective stress
Void ratio		1.5019888		0.0346998	0.4028701
Effective stress		103.14684		Normalized errors	
Hydraulic conductivity		1.81E-04		0.0004031	0.0004448
				Total error	0.0008479

Table 4 – SICTA and Step Loading Results for Tailing Sample PDI-113SPT-06-16-191011 (SI units)

SICTA		Input		Results	
Unit weight of water		9.81		A	1.295
Specific gravity		2.73		B	-0.109
Initial height		0.0314094		Z	0.284
Void ratio @ 0		1.4856753			
Top effective stress		0.1		C	5.08E-04
Darcian velocity		1.32E-03		D	3.741
Final height		0.0299766			
Bottom effective stress		0.5491758		Final calculated	
				Height	Bottom effective stress
Void ratio		0.7807111		0.0299766	0.5491754
Effective stress		103.14684		Normalized errors	
Hydraulic conductivity		2.01E-04		0.0000004	0.0000008
				Total error	0.0000012

Table 5 – SICTA and Step Loading Results for Tailing Sample PDI-114SPT-7.5-12.5-191008 (SI units)

SICTA		Input		Results	
Unit weight of water		9.81		A	2.463
Specific gravity		2.66		B	-0.128
Initial height		0.0326351		Z	0.055
Void ratio @ 0		3.5635533			
Top effective stress		0.1		C	3.62E-05
Darcian velocity		6.60E-03		D	3.911
Final height		0.0260427			
Bottom effective stress		1.2975076		Final calculated	
				Height	Bottom effective stress
Void ratio		1.3632204		0.0260763	1.2930993
Effective stress		103.14684		Normalized errors	
Hydraulic conductivity		1.22E-04		0.0012878	0.0034090
				Total error	0.0046968

Table 6 – SICTA and Step Loading Results for Tailing Sample PDI-118SPT-4.5-15-191014 (SI units)

SICTA		Input		Results	
Unit weight of water		9.81		A	2.760
Specific gravity		2.53		B	-0.152
Initial height		0.0362815		Z	0.043
Void ratio @ 0		4.4575085			
Top effective stress		0.1		C	1.27E-05
Darcian velocity		1.32E-03		D	4.111
Final height		0.0290542			
Bottom effective stress		0.4037612		Final calculated	
				Height	Bottom effective stress
Void ratio		1.3616118		0.0290565	0.4037617
Effective stress		103.14684		Normalized errors	
Hydraulic conductivity		4.52E-05		0.0000758	0.0000012
				Total error	0.0000770

