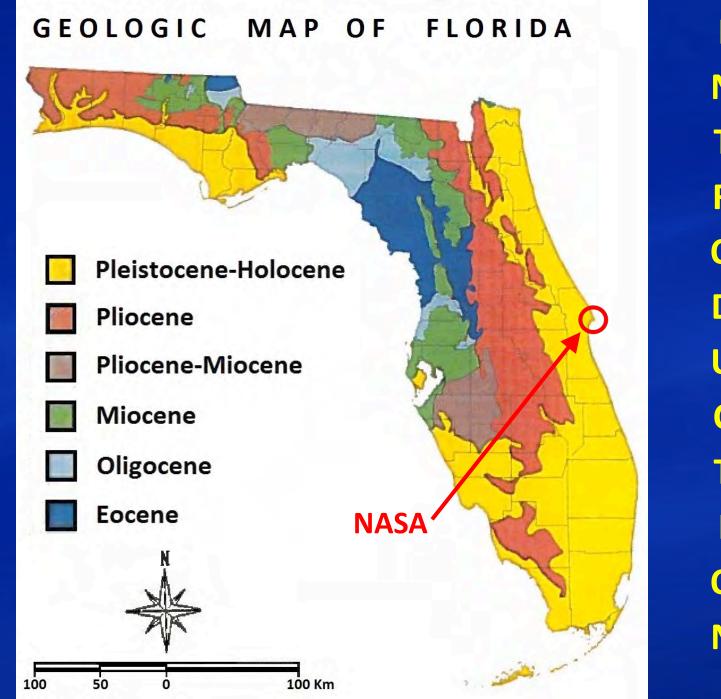
Discovery & Investigation of Negative Aging (-a) of Foundation Sands under NASA Crawlerways

Geo Virginia Sept. 2019

by John H. Schmertmann

Outline

- Introduction
 - 1963-2008
- CPT Discovery of Negative Aging
 - Examples, 2016-2017
 - (Loads ↑/ Resistance ↓)
- Hypotheses for cause
- Pro and Con Evidence
 - hA)- Residual Creep
 - hB D Solution of shell
- Comments and Next Phase
 - Reliability

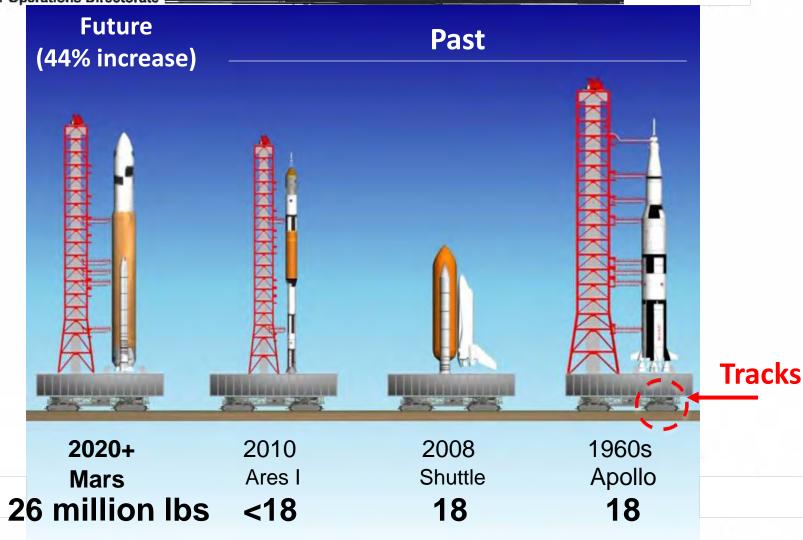


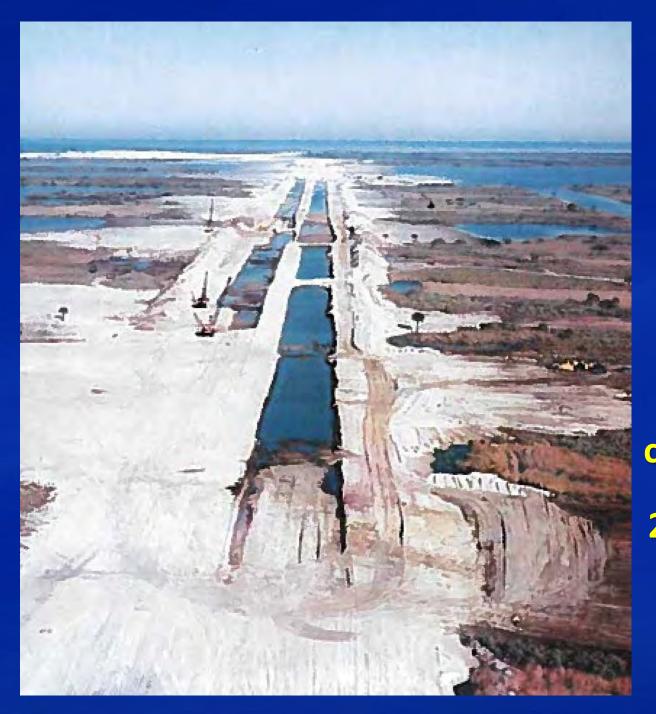
Transporter with Shuttle on Crawlerway A



Heavy Transporter Loads on Crawlerways A and B

Kennedy Space Center Operations Directorate





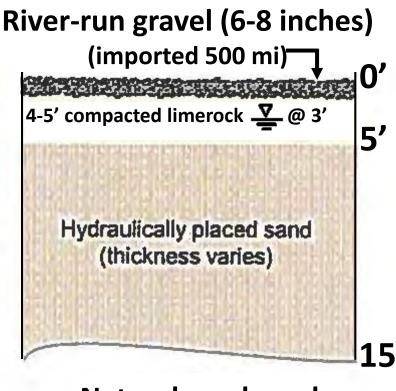
CWA Under Construction (Feb 1964) 2.3 x 10⁶ m³ of hydraulic fill Vibratory and 100 ton rollers compacted roadways 2.3m above sea level (7.5 ft)

