Advanced, Modern, and Innovative Technologies Used at Houston Airport Systems

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HOUSTON AIRPORTS

ADVANCED, MODERN AND INNOVATIVE TECHNOLOGIES USED AT HOUSTON AIRPORT SYSTEMS

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ABSTRACT

Soils in the Houston Area have high plasticity and are considered less desirable when dealing with pavement and foundations because of their swelling and expansive nature. However, with the application of innovative technologies, methods, and materials adopted at Houston Airport Systems (HAS), such problems have successfully been addressed and overcome. Various studies on soils stabilization techniques at HAS have indicated that these techniques are effective in reducing plasticity index, improving compaction characteristics, and increasing compressive strength as well as resilient modulus, which are the key parameters in controlling airfield pavement design. Various advanced modern, and innovative technologies that have been adopted at Houston Airport Systems (HAS) include:

Applications of New Concrete Technology:

- Novophalt Asphalt (Polymer Modified Asphalt) concrete technology.
- Stress Absorbing Membrane Interlayer (SAMI).
- Cement, Fly-ash & Blast Furnace Slag Concrete.

Various Soils Stabilization Techniques for Base, Sub-base and Sub-grade:

- Soil stabilization using Lime/Fly ash in slurry form.
- Soil stabilization using Cement/ Fly ash in slurry form.
- Soil stabilization using a Blend of Fly ash and Bottom ash.
- Lime/Cement/Fly ash/Crushed Concrete stabilized Base
- Cement /Fly ash Crushed Concrete Base.

These project applications have made the Houston Airport Systems one of the leaders in innovative technologies among airports in the United States. The objective of this paper is to introduce some of the innovative pavement technologies used in pavement design at the Houston Airport Systems. This paper will presents some of the innovative approaches regarding application of new concrete technology for pavement surfaces, various soil stabilization techniques for base, sub-base and sub-grade that have using for last twenty-five years in all the three airports at Houston Airport Systems. The outcomes of recent studies on Lime Fly Ash Stabilization in terms of compaction characteristics, strength development, changes on Plasticity Index, and relationship between compressive strength of stabilized soils to the PI of Virgin Soils are also presented. Finally, the outcomes of Finite Elemental analysis for the possible cause of slab cracking and delamination of pavement at TW-WA/WB in conjunction with the operation of B-777 at different loading scenario, and the involvement of environmental factors are also discussed.

Key Words: ***Stabilization, Soil, Cement, Concrete, Compaction, Plasticity, Pavement***

Advanced, Innovative and Leading Edge Pavement Concrete Technologies at Houston Airport Systems:

- **Novophalt Asphalt (Polymer Modified Asphalt) Concrete Technology**
- **Stress Absorbing Membrane Interlayer(SAMI) for reflective cracking of pavements.**
- **New concrete -Cement, Fly ash and Blast furnace slag.**

Soils stabilization Techniques for Base, sub-base & Sub-grade:

- **Lime/Fly ash in the Slurry form.**
- **Cement /Fly ash in Slurry form.**
- **Blend of Fly ash and Bottom ash.**
- **Lime/Cement/Fly ash (LCF) Crushed Concrete Stabilized Base**
- **Cement/ Fly ash Crushed Concrete Base**

These project applications in the real world have made the Houston Airport System one of the leading users of the leading edge of Technologies among Airports in the country.

Pavement Technology

(Innovative Sub-grade, Sub-base, and Surface Material)

New concrete Technology: Novophalt Asphalt (Polymer Modified Asphalt)

- Cement, Fly ash and Blast furnace slag
- SAMI: Stress Absorbing Membrane Interlayer (for reflective cracking of pavements)
- Stabilized Base and Sub-Base

NOVOPHALT HOT MIX ASPHALTIC CONCRETE

(Polyethylene Additive)

Novophalt Asphalt improves the following properties of the Hot Mixed Asphaltic Concrete

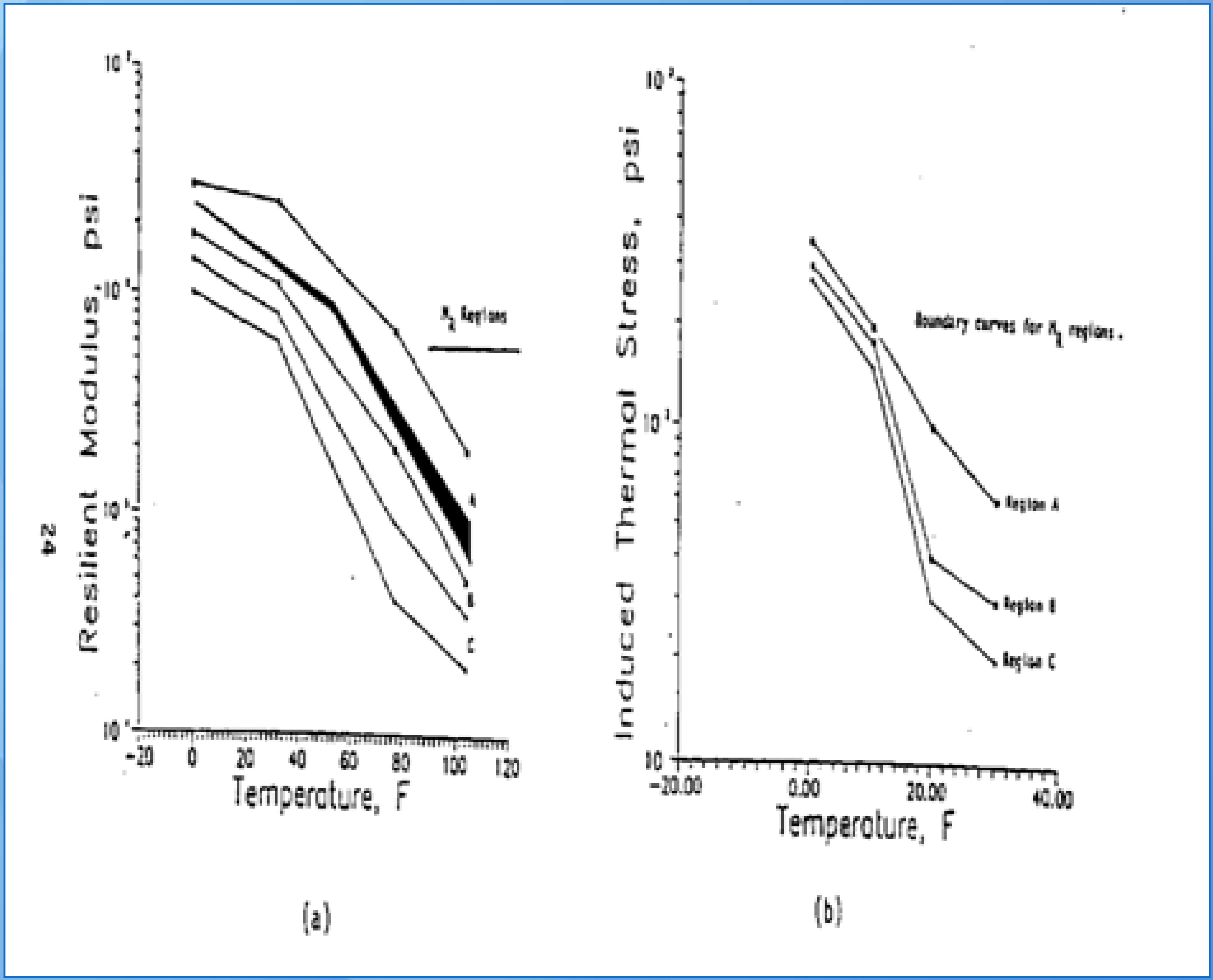
- **Better Viscosity**
- **Improvement in Temperature Susceptibility**
- **Higher Marshall Stability**
- **Higher Modulus of Elasticity**
- **Higher Tensile Strength**

NOVOPHALT HOT MIX ASPHALTIC CONCRETE

(Polyethylene Additive) Contd.

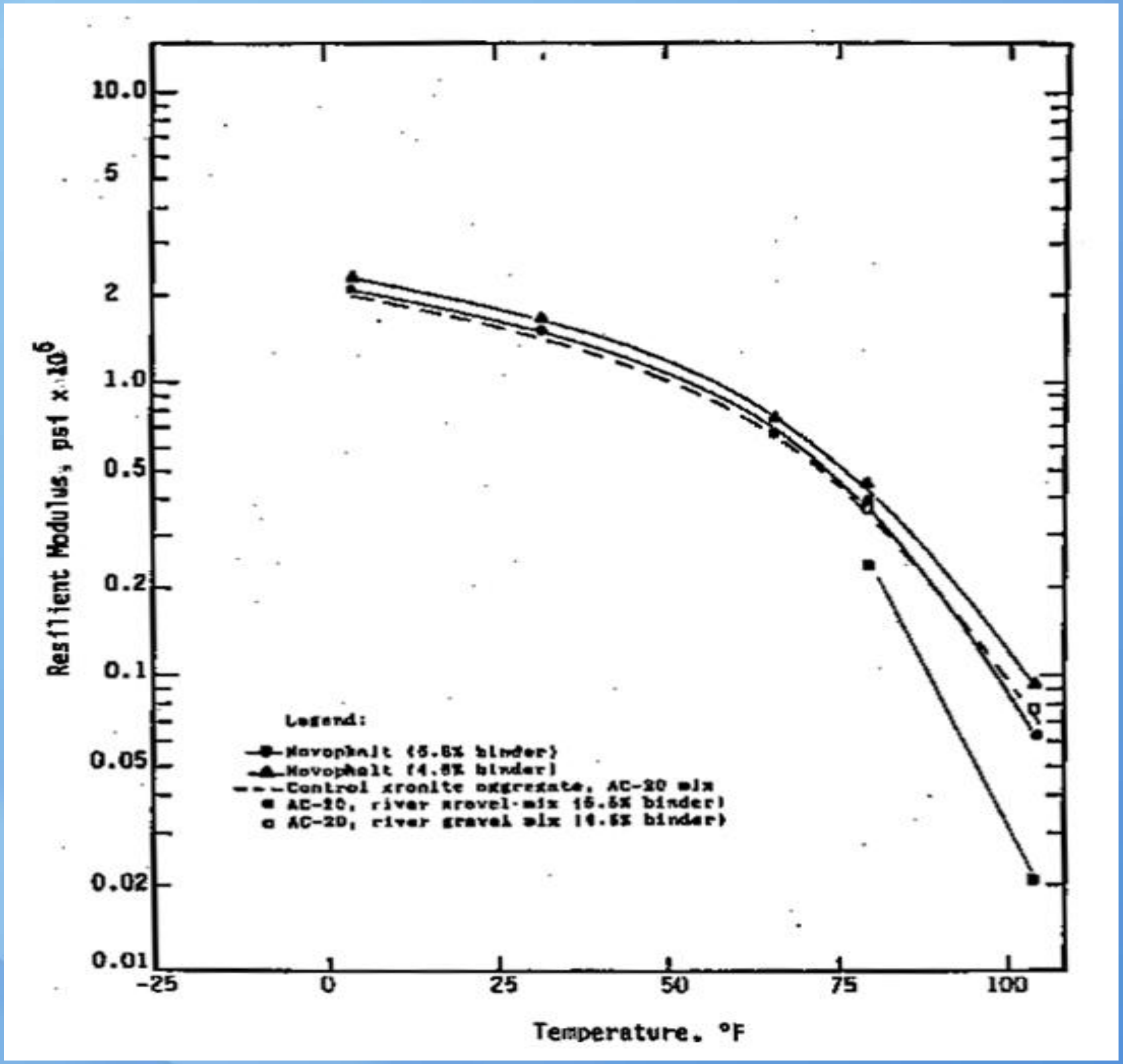
- **Better Moisture Resistance**
- **Better Fatigue Resistance**
- **Better Resistance to Permanent Deformation**
- **Better dynamic Modulus, Creep Resistance, Resilient Modulus, Flexural Modulus**
- **Less Damage to Pavement**
- **Less Rutting**
- **Less Cracking**