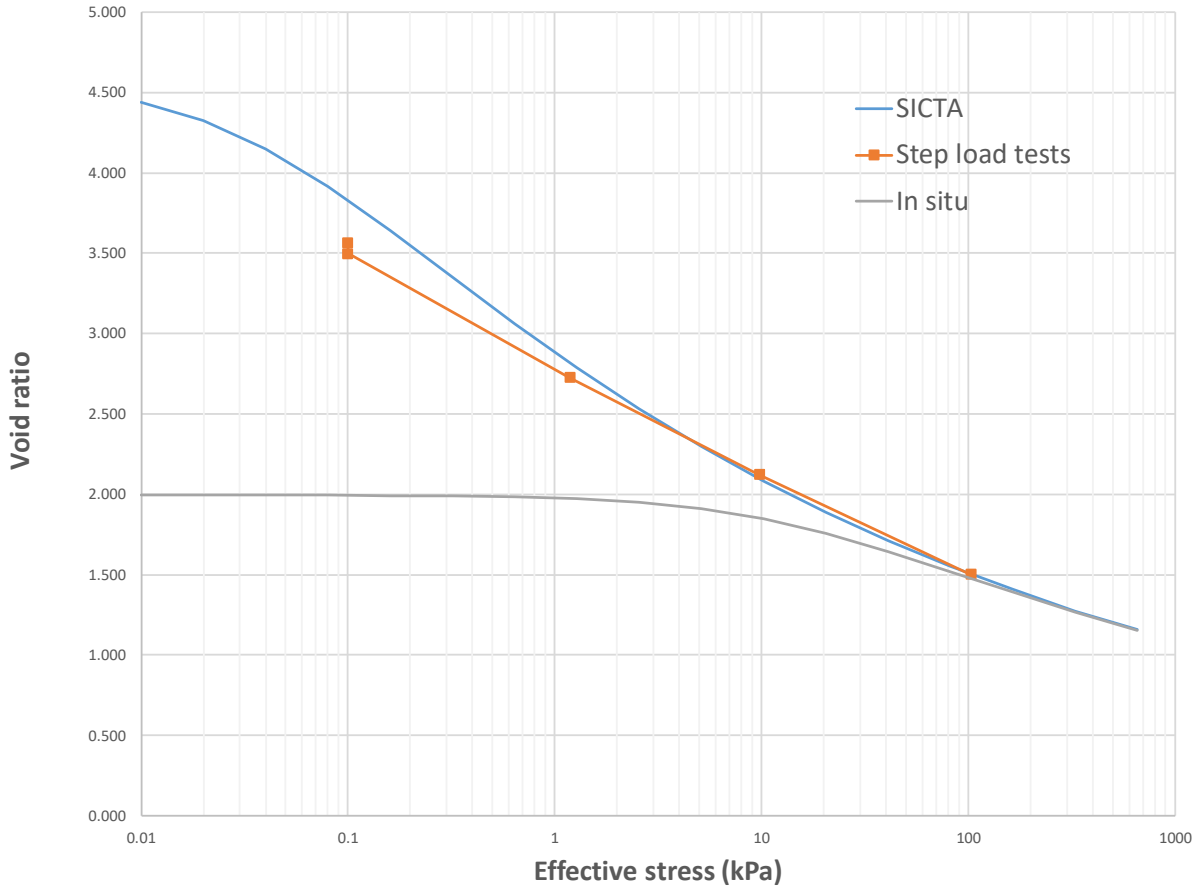

Figure 1 – Compressibility Characteristics for Tailing Sample PDI-107SPT-00-04-190923 (SI units)