Crawlerway History & Section

Kennedy Space Center Center Operations Directorate



1963 to 1966
 5.6-miles long (approx. 9km)
 Constructed through Lagoon System



acilities Division

Natural sands and silts with shell



Peck's 1967 Observation & Phase 1 Study Area

Pad B

Kennedy Space Center Center Operations Directorate

Crawlerway B, Station 49+00 to Station 55+00

Worst-case soils Condition Historical data available

Study Area

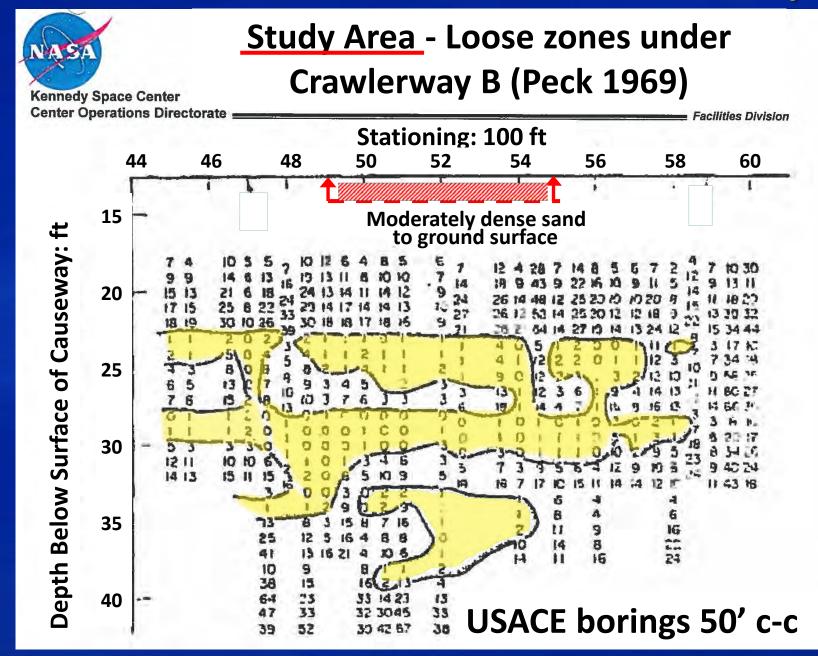
CWB

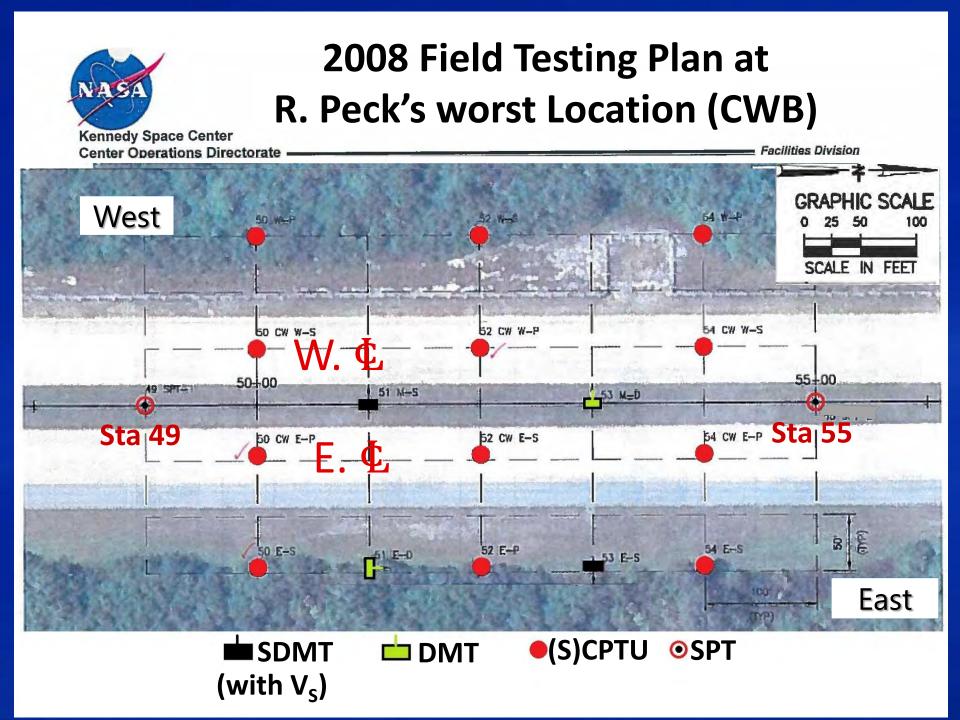
56 Launches 1967-2008 on Pad B, *c.*155 on Pad A

Pad A

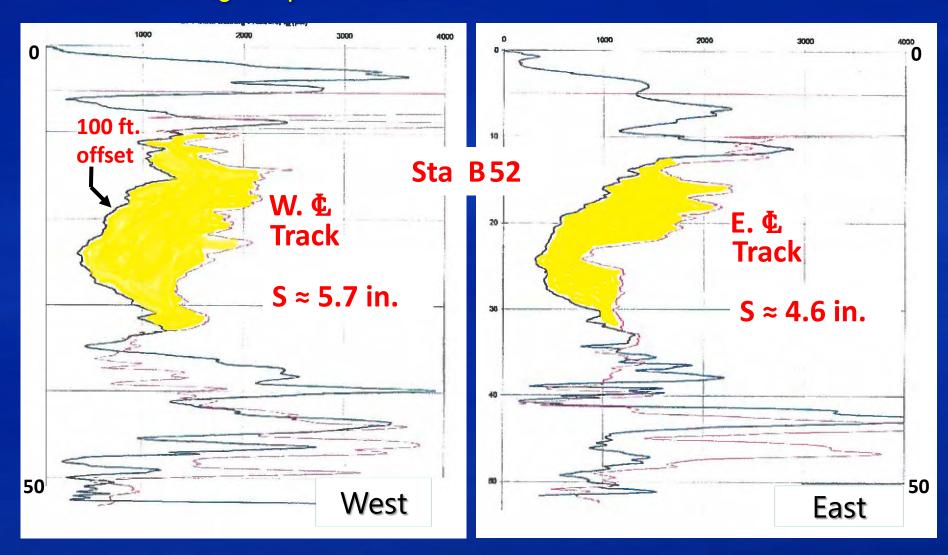
Facilities Division

1967 Loose zones under Crawlerway B





Comparison of CW E & W \pounds and 100' offset CPT q_c profiles, with estimated 1967-2008 settlement, s, based on q_c - D_r changes from Italian chamber tests