NOVOPHALT HOT MIX ASPHALTIC CONCRETE



Resilient Modulus and Thermal Stress VS Temperature

NOVOPHALT HOT MIX ASPHALTIC CONCRETE



Resilient Modulus VS Temperature Relationship

Table 1 – Chemical Composition of Cement and Slag

Chemical Composition	Percentages for Portland Cement	Percentages for Class "C" Fly Ash	Percentages for Ground Granulated Blast Furnace Slag, Grade 120 (GGBFS)
CaO	65	31	42
SiO_2	20	35	38
AL_2O_3	4	17	8
Fe_2O_3	3	6	Trace
MgO	3	5	7
SO_3	3	3.5	--
S	--		1
Na_2O+K_2O	1	1.5	0.4
MnO	--	--	1

When GGBFS is coupled with cement, a synergistic combination is formed. Each product hydrates on its own, forming strength bearing calcium silicate hydrate (CSH). The excess silica from GGBFS and the excess calcium from cement react to form additional strength bearing CSH in the pore spaces of the concrete. This makes a stronger, denser matrix with decreased permeability. The chemical reactions are as follows:

$$\text{Cement} + H_2O = \text{CSH} + Ca(OH)_2$$
$$\text{GGBFS} + H_2O = \text{CSH} + SiO_2$$
$$SiO_2 + Ca(OH)_2 + H_2O = \text{CSH}$$

CEMENT, FLY ASH AND BLAST FURNACE SLAG

Chemical Reactions in Fly Ash Concrete between Cement and Fly Ash

CaO

-Cementitious Materials

MgO

Al_2O_3
SiO_2 -Pozzolanic Materials
Fe_2O_3

$$CaO+MgO+H_2O+Al_2O_3/SiO_2/Fe_2O_3=\text{Cementitious Paste}+Ca(OH)_2$$

$$Ca(OH)_2+Al_2O_3/SiO_2/Fe_2O_3=\text{Cementitious Paste}$$

In concrete using only Portland cement, approximately 35% $Ca(OH)_2$ is formed, which lies dormant. By adding fly ash, the $Ca(OH)_2$ is utilized fully, because it reacts with the pozzolanic materials to form additional cementitious paste.

CEMENT, FLY ASH AND BLAST FURNACE SLAG

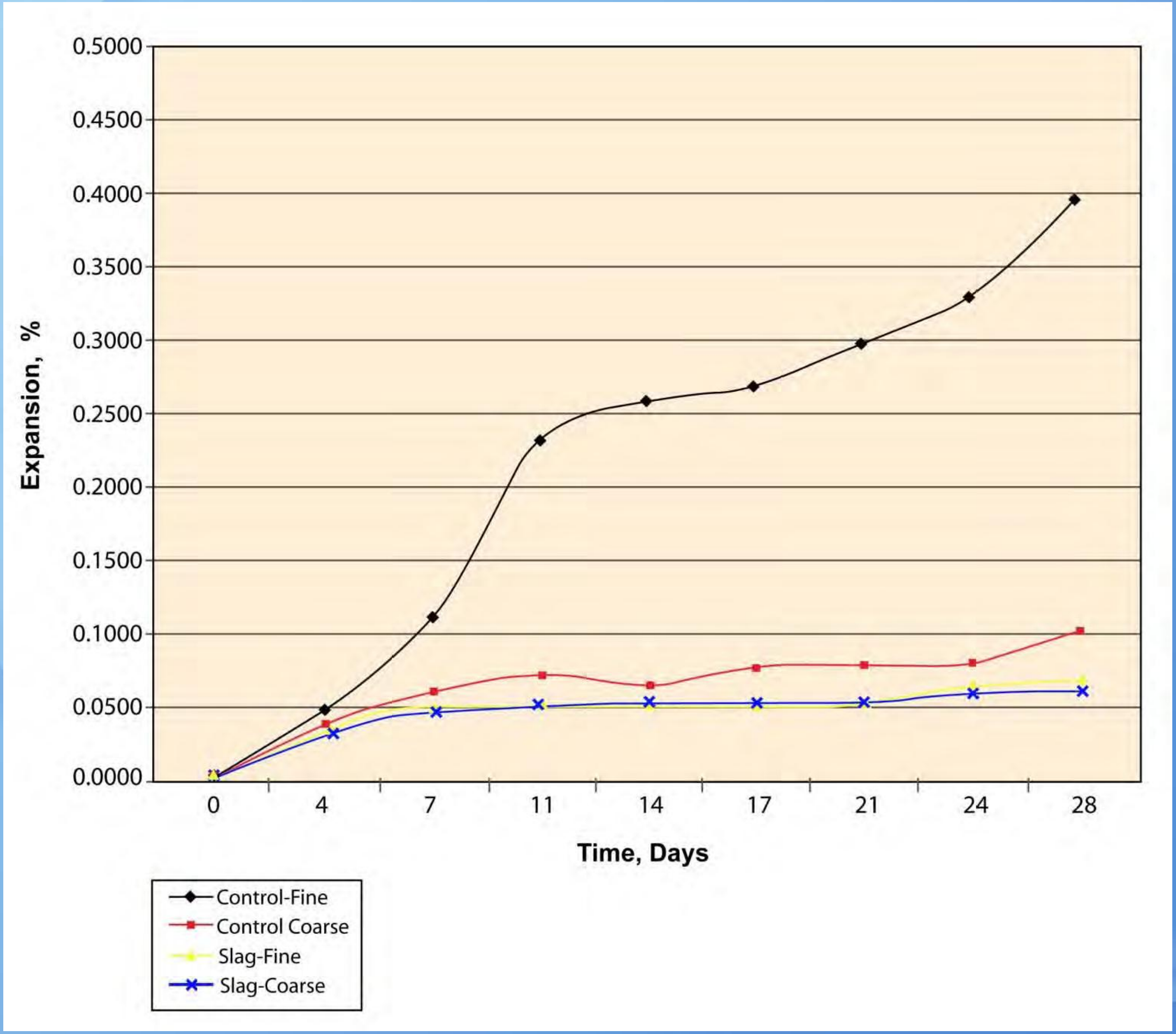
which are not susceptible to alkali silica reaction. Extensive quality assurance and testing requirements were introduced in the concrete pavement specifications to eliminate this hazard, which is becoming more prevalent nowadays.

The concrete mix design was as follows:

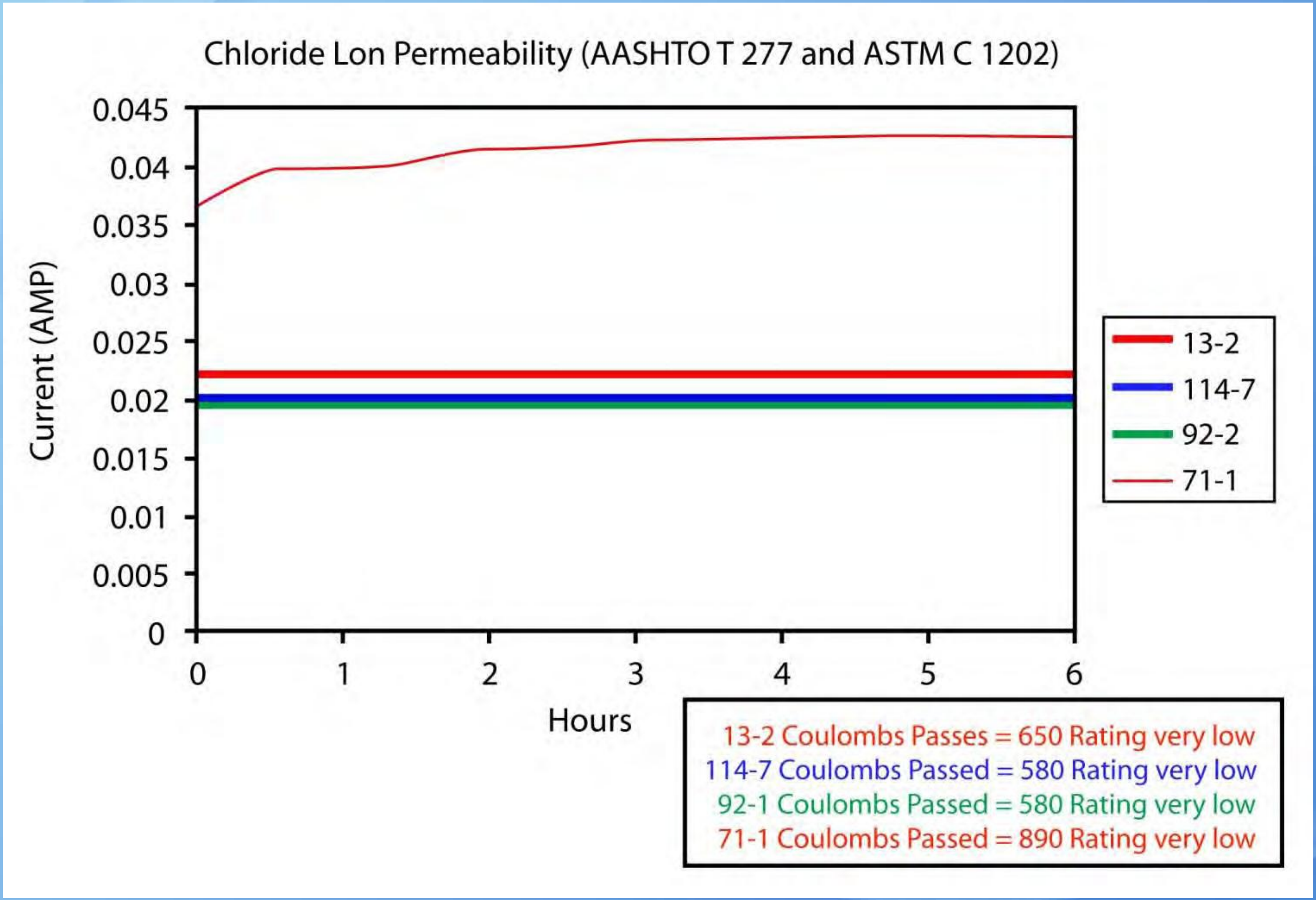
Cement, Type I	270 lbs/C.Y.
Class "F" fly ash	135 lbs/C.Y.
Blast furnace slag, Grade 120	135 lbs/C.Y.
Total cementitious materials	540 lbs/C.Y.
Coarse aggregate (1:5" granite)	1,193 lbs/C.Y.
Fine aggregate (siliceous sand)	1,193 lbs/C.Y.
Water	209 lbs/C.Y.
Water – cementitious materials ratio	0.39
AEA	4.5 ozs/cwt
WRA	22.0 ozs/cwt

Here are the results of the petrographic analysis scanning election microscopic and other tests performed by the Texas Transportation Institute (Dr. Sarkar).