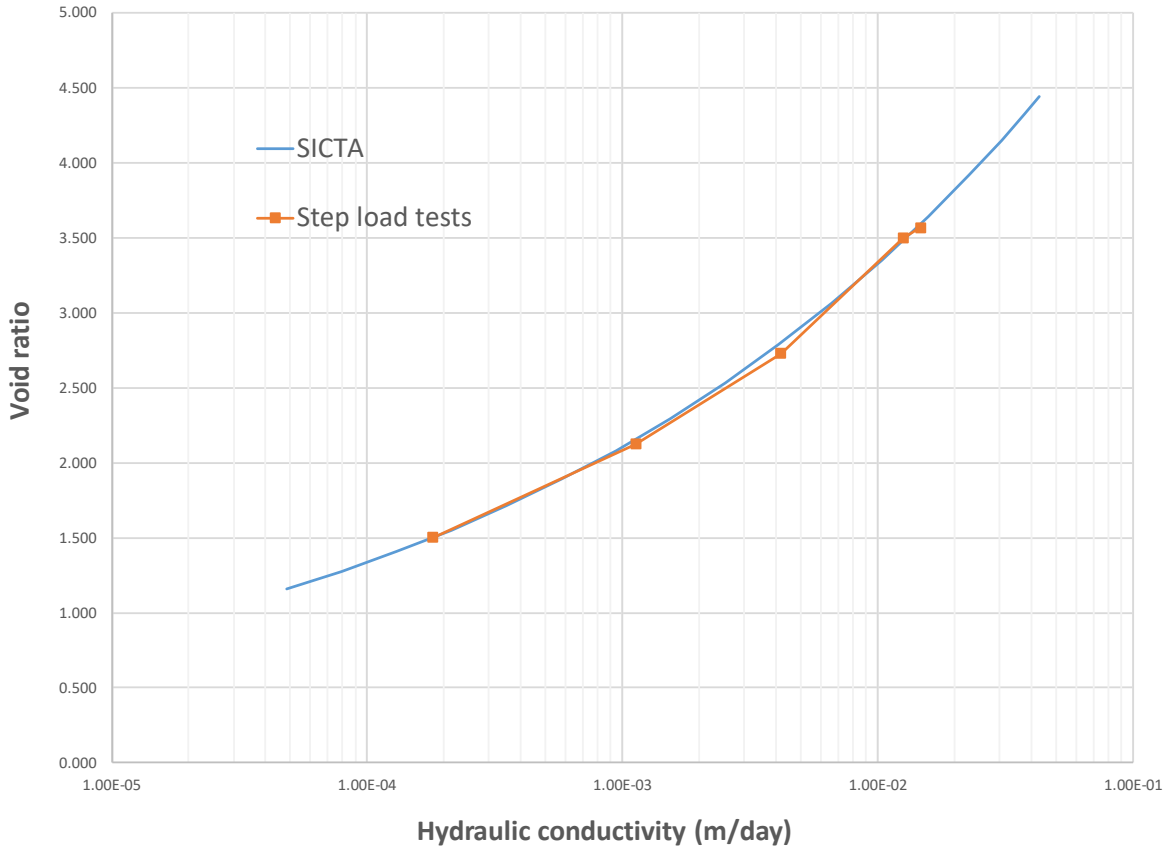

Figure 2– Permeability Characteristics for Tailing Sample PDI-107SPT-00-04-190923 (SI units)

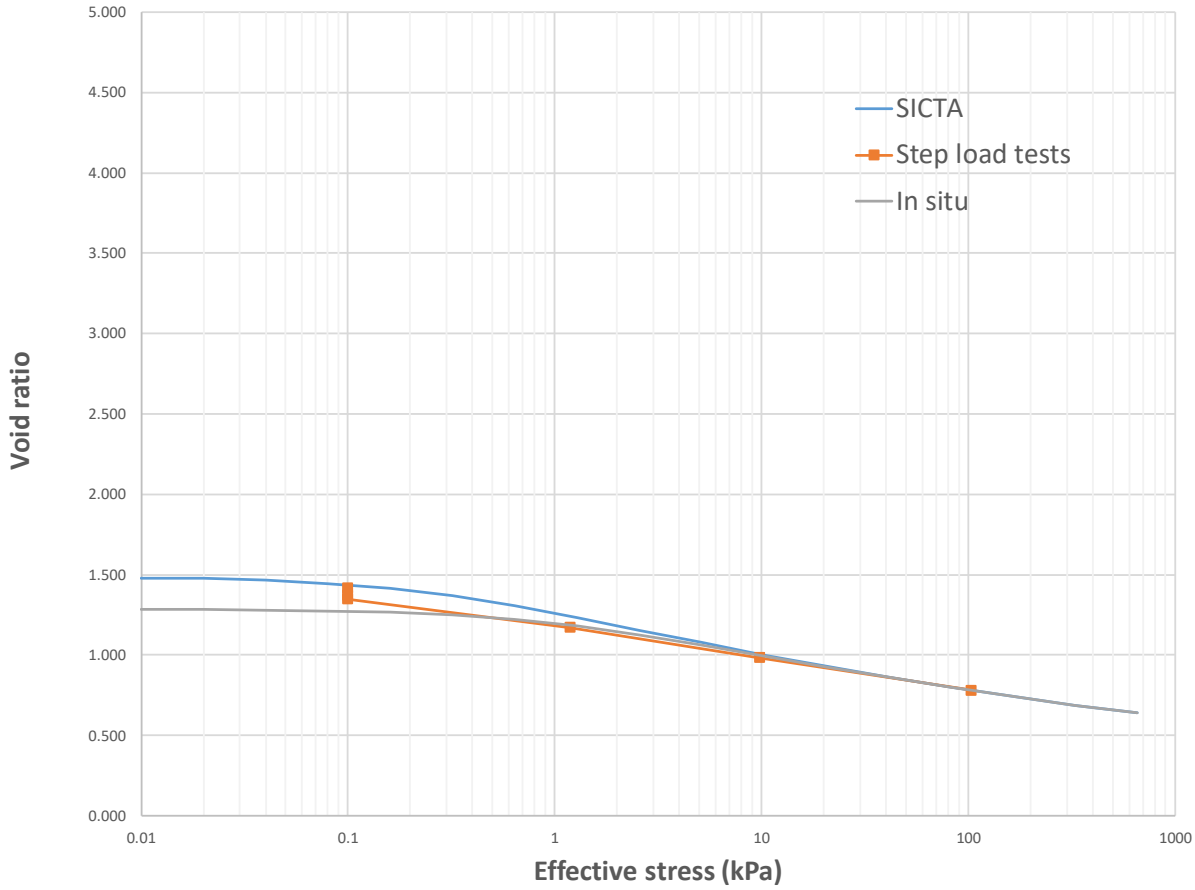

Figure 3 – Compressibility Characteristics for Tailing Sample PDI-113SPT-06-16-191011 (SI units)