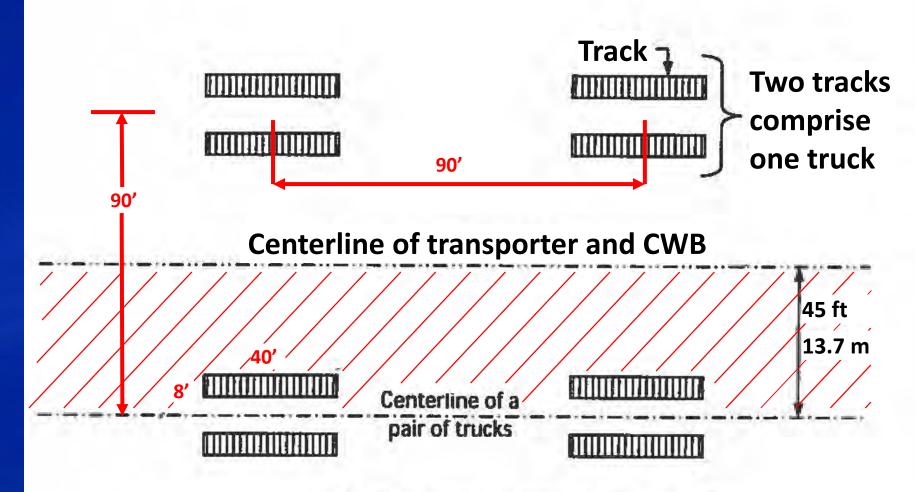


Approx. Speed 1 of 8 Tracks **6" Vertical Adjustment** 0.2-1.0 mph 1C2

JHS George Filz

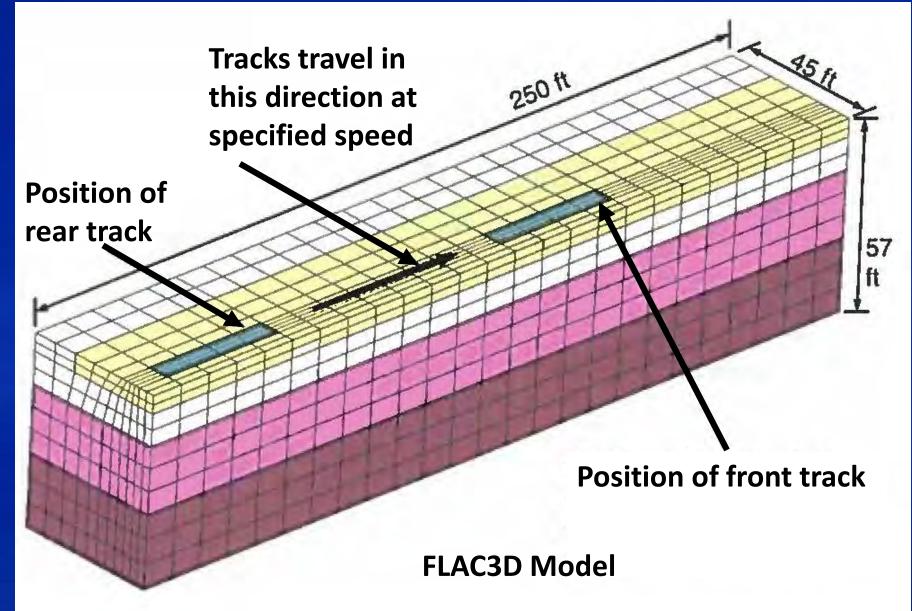
Robert Edmunds

Use of Symmetry in Model

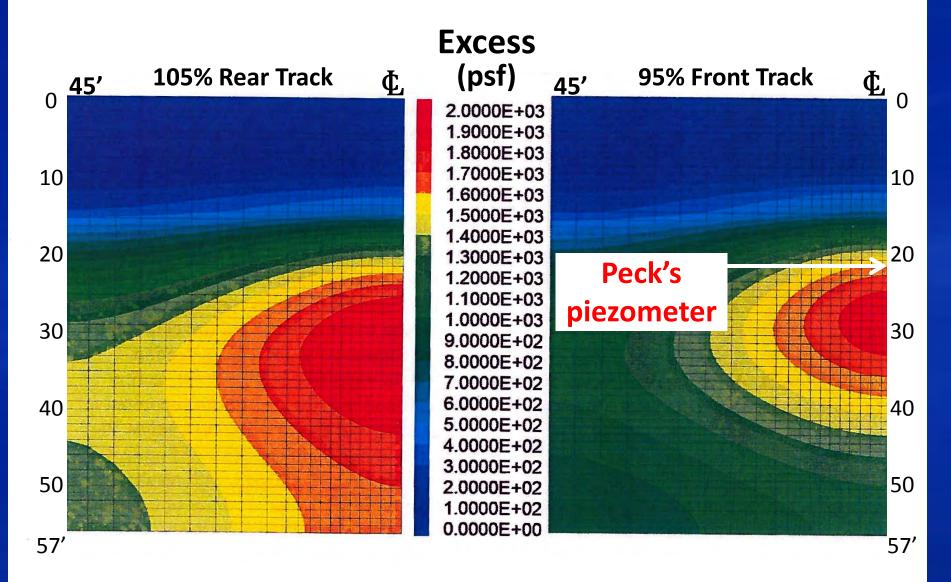


Plan View of Transporter Tracks

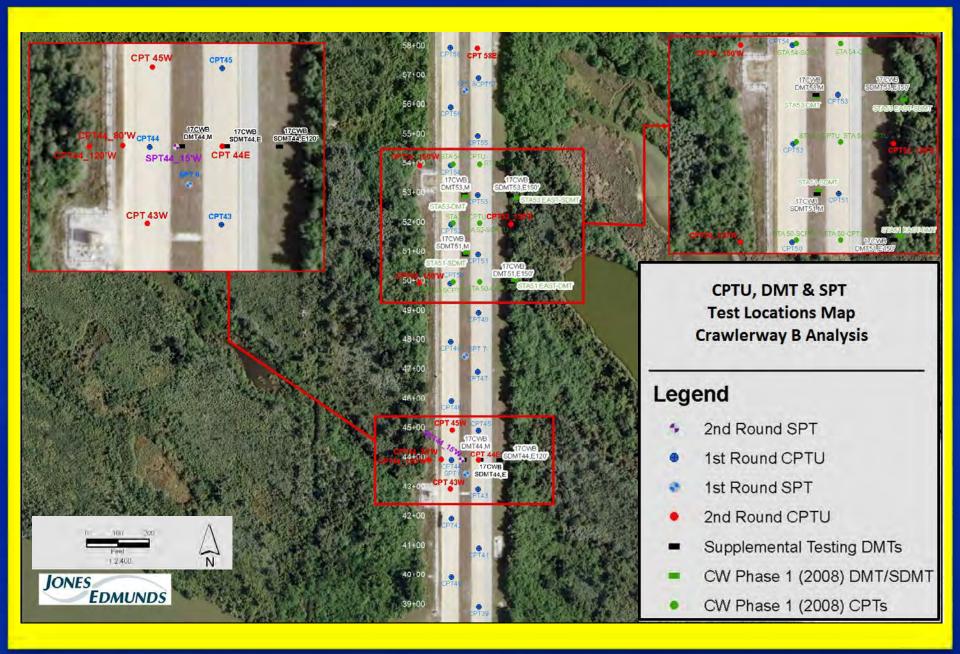
Model and Movement of Tracks



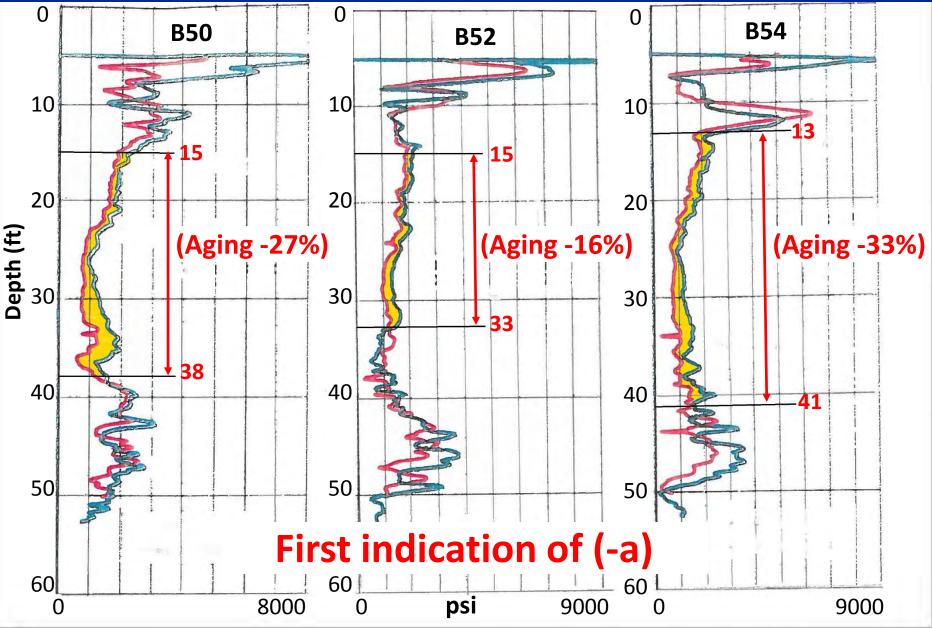
Cross-Sections showing Contours of Excess Pore Water Pressure (psf) from FLAC3D Match with Peck's 1967 Data