CEMENT, FLY ASH AND BLAST FURNACE SLAG



CEMENT, FLY ASH AND BLAST FURNACE SLAG



CEMENT, FLY ASH AND BLAST FURNACE SLAG

Concrete 90 Day Summary

Runway 8R-26L Reconstruction
Project 491B
Plant: W.W. Webber #2
Mix #2600: 294 lbs Type I Cement, 135 lbs Flyash, & 135 lbs Slag per cu. Yard
Mix #259: 423 lbs Type I Cement, 141 lbs Flyash, & 141 lbs Slag per cu. Yard
Specified Strength: 650 psi at 28 days

Lot #	Date	Mix Number	Slump	Air Content	Flexural Strength, psi									Increase, 7-28 Day		Increase, 28-90 Day	
					7 Day	7 Day	7 day Ave	28 Day	28 Day	28 day Ave	90 Day	90 Day	90 Day Ave	psi	%, 28 day	psi	%, 28 day
Lot 33-1	03/17/04	2600	2 1/2"	4.8%	480	520	500	760	780	770	715	705	710	270	35%	-60	-8%
Lot 33-3	03/17/04	2600	2"	5.0%	470	505	488	725	710	718	775	705	740	230	32%	22.5	3%
Lot 34-1	03/18/04	2600	1 1/2"	4.2%	555	530	543	700	760	730	765	830	798	187.5	26%	67.5	9%
Lot 34-3	03/18/04	2600	2"	4.5%	530	505	518	785	660	723	895	860	878	205	28%	155	21%
Lot 34-5	03/18/04	2600	1 1/2"	4.5%	525	510	518	730	705	718	865	800	833	200	28%	115	16%
Lot 35-1	03/19/04	2600	1 1/2"	4.5%	470	460	465	695	645	670	620	630	625	205	31%	-45	-7%
Lot 35-3	03/19/04	2600	2"	4.8%	520	515	518	750	660	705	825	790	808	187.5	27%	102.5	15%
Lot 36-1	03/19/04	2600	2"	4.3%	535	480	508	770	705	738	840	760	800	230	31%	62.5	8%
Lot 36-4	03/19/04	259	5"	6.5%	490	485	488	545	605	575	715	755	735	87.5	15%	160	28%
Lot 37-1	03/20/04	2600	2 1/2"	4.3%	500	490	495	690	705	698	830	785	808	202.5	29%	110	16%
Lot 37-3	03/20/04	2600	1 1/2"	4.5%	440	540	490	715	755	735	885	885	885	245	33%	150	20%
Lot 38-1	03/20/04	2600	1 1/2"	4.8%	530	540	535	700	750	725	860	840	850	190	26%	125	17%
Lot 38-3	03/20/04	2600	1 1/2"	4.3%	505	475	490	755	705	730	900	940	920	240	33%	190	26%
Lot 40-1	03/25/04	2600	1 1/2"	4.0%	480	450	465	645	615	630	820	820	820	165	26%	190	30%
Lot 40-2	03/25/04	2600	1 3/4"	4.2%	505	505	505	675	640	658	780	870	825	152.5	23%	167.5	25%
Lot 40-3	03/25/04	2600	1"	4.0%	560	530	545	635	630	633	885	870	878	87.5	14%	245	39%
Lot 40-4	03/25/04	2600	1 1/2"	4.0%	590	610	600	665	650	658	840	885	863	57.5	9%	205	31%
Lot 41-1	03/26/04	2600	1 1/4"	3.8%	435	385	410	690	765	728	700	800	750	317.5	44%	22.5	3%
Lot 41-3	03/26/04	2600	2"	3.4%	400	435	418	770	800	785	870	780	825	367.5	47%	40	5%

Concrete Statistics

			7 Day	28 Day	90 Day
Average Slump:	1.9"	Average Flexural Strength:	500 psi	701 psi	808 psi
Average Air Content:	4.4%	S.D., Flexural Strength:	43 psi	52 psi	71 psi
		Minimum Beam Strength:	385 psi	545 psi	620 psi
		Maximum Beam Strength:	610 psi	800 psi	940 psi

Average Increase, 7 day to 28 dayi: 201 psi
Average Increase, 7 day to 28 day, % of 28 day: 28%
Average Increase, 28 day to 90 day: 107 psi

Fig. 6: Final Pavement Cross Section for Taxiway "WP"

Soil Stabilization

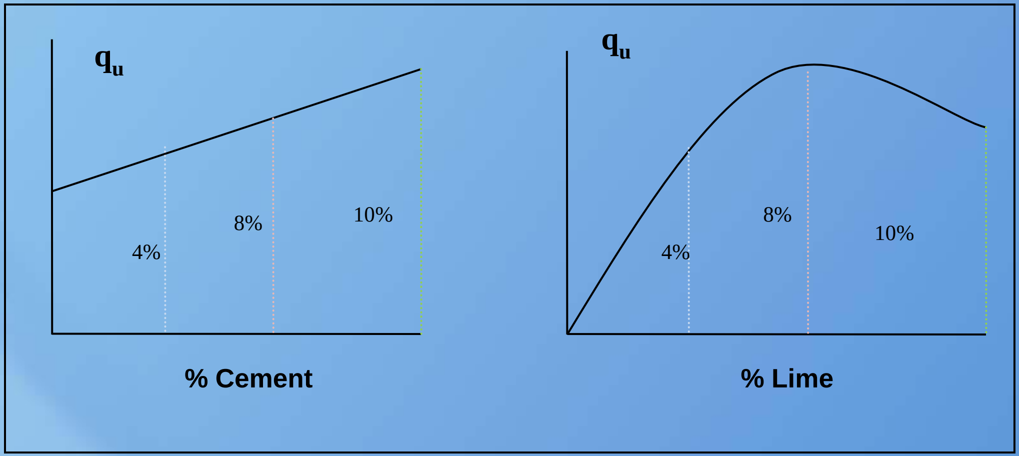
High plasticity soils are less desirable in the pavement sub-grade. Because of their swelling and expansive nature, proper compaction for the preparation of sub-grade is difficult to achieve. Recent practice and research have shown that Millions of dollars can be saved by soil stabilization rather than cutting and replacing the unstable soil for sub-grade preparation of pavement.

Soil Stabilization Techniques Adopted at HAS

- Lime-fly Ash Slurry
- Cement Fly Ash Slurry
- Lime-cement Fly Ash (Lcf) Crushed Concrete Base
- Cement/ Fly Ash Crushed Concrete Base
- Blend Of Fly Ash And Bottom Ash.

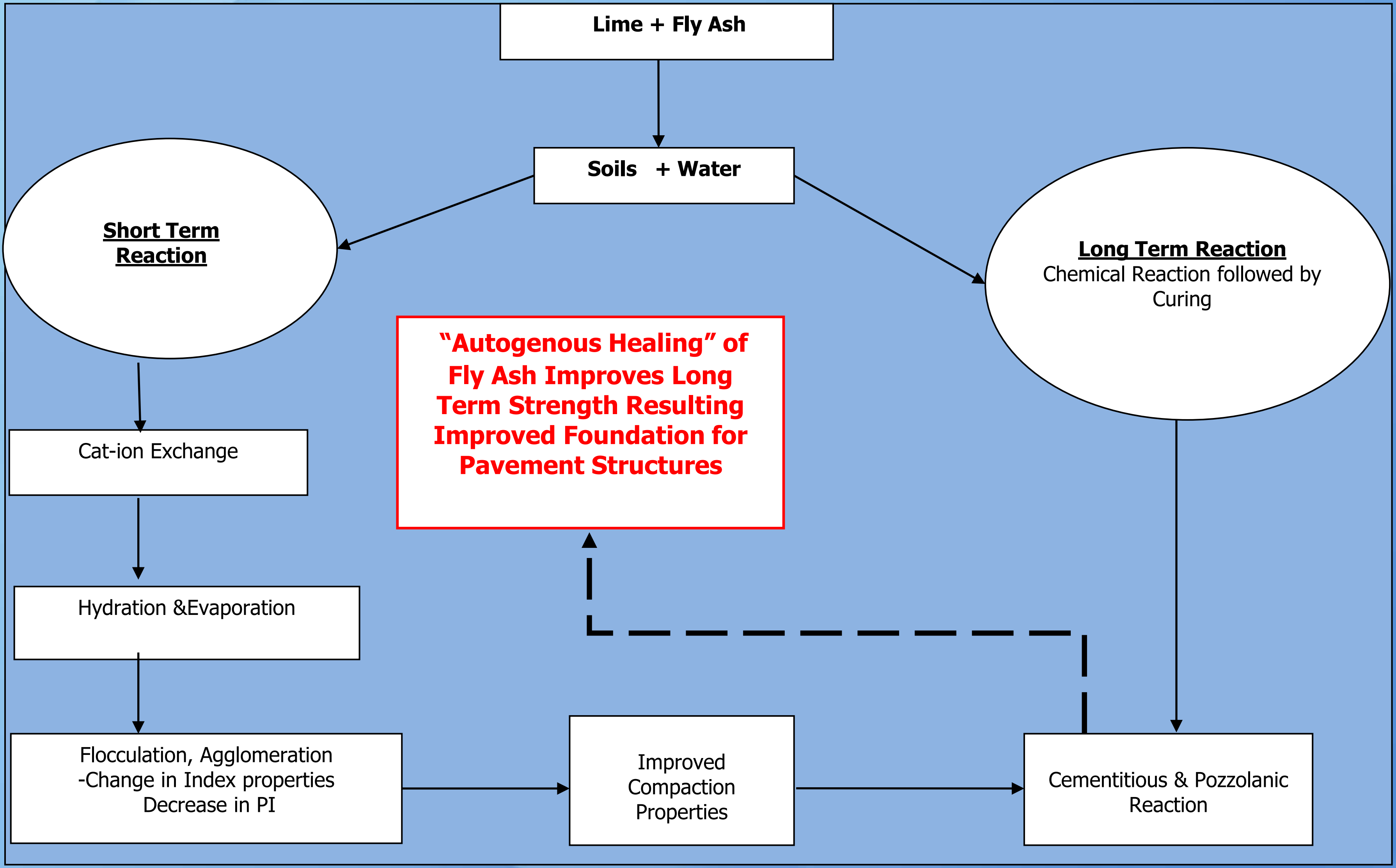
Lime Fly-ash Stabilization

- High Plasticity Soils are Undesirable for Pavement
- Lime Fly Ash Stabilization gives the Economical, Structurally and Environmentally Sound Pavement Design



General Strength Response Behavior in Lime and Cement

Lime fly-ash Stabilization Model



A Schematic Diagram for Lime Fly ash Stabilization Model

Lime fly-ash Stabilization Research

R/W 4-22 Hobby Airport (2011)

Objective:

- To Evaluate the Change In Index Properties of Lime Fly-ash Stabilized soils.
- To Study the Compaction Behavior of Stabilized Soils.
- To Study the Development of Compressive Strength with the Stabilization.
- To Establish the Relationship Between Compressive Strength and PI Of Virgin Soil.