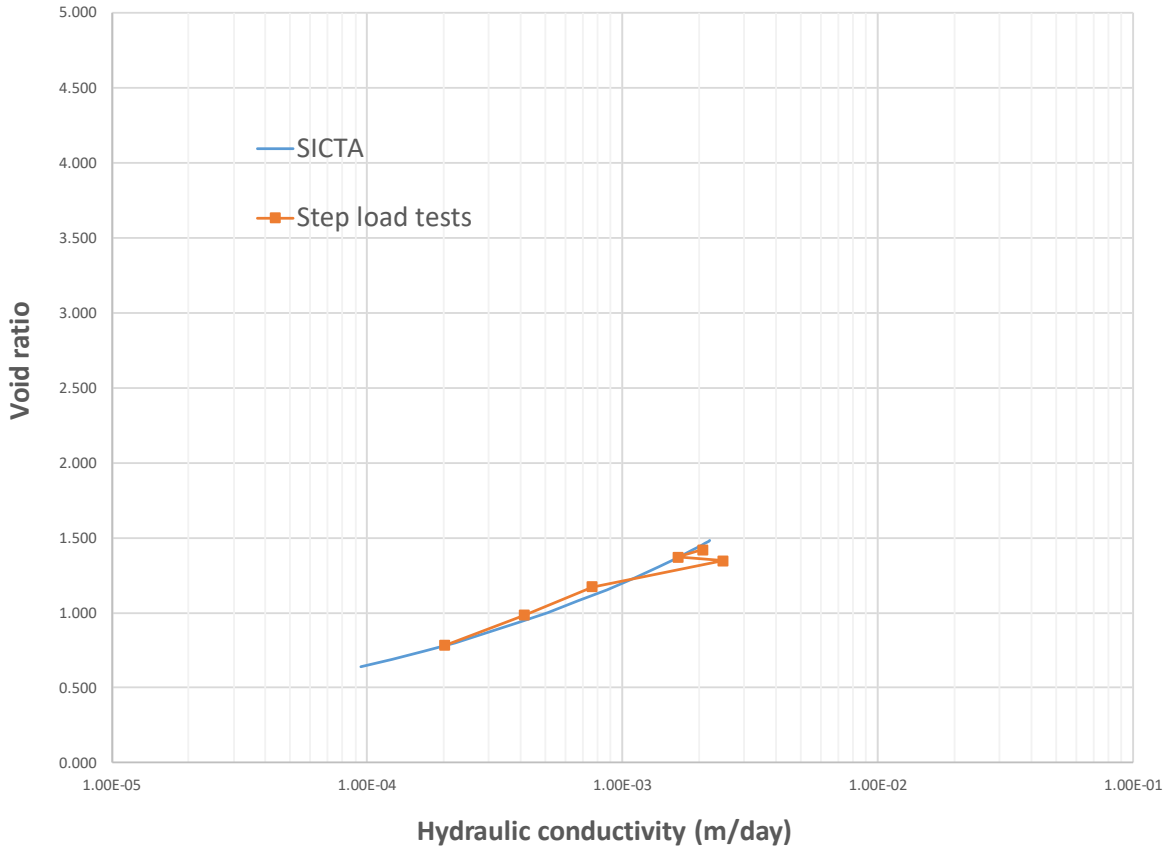

Figure 4– Permeability Characteristics for Tailing Sample PDI-113SPT-06-16-191011 (SI units)