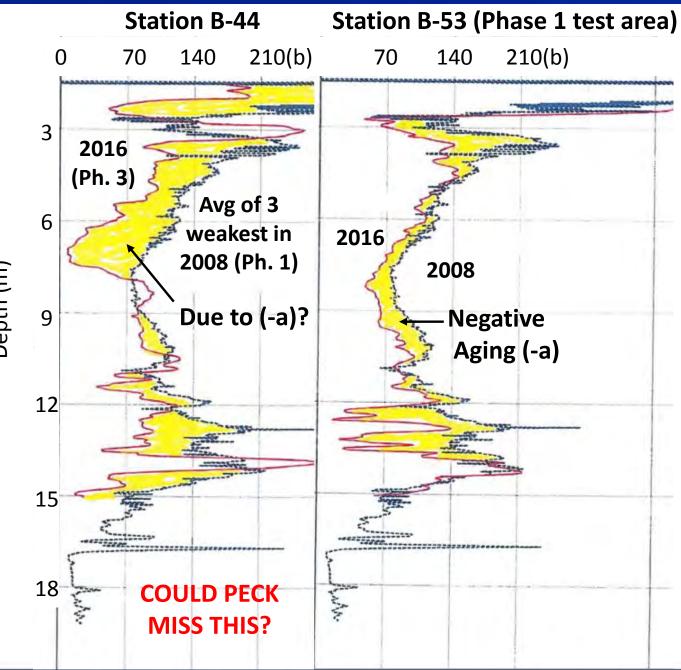


Air Photo Plan of 2016/17 Field Tests in CWB



CPT q_c Profiles, Under & Tracks, 2008 (blue) 2016 (red) No New Loadings – Direct Comparisons

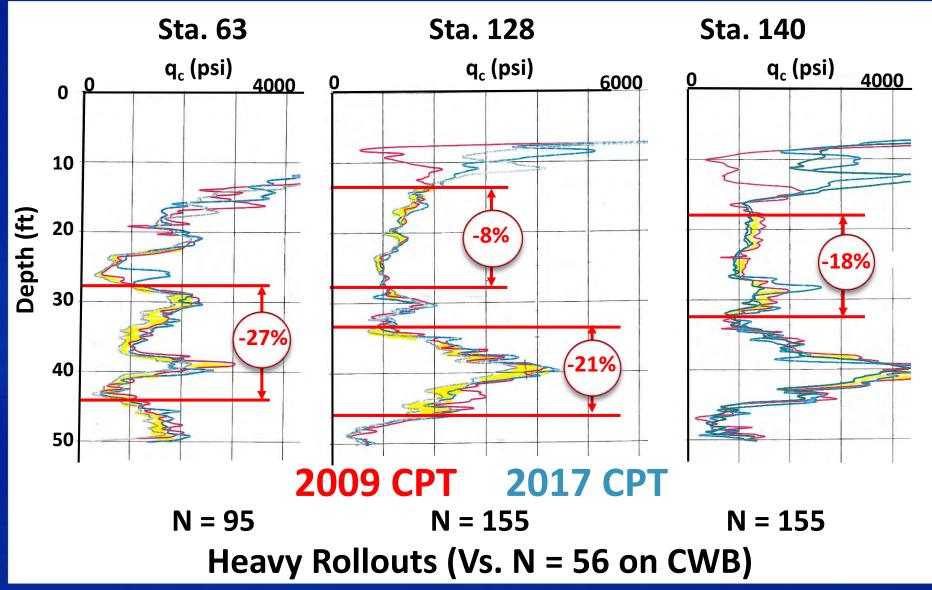




Comparing CPT q profiles under CWB tracks, Peck's (1969 R.L.) weakest in 1967 vs. weakest found in 2016 (Ph. 3)

Depth (m)

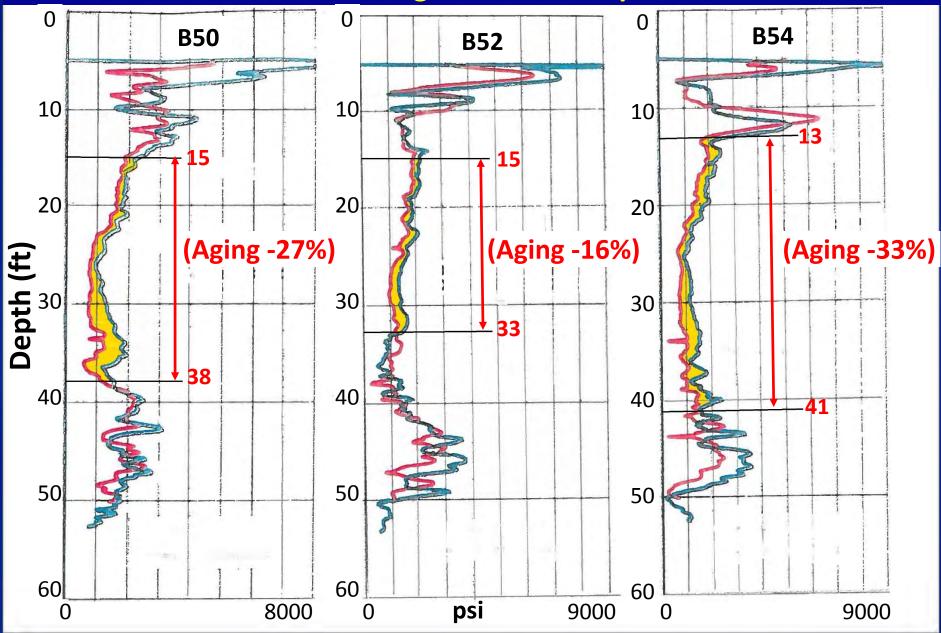
Last Heavy Rollout 2011, CPTs in 2009 and 2017 Examples of Negative Aging Under CWA