LIME-FLY ASH

- The addition of lime to clay soils initiates two reactions:
- Cat-ion exchange and Flocculation-Agglomeration Reaction – Rapid reaction- can produce immediate changes in soil plasticity, uncured strength and load deformation properties.
- Pozzolanic Reaction –long term reaction. This results in the formation of various cementing agents which increases strength and durability.
- Pzzolanic Reaction is time dependent reaction, therefore strength development is gradual but continuous for long period of time and some instances it can take several years.

LIME-FLY ASH

- In Houston, the great majority of the soil is montmorillionite clays with high organic, which are non reactive with lime. The addition of lime only lowers the plasticity index of the soils, while barely increases the compressive strength by 20-50 psi in twenty eight (28) days.
- The addition of Fly ash & lime in such soils helps to achieve extensive pozzolanic strength development in a long run.
- Lime-Fly ash used for the soil stabilization for Runway 4-22 at Hobby Airport in 1988 is probably the first runway in the world to use this technique.

ELLINGTON FIELD AIRPORT - 90-110G - RESULTS OF 90-DAY BREAKS

Table 1: Compressive Strength Results

DRY DESCRIPTION	LL	PI	DENSITY (pcf)	q (kPa)	q (psi)
UNMODIFIED CLAY	55	38			
UNMODIFIED SANDY CLAY	45	29			
CLAY W/7% LIME		12			
CLAY W/ 4% LIME & 10% FLYASH		NP	97.8	3.50	50.83
		NP	97.6	4.20	60.56
CLAY W/ 4% LIME & 12% FLYASH		NP	95.1	12.18	174.40
		NP	94.2	12.39	177.22
SANDY CLAY W/ 4% LIME & 10% FLYASH		NP	100.4	19.32	276.11
		NP	100.6	16.38	234.44
SANDY CLAY W/ 4% LIME & 12% FLYASH		NP	103.2	20.02	286.39
		NP	101.0	28.21	403.61

Samples made on: September 29, 1990
Samples tested on: January 4,1991

The following Standards were used in performing the test:

1. Sample preparation — ASTM D 558 (Method A)
2. Compaction — ASTM D 559 (Method A)
3. Curing — ASTM D 1632
4. Compressive strength — ASTM D 1633 (Method A)

Table 4: Cement-Flyash Stabilized Subgrade Summary
Runway 8r-26l Reconstruction
For 4% Cement And 10% Flyash

				7 Day					28 Day					90 Day				
Date	Report #	Moisture Content	Ave. Dens. pcf	Cyl 1 psi	Cyl2 psi	Average	Difference psi	Difference %	Cyl 1 psi	Cyl 2 psi	Average	Difference psi	Difference %	Cyl 1 psi	Cyl 2 psi	Average	Difference psi	Difference %
12/30/2003	38	23.3%	99.5	155	160	157.5	5	3.2%	190	195	192.5	5	2.6%	200	200	200	0	0.0%
12/30/2003	40	21.0%	101.1	50	50	50	0	0.0%	55	50	52.5	5	9.5%	40	30	35	10	28.6%
12/30/2004	42	16.0%	104.5	425	420	422.5	5	1.2%	565	570	567.5	5	0.9%	725	770	747.5	45	6.0%
1/10/2004	94	15.0%	110.5	395	400	397.5	5	1.3%	680	675	677.5	5	0.7%	1210	1215	1212.5	5	0.4%
1/102004	96	24.0%	95.5	425	440	432.5	15	3.5%	790	790	790	0	0.0%	1130	1235	1182.5	105	8.9%
1/14/2004	136	16.4%	109.9	55	55	55	0	0.0%	60	55	57.5	5	8.7%	65	65	65	0	0.0%
1/20/2004	166	14.8%	110.4	170	155	162.5	15	9.2%	315	325	320	10	3.1%	510	510	510	0	0.0%
1/20/2004	169	15.2%	110.2	180	170	175	10	5.7%	270	280	275	10	3.6%	365	385	375	20	5.3%
1/23/2004	190	16.7%	108.9	215	225	220	10	4.5%	390	390	390	0	0.0%	460	460	460	0	0.0%
1/23/2004	192	13.5%	113.6	410	410	410	0	0.0%	650	640	645	10	1.6%	885	780	832.5	105	12.6%
3/8/2004	587	19.7%	96.2	395	355	375	40	10.7%	595	580	587.5	15	2.6%	880	840	860	40	4.7%
3/8/2004	588	17.6%	105	115	110	112.5	5	4.4%	355	365	360	10	2.8%	725	700	712.5	25	3.5%
3/8/2004	589	15.1%	107.4	330	385	357.5	55	15.4%	680	695	687.5	15	2.2%	1000	885	942.5	115	12.2%
3/24/2004	756	14.8%	111.5	150	165	157.5	15	9.5%	165	170	167.5	5	3.0%	250	275	262.5	25	9.5%
3/24/2004	759	16.7%	109	105	105	105	0	0.0%	105	110	107.5	5	4.7%	125	115	120	10	8.3%
3/28/2004	803	19.4%	105.1	40	40	40	0	0.0%	35	35	35	0	0.0%	55	50	52.5	5	9.5%
3/28/2004	806	20.5%	103.7	45	45	45	0	0.0%	40	40	40	0	0.0%	68	75	70	10	14.3%
3/28/2004	809	13.4%	98.5	70	70	70	0	0.0%	80	90	85	10	11.8%	250	265	251.5	15	5.8%
3/30/2004	826	15.5%	112.3	445	460	452.5	15	3.3%	780	760	770	20	2.6%	1190	1165	1177.5	25	2.1%
3/31/2004	837	13.3%	102.2	240	250	245	10	4.1%	355	345	350	10	2.9%	475	495	485	20	4.1%
3/31/2004	840	12.8%	104.3	345	335	340	10	2.9%	435	445	440	10	2.3%	805	706	755.5	99	13.1%
3/31/2004	843	16.5%	106.8	175	170	172.5	5	2.9%	325	345	335	20	6.0%	645	730	687.5	85	12.4%
4/16/2004	968	18.9%	104.5	280	290	285	10	3.5%	430	445	437.5	15	3.4%	595	565	580	30	5.2%
4/16/2004	970	19.1%	104.4	345	350	347.5	5	1.4%	520	510	515	10	1.9%	735	710	722.5	25	3.5%
4/16/2004	973	20.5%	102.4	320	310	315	10	3.2%	380	360	370	20	5.4%	470	460	465	10	2.2%
4/19/2004	991	21.4%	100	160	155	157.5	5	3.2%	250	255	252.5	5	2.0%	335	330	332.5	5	1.5%
4/19/2004	993	14.1%	107.7	580	575	577.5	5	0.9%	660	690	675	30	4.4%	815	805	810	10	1.2%
4/19/2004	996	13.8%	112.1	360	375	367.5	15	4.1%	605	590	597.5	15	2.5%	725	735	730	10	1.4%
4/30/2004	1068	16.4%	105.1	760	755	757.5	5	0.7%	1475	1310	1392.5	165	11.8%	1860	1835	1847.5	25	1.4%
4/30/2004	1069	18.1%	104.7	480	515	497.5	35	7.0%	955	825	890	130	14.6%	1310	1440	1375	130	9.5%
4/30/2004	1070	18.2%	105	145	140	142.5	5	3.5%	275	245	260	30	11.5%	315	300	307.5	15	4.9%
5/3/2004	1082	21.4%	853	575	570	572.5	5	0.9%	720	750	735	30	4.1%	730	760	745	30	4.0%
5/3/2004	1084	15.1%	102.1	275	260	267.5	15	5.6%	400	400	400	0	0.0%	450	460	455	10	2.2%
5/3/2004	1085	23.3%	95.6	60	60	60	0	0.0%	85	80	82.5	5	6.1%	95	95	95	0	0.0%
5/5/2004	1099	14.2%	98.7	595	535	565	60	10.6%	1035	855	945	180	19.0%	1445	1565	1505	120	8.0%
5/5/2004	1100	14.9%	101.2	425	425	425	0	0.0%	580	565	572.5	15	2.6%	730	675	702.5	55	7.8%

Strength Statistics

	Moisture Content	Density pcf.
Average	17.2%	104.1
St. Dev.	3.1%	5.8
Minimum	12.8%	85
Maximum	24.0%	114

7 Day		28 Day		90 Day	
Avg. Compressive Strength, psi:	286	Avg. Compressive Strength, psi	446	Avg. Compressive Strength, psi	630
S.D. Compressive Strength, psi	180.9	S.D. Compressive Strength, psi	303.4	S.D. Compressive Strength, psi	437.0
Minimum Strength, psi	40	Minimum Strength, psi	35	Minimum Strength, psi	30
Maximum Strength, psi	760	Maximum Strength, psi	1475	Maximum Strength, psi	1860
Average Within Set Variation, psi	11.0	Average Within Set Variation, psi	22.9	Average Within Set Variation, psi	34.4
Number of sets:	36	Number of sets:	36	Number of sets:	36
Average compressive strength, 2000 kPa		Average compressive strength, 3120 kPa		Average compressive strength, 4400 kPa	

Lime fly-ash Stabilization

Sample No.	Sample Description	% Finer than #200 Sieve	LL	PL	PI	Max Dry Density Pcf	Optimum Moisture %
1	Dark Gray Fat clay w/sand	85	63	25	38	97.5	22.4
2	Dark Gray Fat clay w/sand	85	68	25	43	99.9	22
3	Dark Gray Fat clay w/sand	84	70	26	44	96.8	23.1
4	Dark Gray Fat clay w/sand	85	66	24	42	97.8	23.4
5	Light Gray Reddish Brown Lean Clay w/sand	76	40	19	21	106	18.4
6	Reddish Brown Lean Clay w/sand	75	40	18	22	110	16.2
7	Light Gray Reddish Brown Lean Clay w/sand	76	40	18	22	101.1	21.2
8	Reddish Brown Lean Clay w/sand	75	46	20	26	109.9	16.8

Soil Sampling/ Test Results Runway 4-22 Hobby Airport, 2011

LIME-FLY ASH

Sample No.	Soil Description	PI of Virgin Soils	PI of Stabilized Soils	% Compaction	Avg. Compressive Strength, psi		
					7 Days	28 Days	90 Days
1	Dark Gray Fat Clay w/Sand	38	11	95	285	495	635
3	Dark Gray Fat Clay w/Sand	44	12	99	355	473	525
5	Light Gray Reddish Brown Lean Clay w/Sand	24	9	98	428	483	655
8	Reddish Brown Lean Clay w/Sand	26	11	100	450	615	723