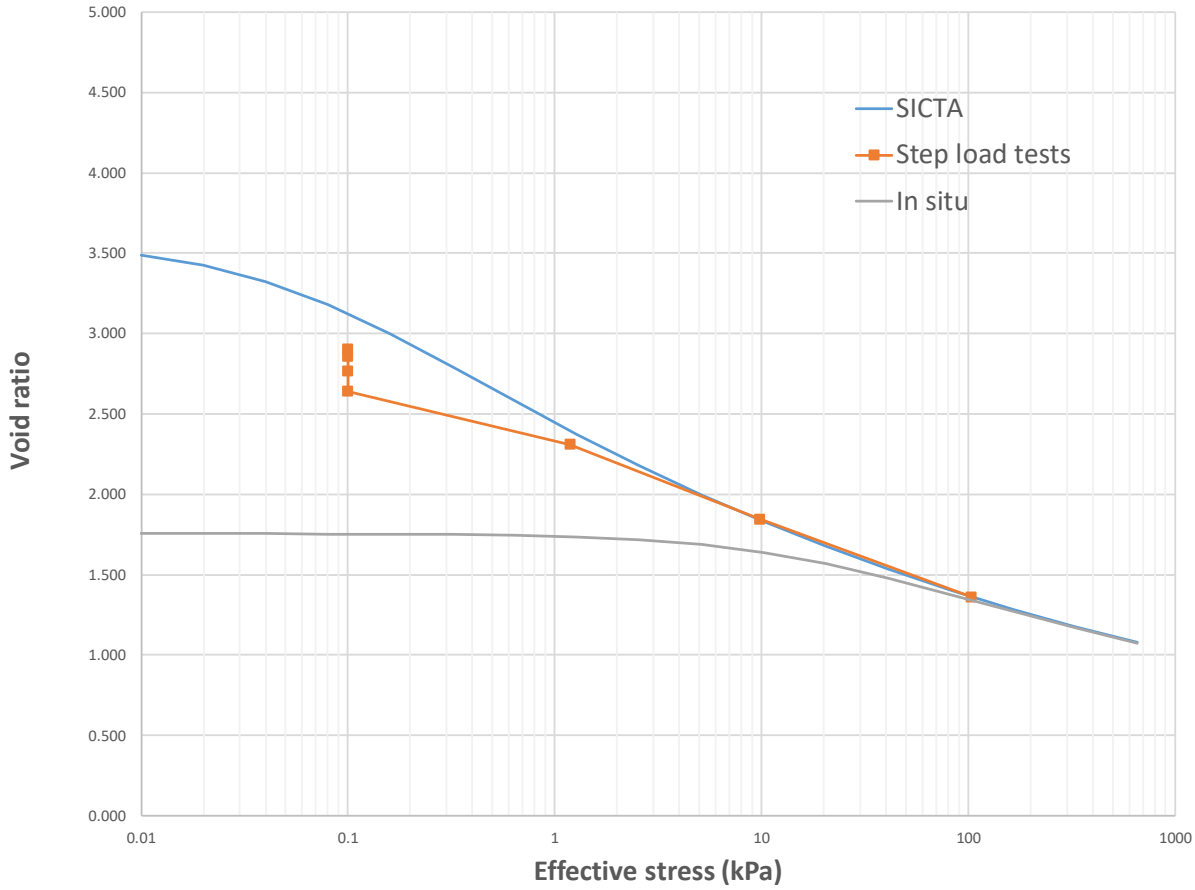

Figure 5 – Compressibility Characteristics for Tailing Sample PDI-114SPT-7.5-12.5-191008 (SI units)