Hypotheses Considered for Cause of Negative Aging Creep reduction of residual lateral stresses produced in CW foundations under the moving CT, Some Chamber Research shows $[q_c \alpha \Delta \sigma'_h]$ **Evidence** Accelerated Solution of calcite (shell fragments) by acid rain flowing downward into lagoon sands, which increases void ratio and weakens the sands. Much **Downward erosion of – 200 fines into underlying shelly** layers, which similarly weakens the sands. None Decay of overhead organics, which also weakens surrounding sands and produces organic acids that accelerate the hB solution of calcite. Some

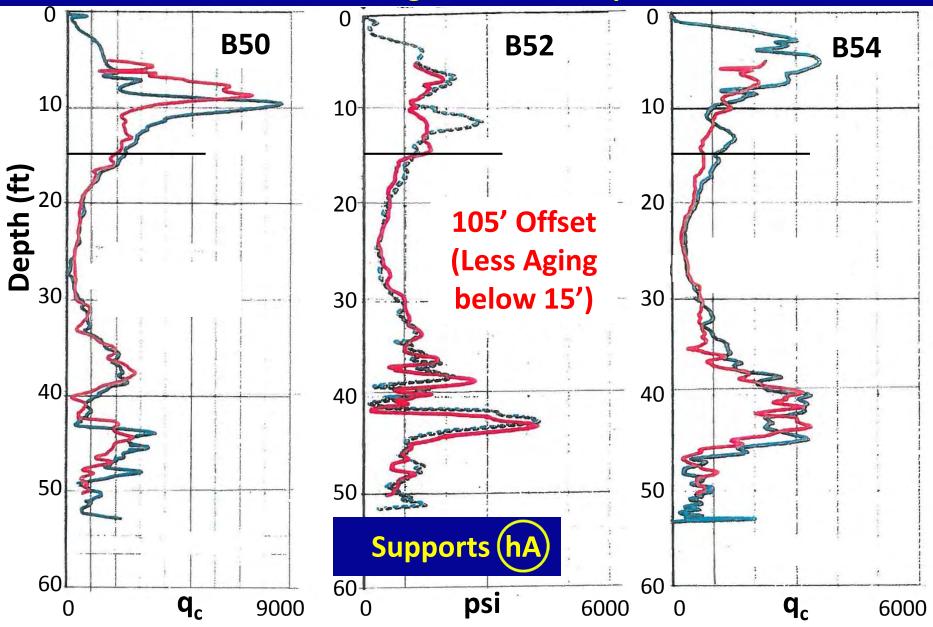
CPT q_c Profiles, Under & Tracks, 2008 (blue) 2016 (red)

No New Loadings – Direct Comparisons



CPT q_c Profiles, <u>105' Offset</u> from **£** Tracks, 2008 (blue) 2016 (red)

No New Loadings – Direct Comparisons



Discussion of "Experimental and DEM Examinations of K_0 in Sand under Different Loading Conditions" by Y. Gao and Y. H. Wang

DOI: 10.1061/(ASCE)GT.1943-5606.0001095

G. Mesri, M.ASCE¹; and Cai Wang² 2015

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²Graduate Student, Univ. of Illinois at Urbana-Champaign, IL 61801, Hong Kong, China.

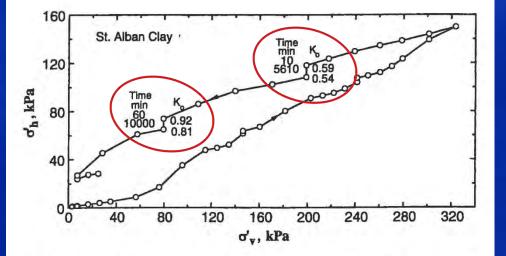


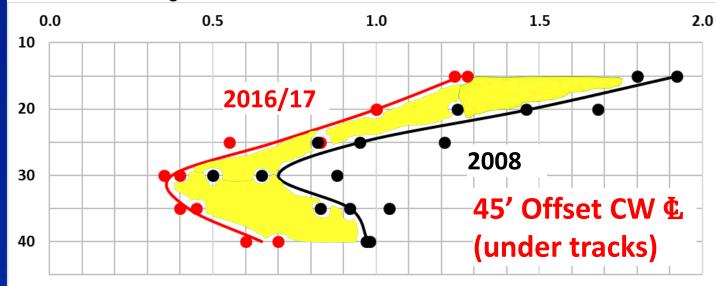
Fig. 1. Decrease in K_o during secondary rebound in an odometer; 10 and 60 min are the duration of end of primary rebound, 5,610, and 10,000 min are the elapsed time including secondary rebound (data from Mesri and Hayat 1993)

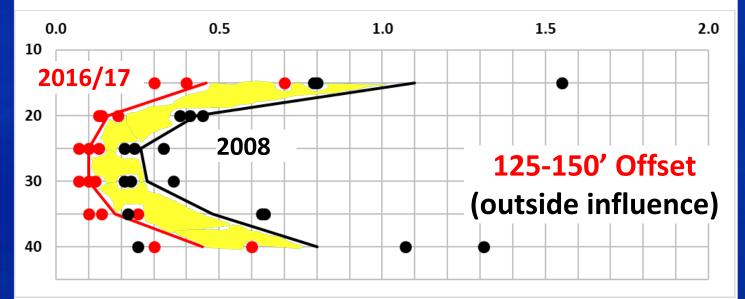
Mesri and Wang provide a Method for Estimating the Future Secondary Lateral Stress Creep Rate in Sands and Silts

$$K_{o} = \frac{[K_{o}]_{t_{p}}}{\left(\frac{t}{t_{p}}\right)^{C_{sa}/C_{s}}}$$
(2)
$$\frac{C_{s\alpha}}{C_{s}} = \alpha (\text{OCR})^{1/2}$$
(3)



f_s = CPT unit side shear (tsf)