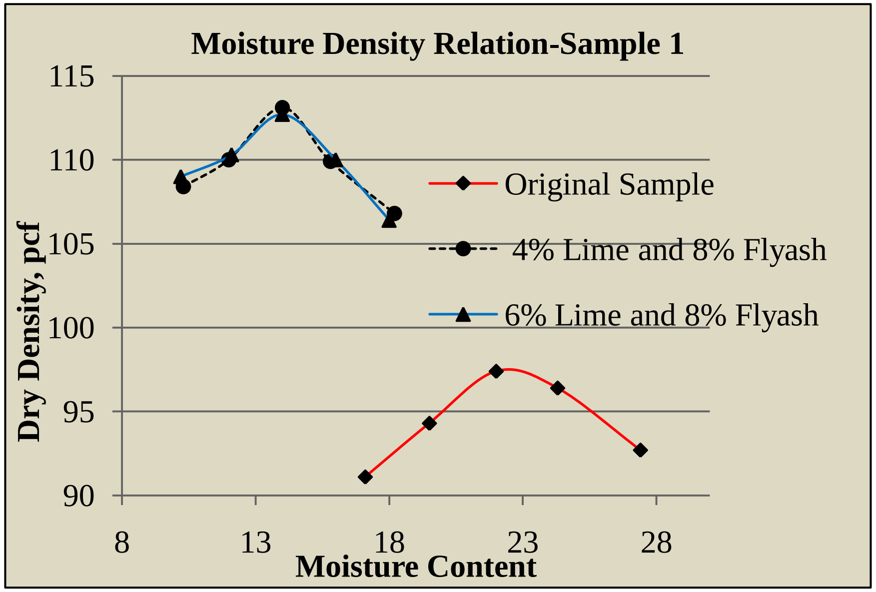
4% lime and 8% of Fly ash: 90 Days Compressive Strength, 2011

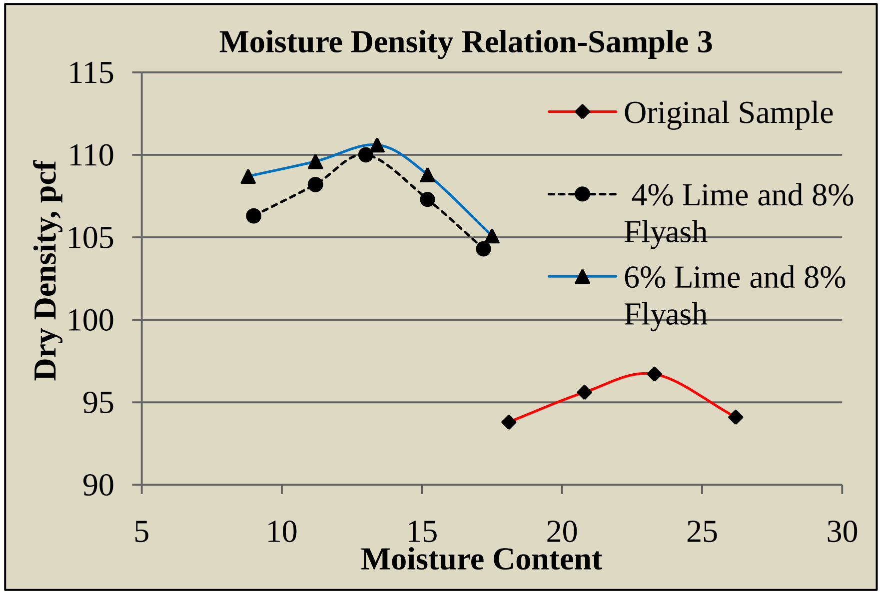
LIME-FLY ASH: Hobby Airport

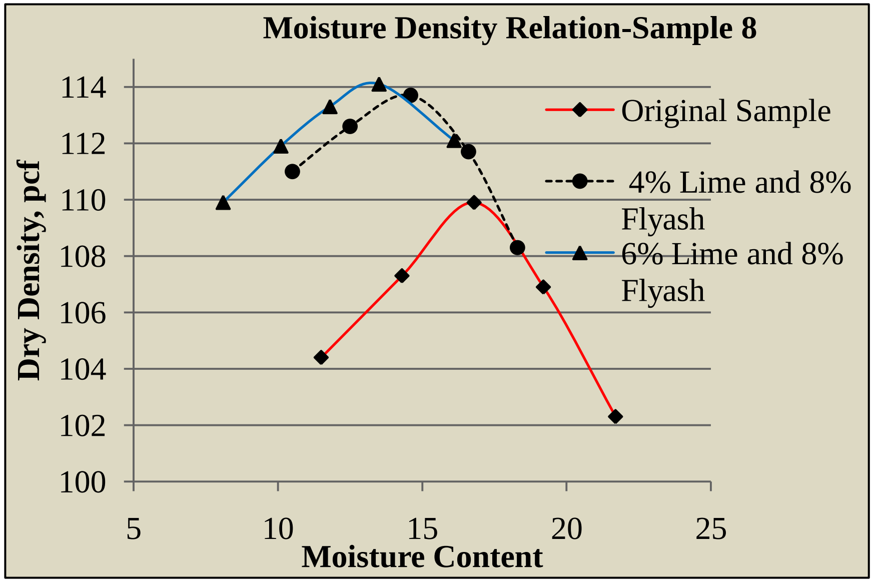
Sample No.	Soil Description	PI of Virgin Soils	PI of Stabilized Soils	% Compaction	Avg. Compressive Strength, psi		
					7 Days	28 Days	90 Days
1	Dark Gray Fat Clay w/Sand	38	9	95	408	465	550
3	Dark Gray Fat Clay w/Sand	44	9	97	400	568	720
5	Light Gray Reddish Brown Lean Clay w/Sand	24	6	98	390	493	678
8	Reddish Brown Lean Clay w/Sand	26	9	98	453	523	675

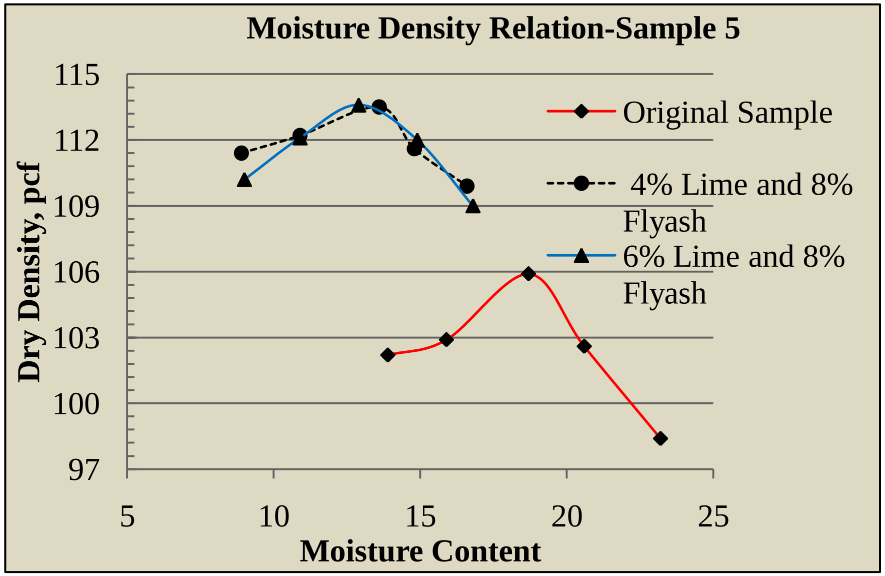
6% lime and 8% of Fly ash: 90 Days Compressive Strength, 2011

Moisture Density Relationship (Hobby Airport, 2011)