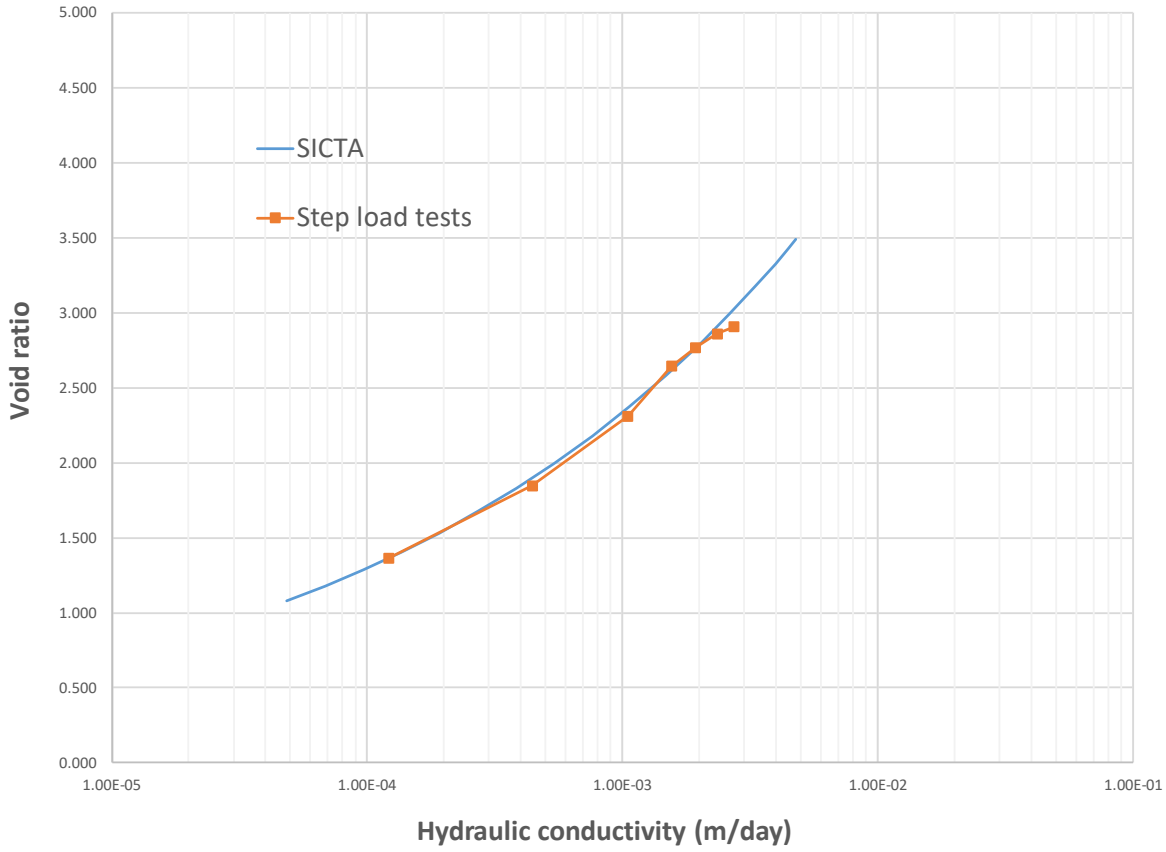

Figure 6– Permeability Characteristics for Tailing Sample PDI-114SPT-7.5-12.5-191008 (SI units)