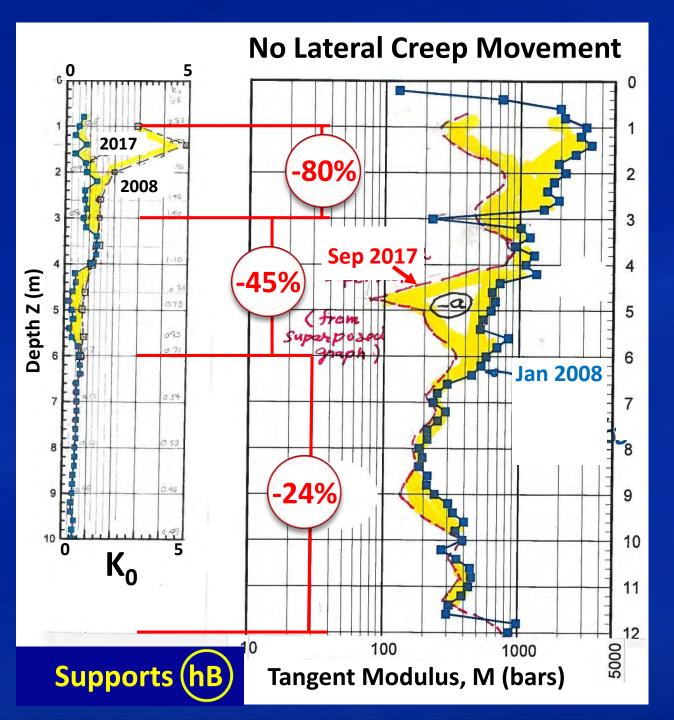




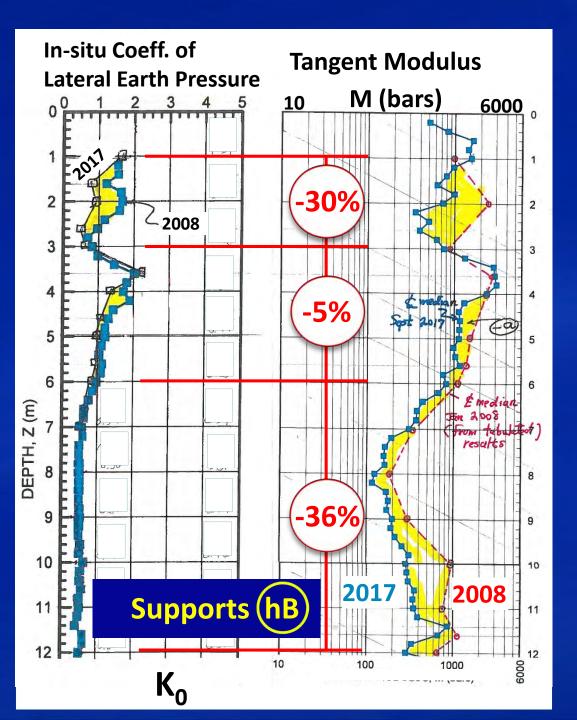
Direct Comparisons between 2008 and 2016/17 CPT unit side shear in B50-B54 Test Area

Similar pattern in both offsets suggests same cause



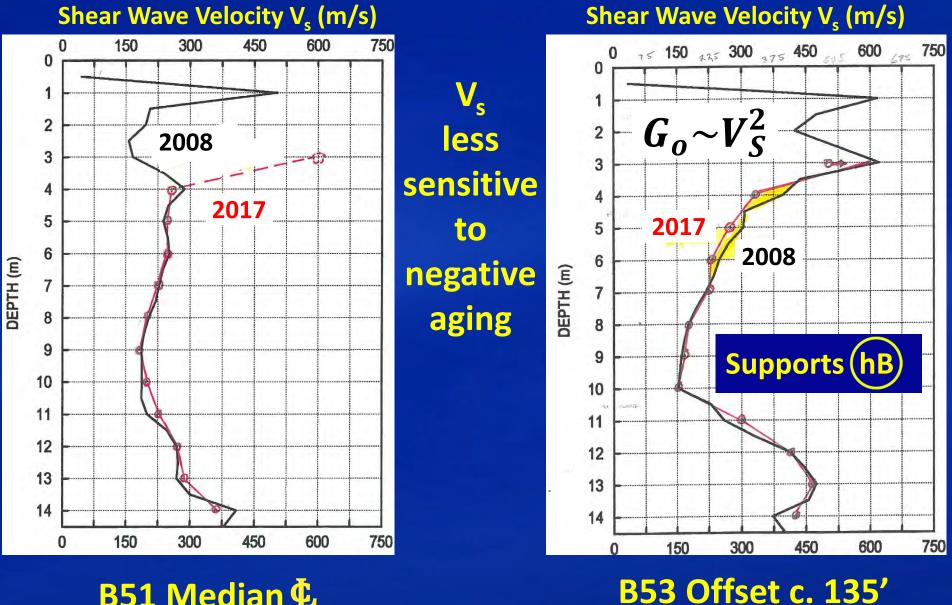


Negative Aging, 2008 - 2017,DMT **<u>©**</u> Median Direct **Comparisons** of Predicted K₀ and M at **Test Area** Sta. B51



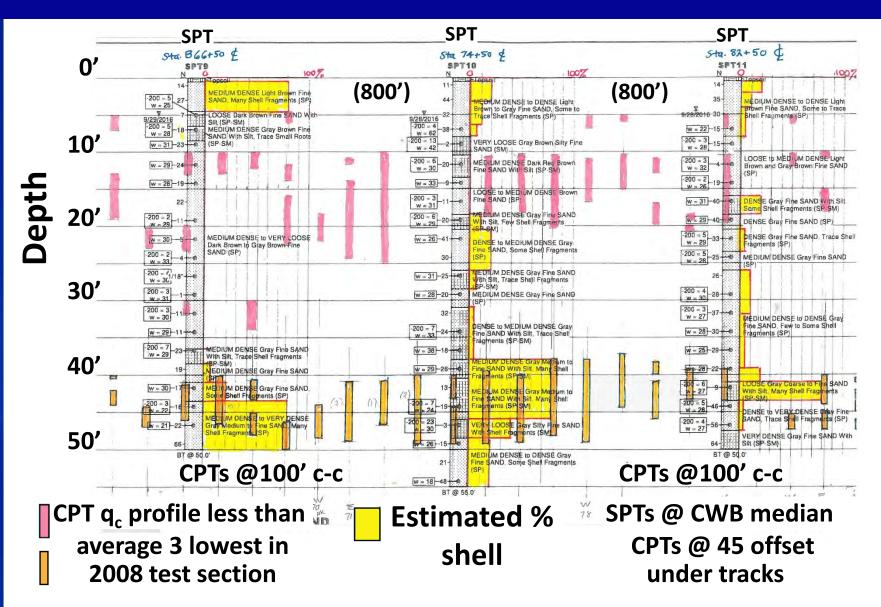
Negative Aging, 2008 - 2017,**DMT & Median** Direct **Comparisons of** Predicted K_o and **M** at Test Area Sta. B 53