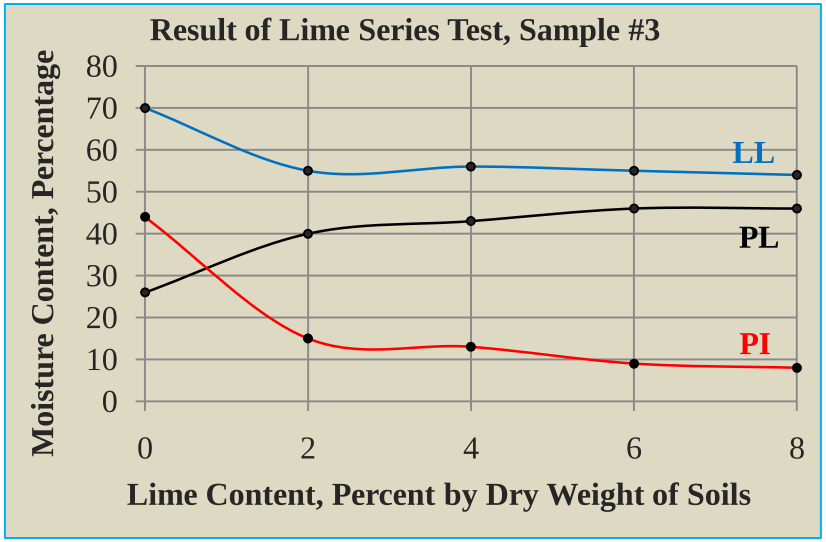


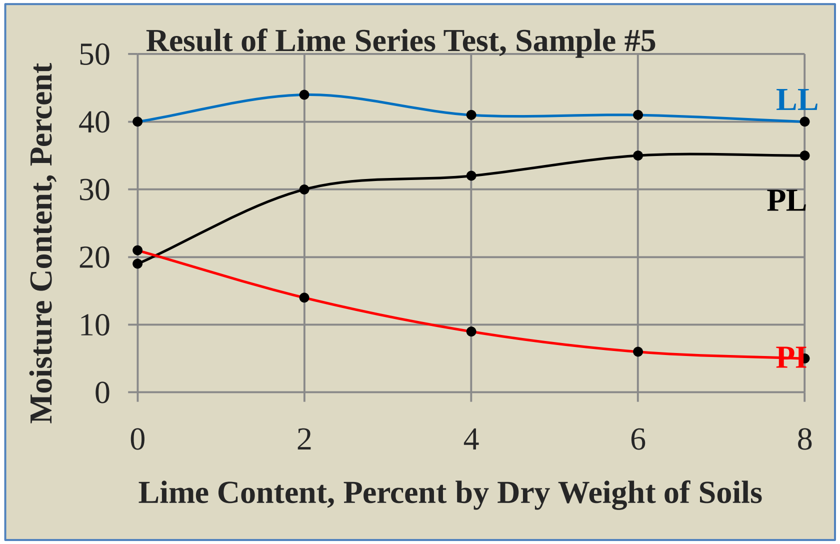


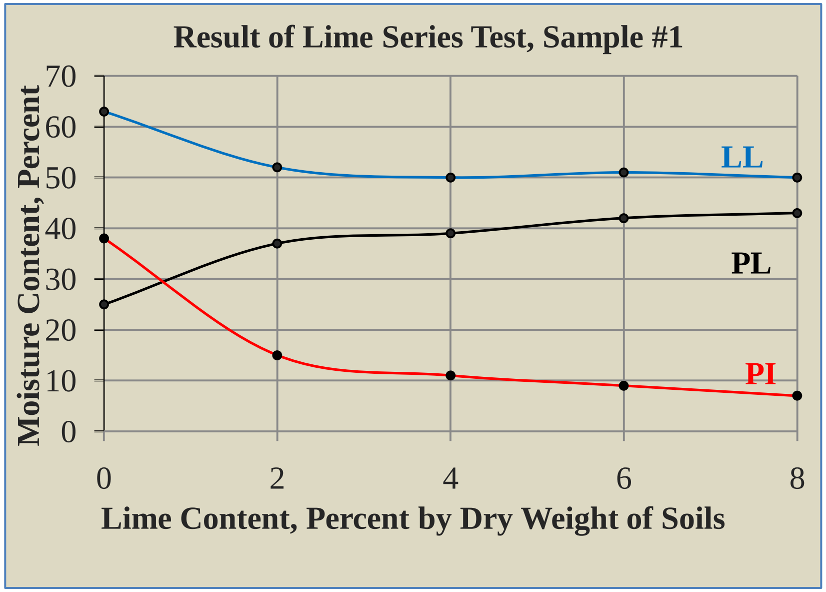


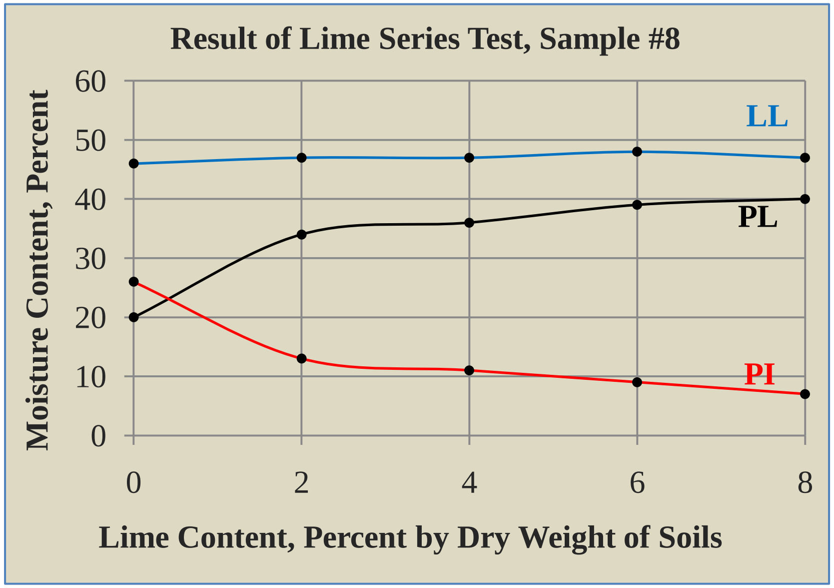
Lime fly-ash Stabilization

Lime Fixation Test





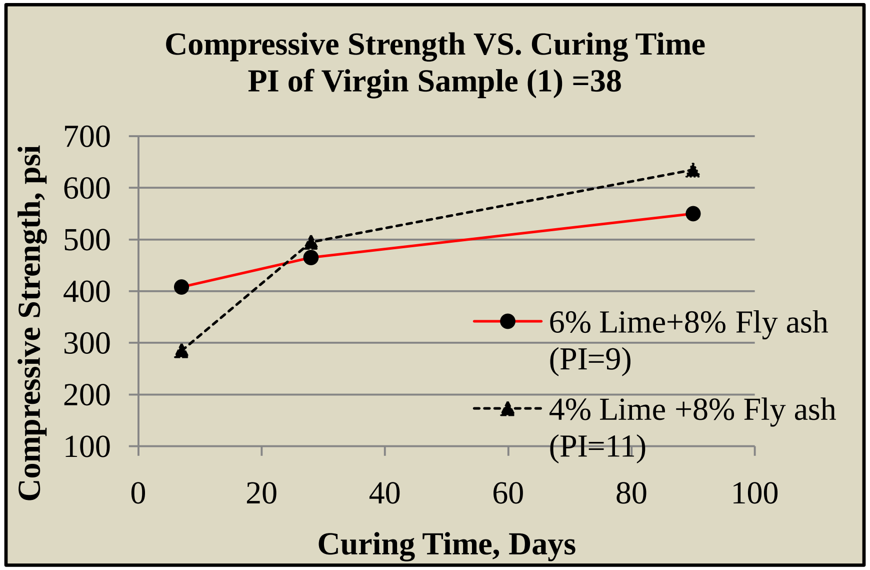


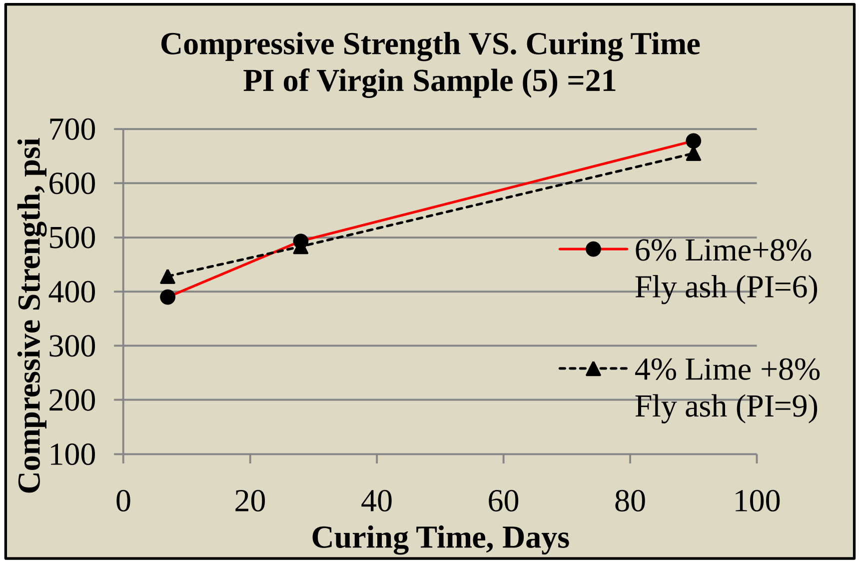


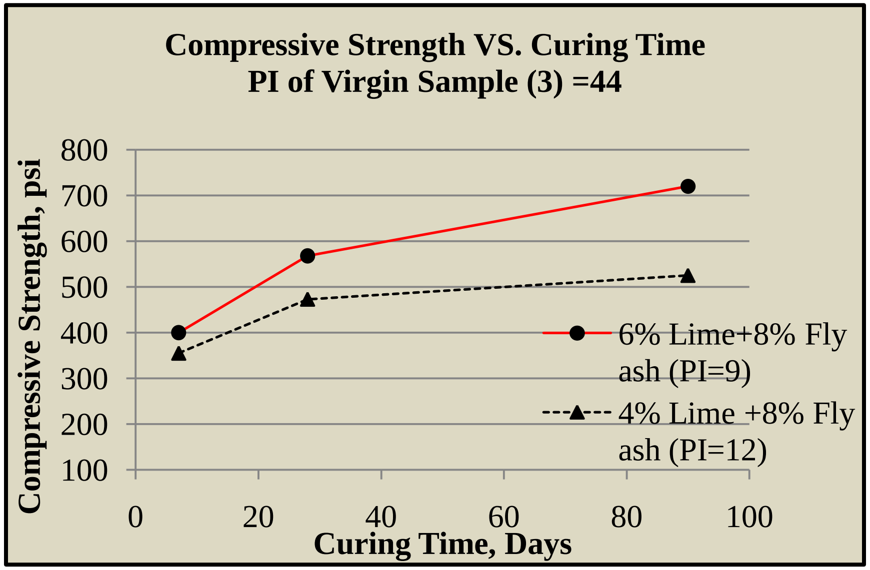
Plastic Limit Is The Indication Of Lime Fixation Test