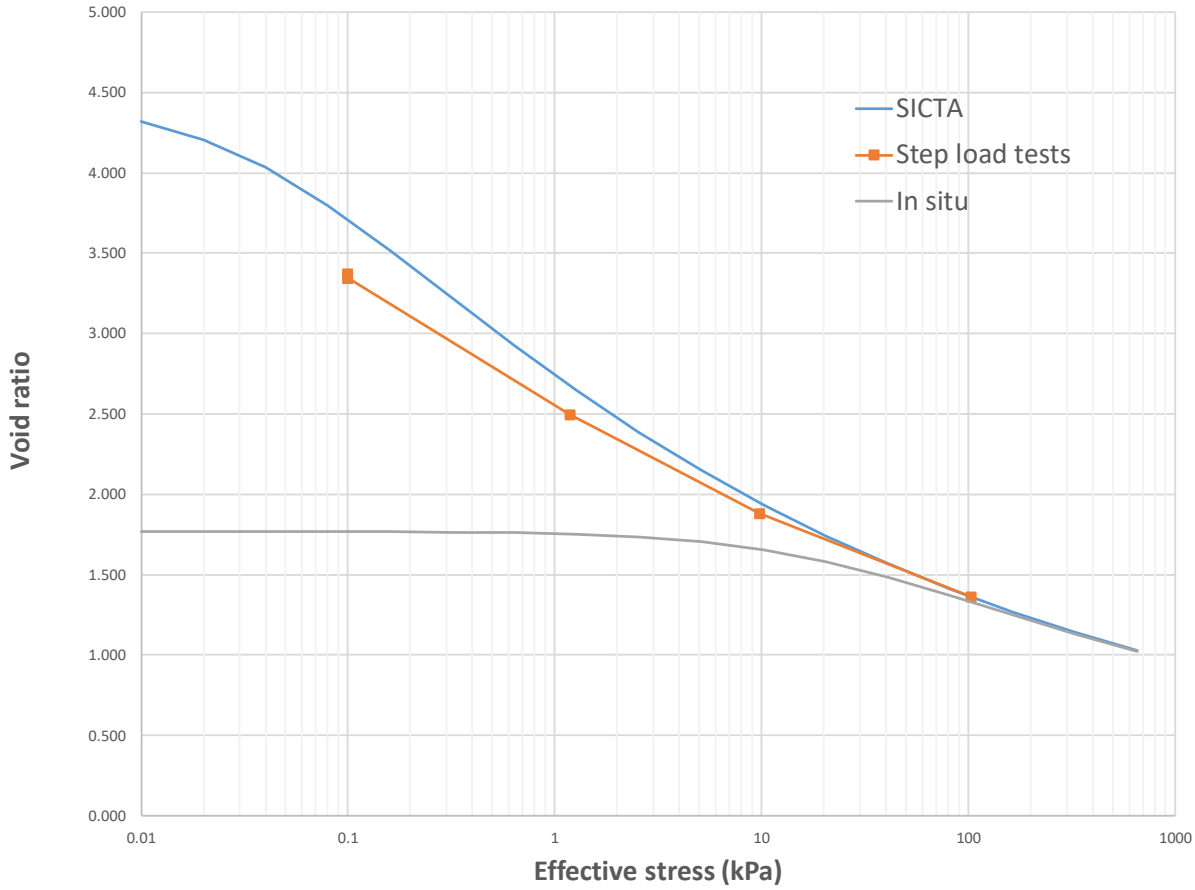

Figure 7 – Compressibility Characteristics for Tailing Sample PDI-118SPT-4.5-15-191014 (SI units)