CWB Test Area 2008/2017 V_c Direct Comparisons



B51 Median **C**

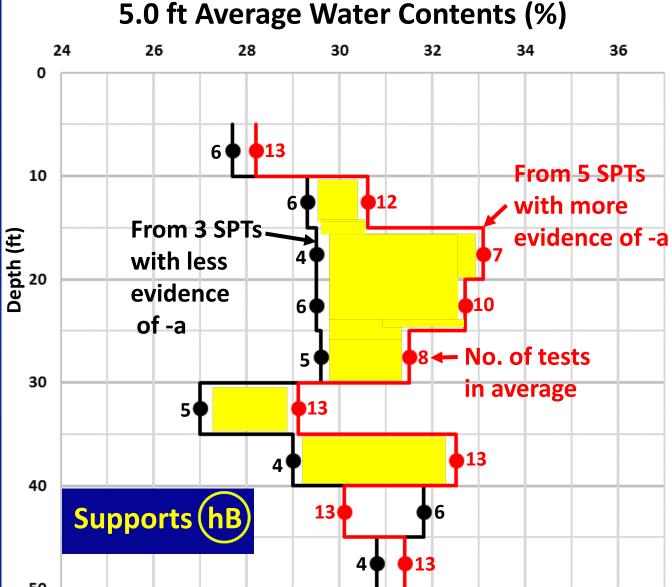
CWB Section with Expected Less Than Average Aging (-a)



CWB Section with Expected More Than Average Aging (-a)

Ste. 8 34+ 50 E	(900') SP	63+50 É F6	(400') SPT7	1002	(900') Ste. 56+ 50 \$	
10/3/2015 56 0 Limerock	14- 26-	MEDIUM DENSE Light Brown Fine SAND, Some Shell Fragments (SP)	16 Small Re	te MEDIUM DENSE Light ine SAND, Few to Some pots (SP)	13- 13- 34- Brown Fine Su Shell Fragmen	
57 to Brown Fine SAND Trace to Some Shell Fragments (SP) w = 59 - 21 to MEDIUM DENSE Dark Brown Fine SAND, Some Small Roots (SP) w = 28 - 30 to MEDIUM DENSE Dark Brown Fine	9/30/2016 w = 27-16-0 w = 30-19	Fine SAND (SP)	9/30/2016 6 (w = 25)-17	te MEDIUM DENSE Dark wyn to Gray, Brewn Fine (P)	9/29/2016 200 = 3 w = 29 w = 29 w = 32 -21 -21 -20 -21 -20 -21 -20 -21 -20 -20 -21 -20 -20 -20 -20 -20 -20 -20 -20	
w = 20 w = 27 -3756 -200 = 3 w = 28 -29 - 90	-200 = 6 w = 29 w = 28 - 35 - 60	MEDITM DENSE Dark Brown Fine SAND With Silt (SP SM)	w = 33-47 + 0 Sir (SP- 200 = 4 w = 32 - 19 - 0 Sir (SP-	Dark Brown Fine SAND With SM)	w = 28)-19	
23-	16-	DENSE to VERY LOOSE Dark Red	W = 32-21-0 MEDIUM	DENSE Red Brown Fine tace Shell Fragments (SP)	w=30-18-0	
w = 29-11 + 0 DENSE to LOOSE Red Brown and [200 - 2] w = 29 [200 = 2] [200 = 2] [200 = 2] [200 = 2]	<u>w = 30</u> -5 -0 200 - 2 <u>w = 31</u> -2 -0	Brown to Gray Brown and Gray Fine SAND (SP)	w = 38-12-0		200 = 4 w = 30 w = 31 200 = 5	
$\frac{w = 26}{200 = 2} -7 - 6$	w = 31 - 1 - 0 $200 = 5 - 2 - 400$ $w = 35 - 2 - 400$	VERY LOOSE to LOOSE Gray Fine	w = 34 Light Bro (SP)	OSE to LOOSE Brown to wn and Gray Fine SAND	$\begin{array}{c} 200 = 3 \\ w = 27 \\ \hline 200 = 2 \\ w = 30 \\ \hline \end{array}$	
w = 30 - 8 - 40 w = 26 - 25 - 26 MEDIUM DENSE Gray Fine SAND. Few Shell Fragments (SP) 200 - E	w = 27 7 10	SAND With Silt (SP-SM) LOOSE to MEDIUM DENSE Gray. Fine SAND, Few to Some Small Roots (SP)	w = 33 -200 = 3 w = 30 -200 = 3 -200 = -20 -200 = -200 -200 = -200 -200 -200 = -200 -200 -200 = -200 -200 -200 = -200 -2		<u>w = 31 - 8 - 0</u> 12-	
-200 = 5 w = 29 17 W With Sitt, Many Shell Fragments SP SM 15-	w = 20 - 13 - 16	MEDIUM DENSE IN LOOSE Grav	W = 27-39-00	DENSE Gray Fine SAND	200 - 4 	
w = 20 - 10 - e Fini SAND. Many Stell Fragments w = 18 - 18 - w (SP)	(D) (B)	COOSE Gray Fine SAND with Silt, Some Shall Fragments (SF-SM)	w = 30	iray Fine SAND With Silt Fragmente (\$P \$M) of End ManelosE Gray of the SAND, Mr. Shell ()	200 = 16 w = 28 w = 28 - 7 - 200 = 16 - 200 = 16 - 200 = 16 - 200 = 10 - 200 =	
200 - 9 - 16 - C ME DIUM DENSE Gray Fine SAND Wux 26 - Wux Sit (SP'SM) w - 28 - 37 - C DENSE Gray Fine SAND, Trace Shell Fragments (SP)	200 = 7 w = 9 200 = 7 w = 9	MEDIU DENSE Gray Stor Fine SAND, Wany Shell Fragments (SN) DENSE Gray Fine SAND with Sill, Some Shell Fragments (SP SM)	W - 10 1 10 00	DENSE toiLOOSE Grav. C. O. Many Shell Fragments	w=331-11- SAND, Some 5 35- DENSE Gray F Filtments (SP	
200 = 19 w 45 - 4 - 10 LOOSE Gray Silly File SALC, SM) BT 60 50.0'	200 = 0 w = 30 ² 200 = 21 w = 37 8 4 200 = 21 8 4 4 4 4 4 4 4 4 4 4 4 4 4	LOOSE Gray Fine SAND with Siti and Ci Many Shell Fragments (SE SM) LOOSE Gray Sity Fine SAND With Clay, Many Shell Fragments (SM)	BT @ 50.0'		w - 37 - 6	
CPTs @100' c-c	4 47 BT @ 55	5.0°	E6 47 48	s @100' c-c	W = 38 - 58 - 58 - 58 - 58 - 55.0'	
CPT q _c profiles less than Estimated % SPTs @ CWB median						
average 3 lowest in2008 test section				-	@ 45' offset, Ider tracks	