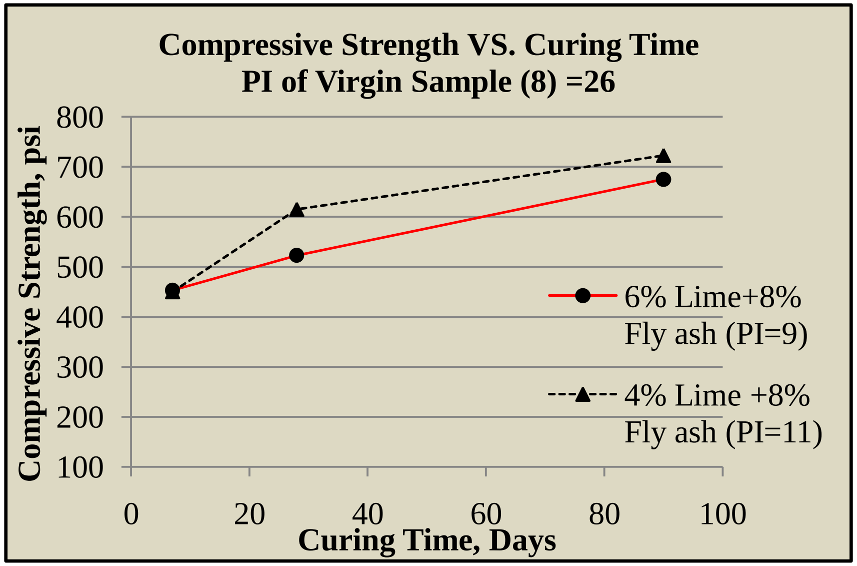
Lime fly-ash Stabilization

Compressive Strength

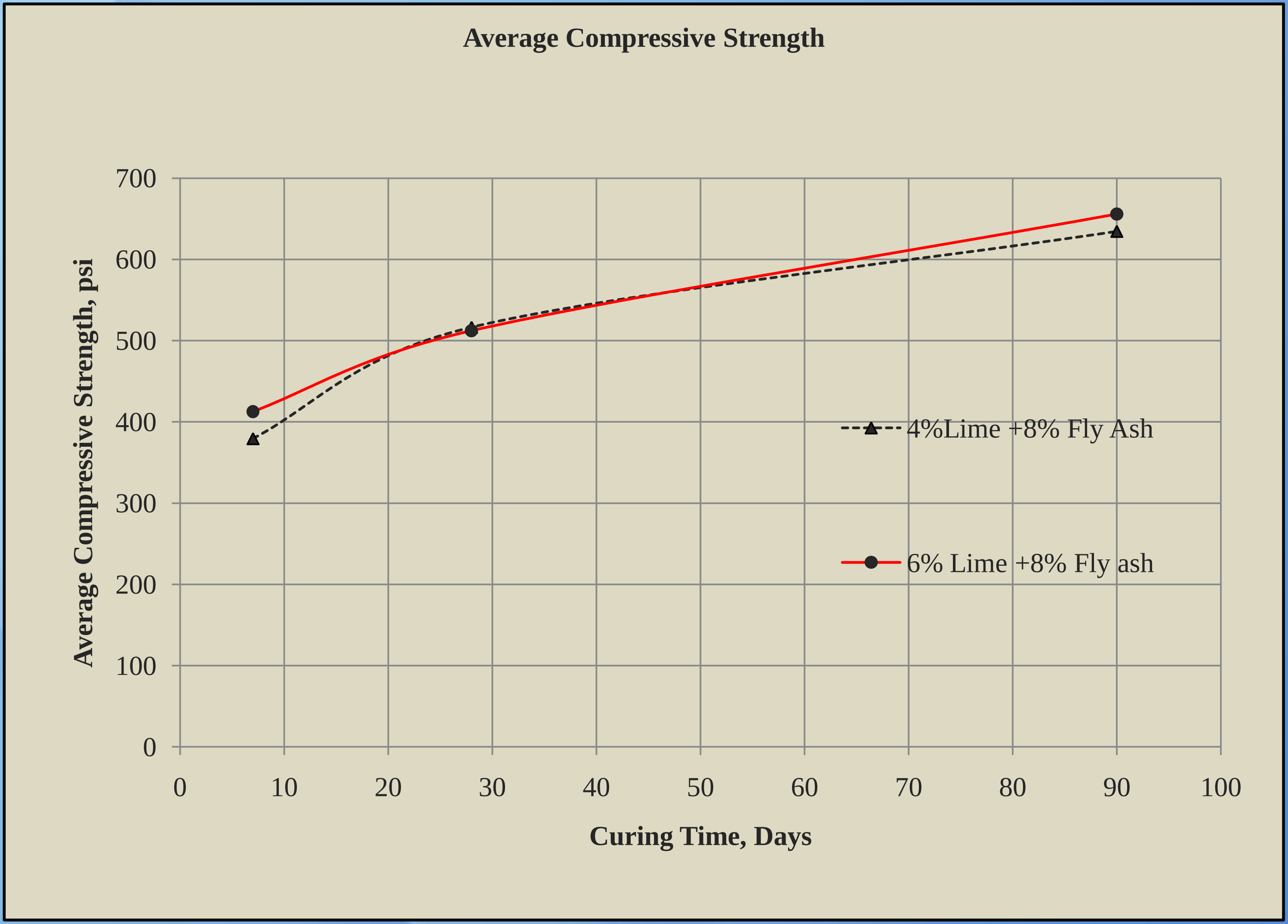






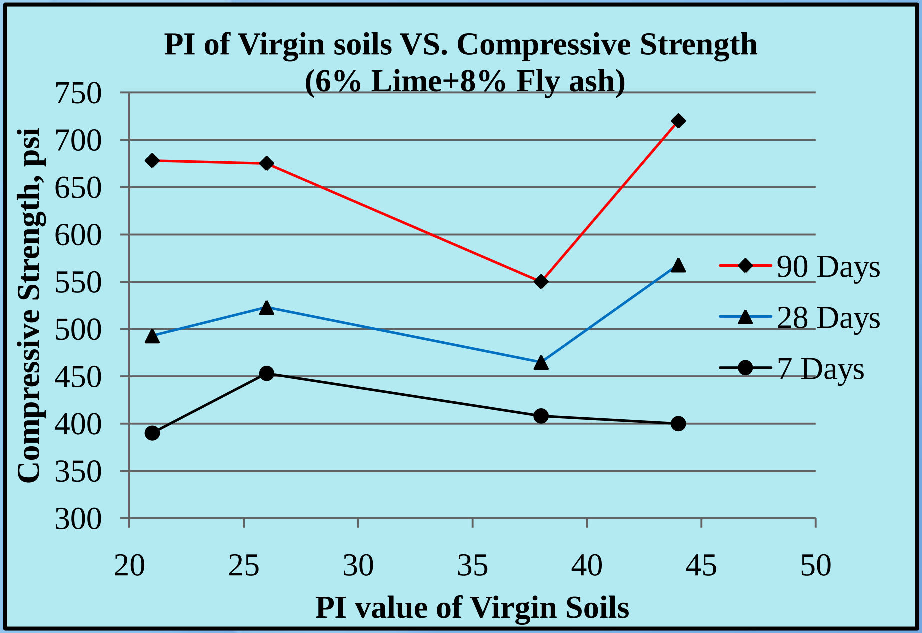


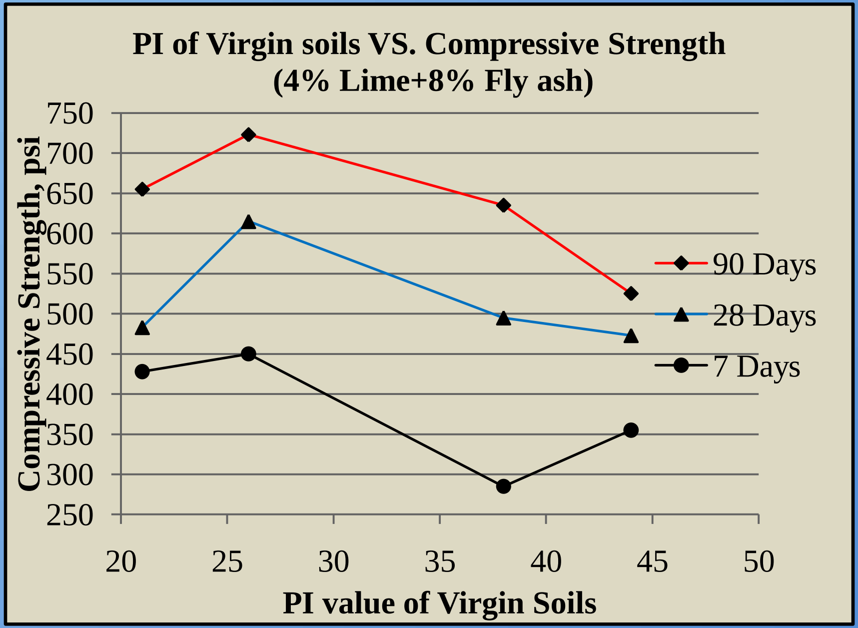
Lime fly-ash Stabilization



Average Compressive Strength

Lime fly-ash Stabilization

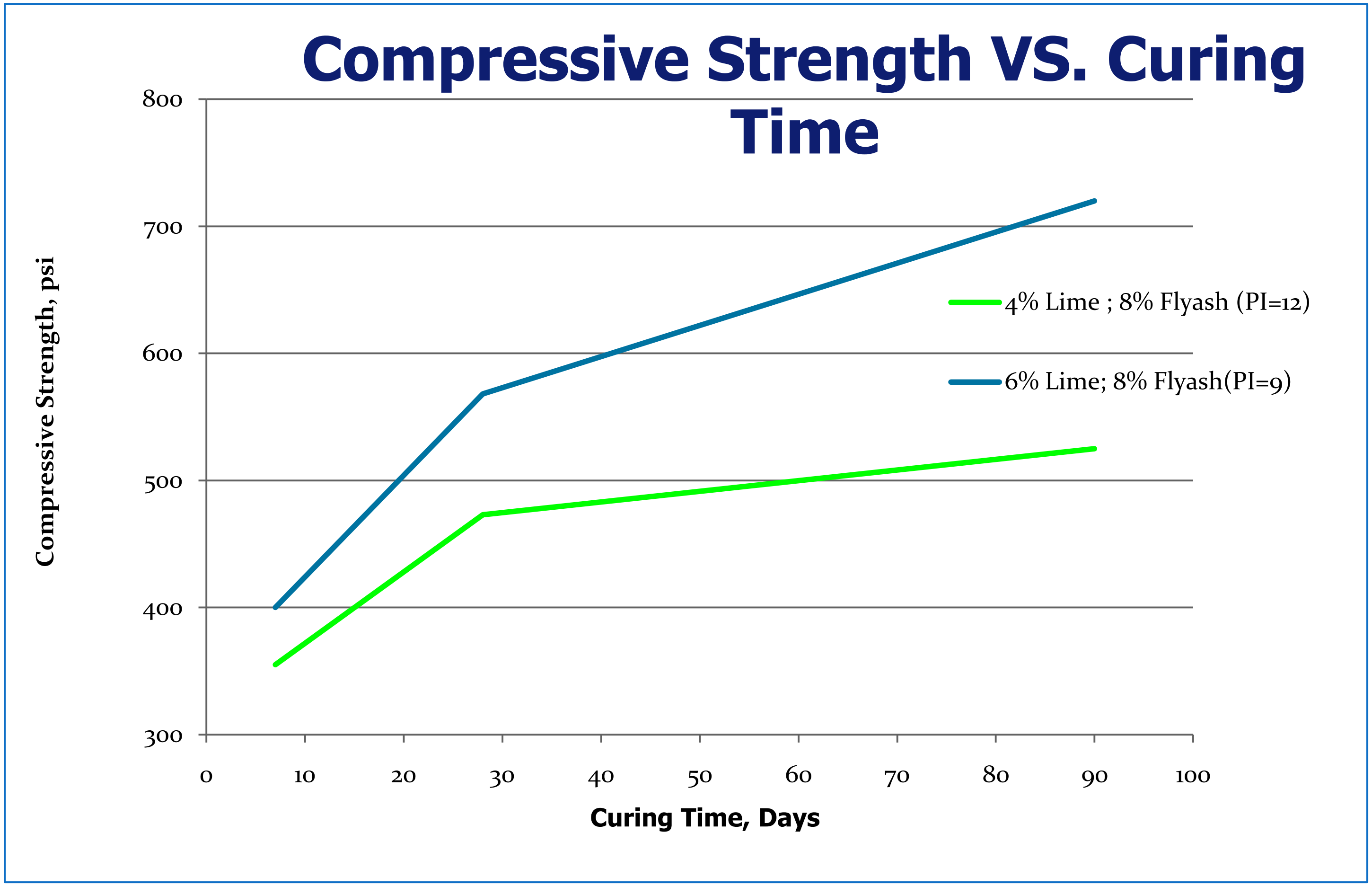




Relationship Between PI VS. Compressive Strength

(Hobby Airport, 2011)

LIME-FLY ASH: (PI of Virgin Soils=44)



6% Lime and 8% of Fly ash Combination Resulted Average Highest Compressive Strength @ 90 Days

LIME-CEMENT FLY ASH (LCF) CRUSHED CONCRETE

LIME-CEMENT-FLYASH BASE COURSE

- LCF Technology developed by Nai Yang
- Pozzolanic base stabilization
- 4 Airports used LCF base stabilization
  - Newark International Airport 1969
  - Portland International Airport 1974
  - Zurich, Switzerland, International Airport 1979
  - Bush Intercontinental Airport 1986