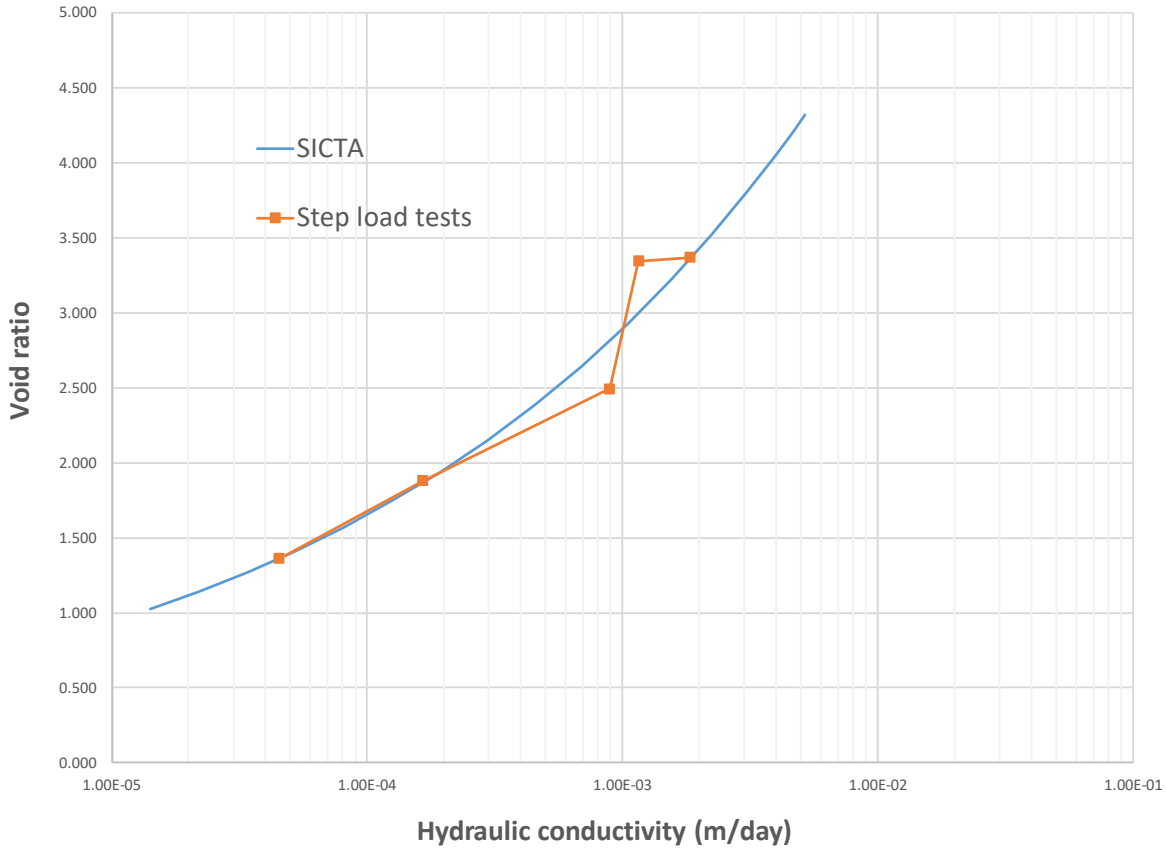

Figure 8– Permeability Characteristics for Tailing Sample PDI-118SPT-4.5-15-191014 (SI units)

Seepage Induced Consolidation Test (SICT)

The seepage induced consolidation test is an experimental procedure used for determining the consolidation characteristics of soft soils and soil like materials (slurry mine waste, dredged spoils, sludge from waste water treatment plants etc.). The testing procedure consists of three steps.

In the first step the void ratio at the effective stress zero is determined by allowing a slurry column about 0.05 m high to consolidate under its own weight. The average void ratio of the settled slurry is considered the void ratio at the effective stress of zero, or the void ratio at which the soil is formed and the consolidation theory, as opposed to the sedimentation theory, applies.

In the second step, seepage at a constant flow rate is applied through the soil by means of a flow pump and the sample is allowed to consolidate completely, i.e. until the steady state is reached. The steady state is determined from the pressure difference across the sample that is continuously monitored during the test. At steady state, the pressure difference and the final height of the sample are recorded. It is recognized that during this phase of the test the void ratio within the sample is non-uniform and this is correctly accounted for in the test analysis.

In the third step the sample is consolidated under the maximum desired stress level and the hydraulic conductivity is measured with the flow pump using a low flow rate to maintain sample uniformity during the test. At the end of the test the sample is dried and the total volume of solids is determined.

The analysis of the test is performed using the software package SICTA (Seepage Induced Consolidation Test Analysis). The procedure is based on the inverse problem solution approach and the theory used is compatible with the finite strain nonlinear consolidation theory (i.e. no simplifying or restrictive assumptions are made in the analysis). The input data for the SICTA program are all obtained from the described test. The output gives five parameters A, B, Z, C and D that define the consolidation properties for the sample. The compressibility and hydraulic conductivity relations with the five parameters are defined as:

Compressibility $e = A\,(\sigma' + Z)^B$

Hydraulic Conductivity $k = C\,e^D$

The more detailed description of the testing equipment and testing and analysis procedures can be found in the following publications:

Abu-Hejleh, A.N., and Znidarcic, D., 1992, User Manual for Computer Program SICTA, Prepared for Florida Institute of Phosphate Research, University of Colorado, Boulder, 122 pp.

Znidarcic, D., Abu-Hejleh, A.N., Fairbanks, T. and Robertson A., 1992, Seepage-Induced Consolidation Test; Equipment Description and Users Manual, Prepared for Florida Institute of Phosphate Research, University of Colorado, Boulder, 52 pp.

Abu-Hejleh, A.N. and Znidarcic, D., 1994, Estimation of the Consolidation Constitutive Relations, Computer Methods and Advances in Geomechanics, Siriwardane & Zaman (eds) Balkema, Rotterdam, pp. 499-504.

Abu-Hejleh, A. N. and Znidarcic, D., 1996, Consolidation Characteristics of Phosphatic Clays, Journal of Geotechnical Engineering, ASCE, New-York, Vol. 122, No. 4. pp. 295-301.