Average + Δw = 2.6%, suggests Calcite (shell) solution

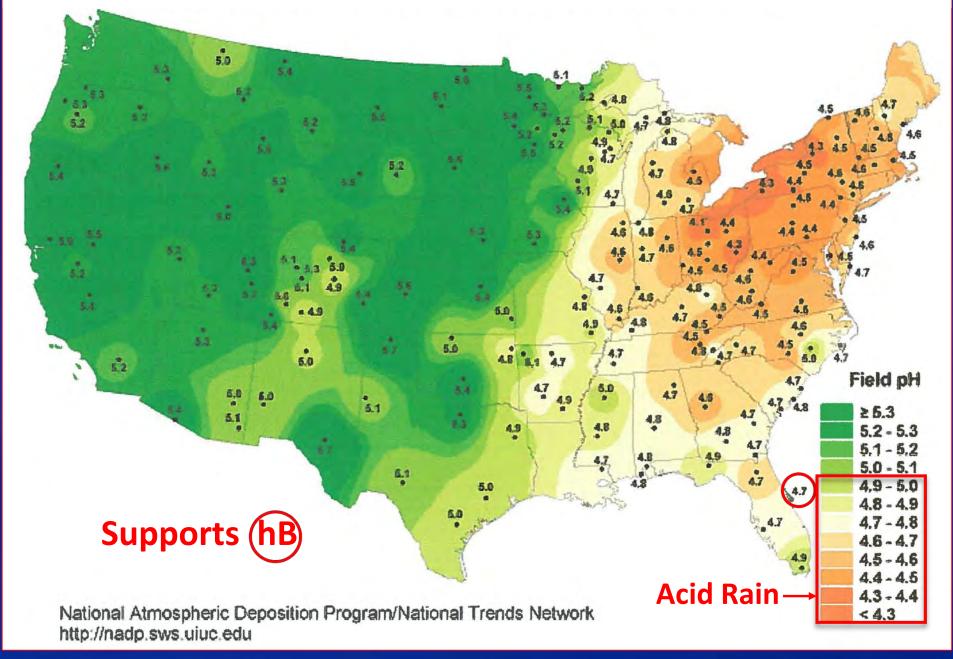


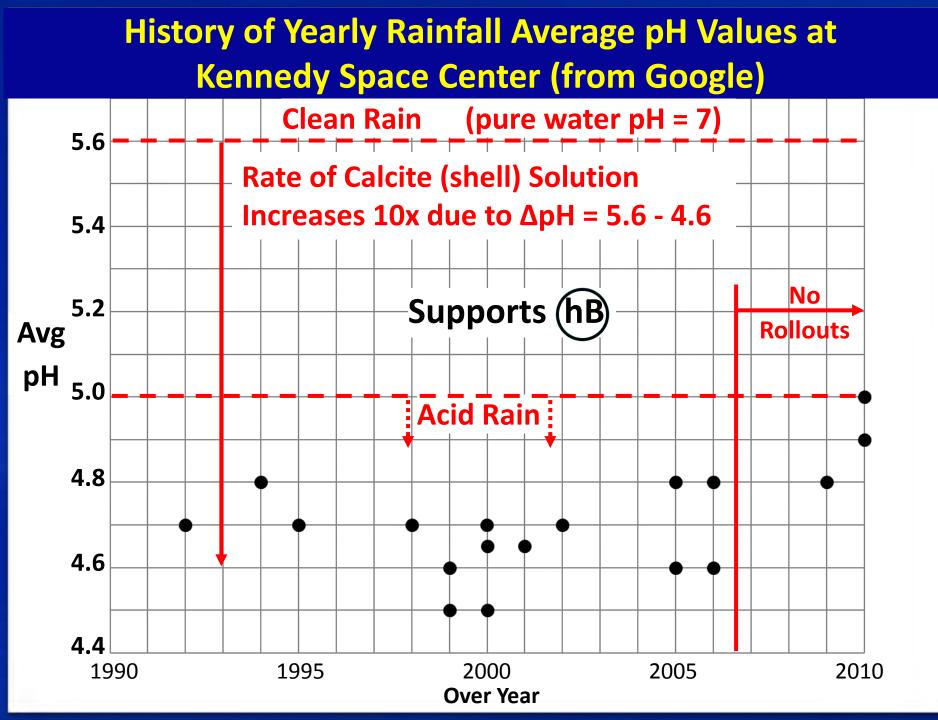
Comparison of Average water content between parts of CWB with more and less than average evidence of negative aging

Note: Another comparison, with 4 SPTs each, gave Δw over 10-40' = +1.0%

50

Hydrogen ion concentration as pH of precipitation, 2002







Rocket Exhaust Clouds Contribute to temporary reductions of pH in Acid Rain in Kennedy Space Center Area

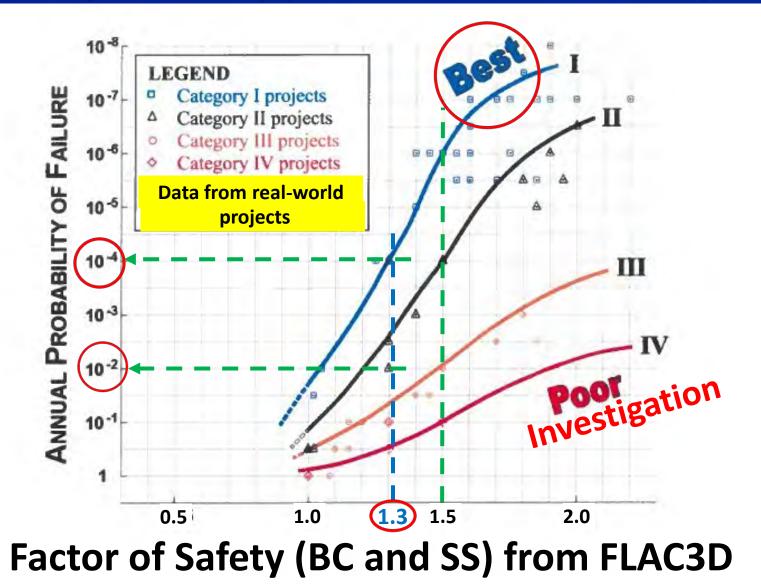


- Studied extensively by NASA in 1980s, especially solid boosters
- ~ 70 tons per launch of HCI released below c. 3km
- Area affected 28km² with pH = 1-3
- Sometimes a 0.5 drop in pH 100km downwind
- Solids deposited on pad were wash-cleaned. Wash stored in ponds with pH ~ 1 to 2.

Comments

- Exceptionally 'clean' 50-year case history of 6-9 years with negative aging in sands
 Most likely due to effects of acid rain
 Needs more investigation
 Next Phase 4 (2020+)
- 4. Full scale CWAB conditioning
- 5. Improve prediction model
- 6. Plan future monitoring
- 7. Observational method
- 8. NASA wanted 99.99% reliability, now accepts 99%

Estimating Reliability from FS for Bearing Capacity and Slope Stability (Silva, Lambe, Marr 2008)





The End