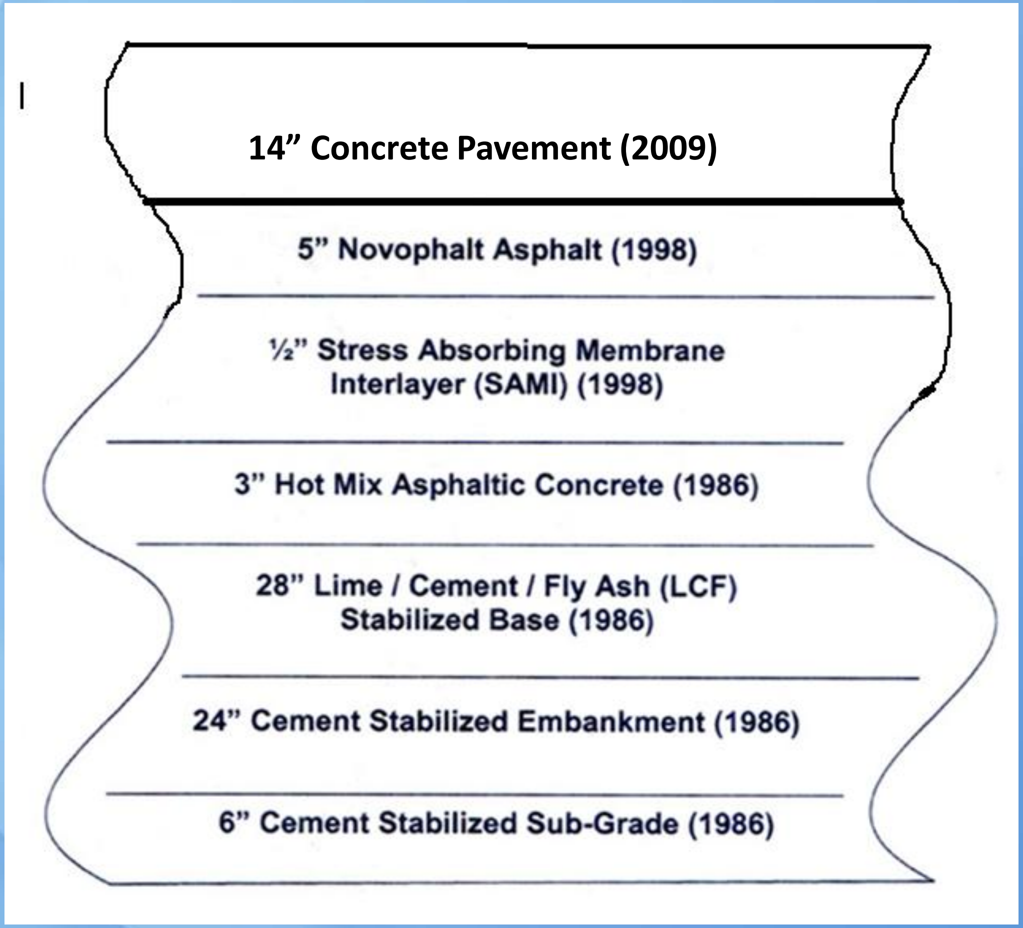
RUNWAY 9-27 LCF PAVEMENT
GEORGE BUSH INTERCONTINENTAL AIRPORT – HOUSTON

LIME-CEMENT FLY ASH (LCF)

LCF material mix proportions by weight: for construction

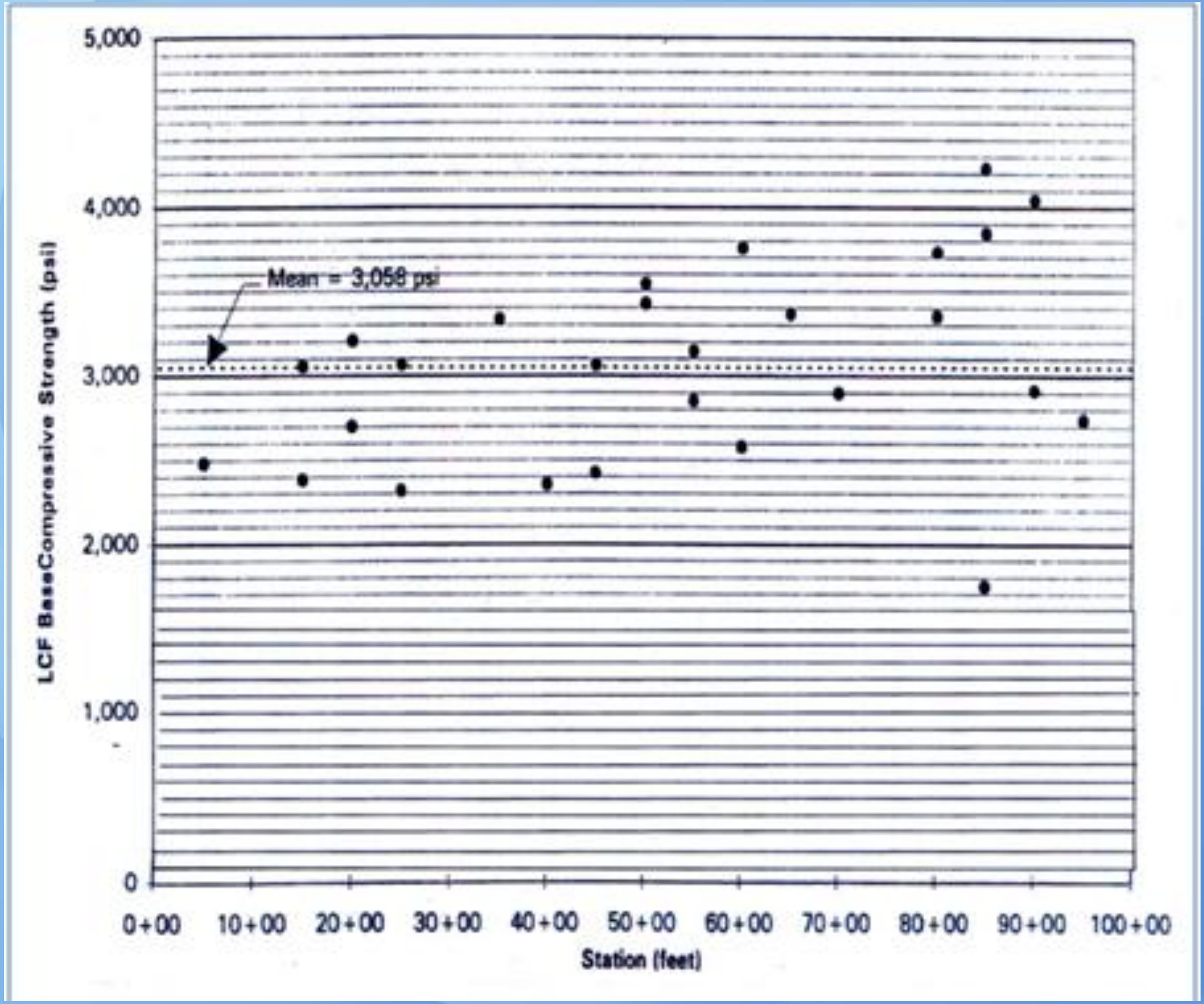
Sand/gravel	73.5%
Bank Sand	12.5%
Lime	4.0%
Cement	0.5%
Fly Ash	9.5%

LCF Stabilized Base - Runway 9-27



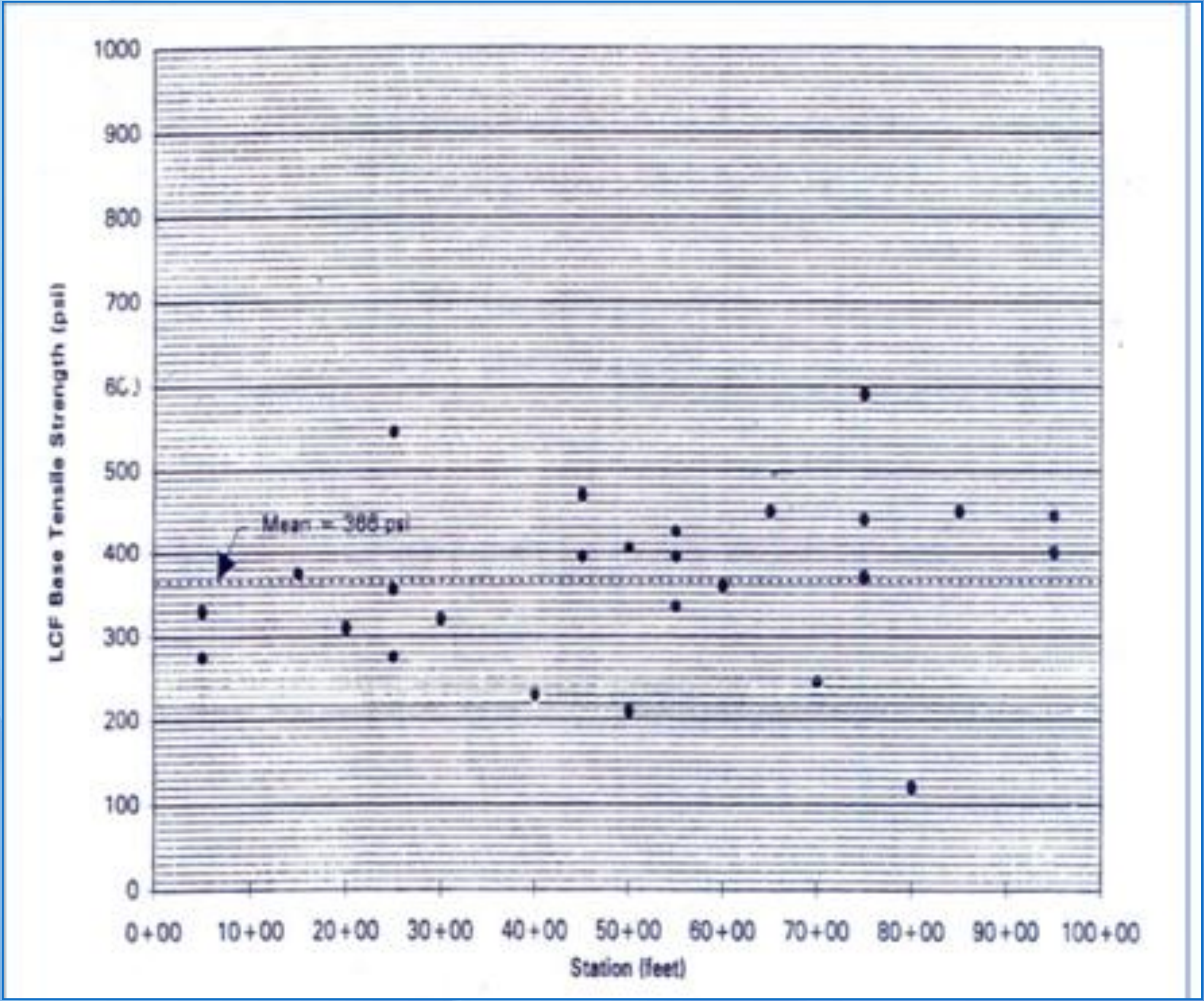
Pavement Cross-Section Runway 9-27

LIME-CEMENT FLY ASH (LCF)



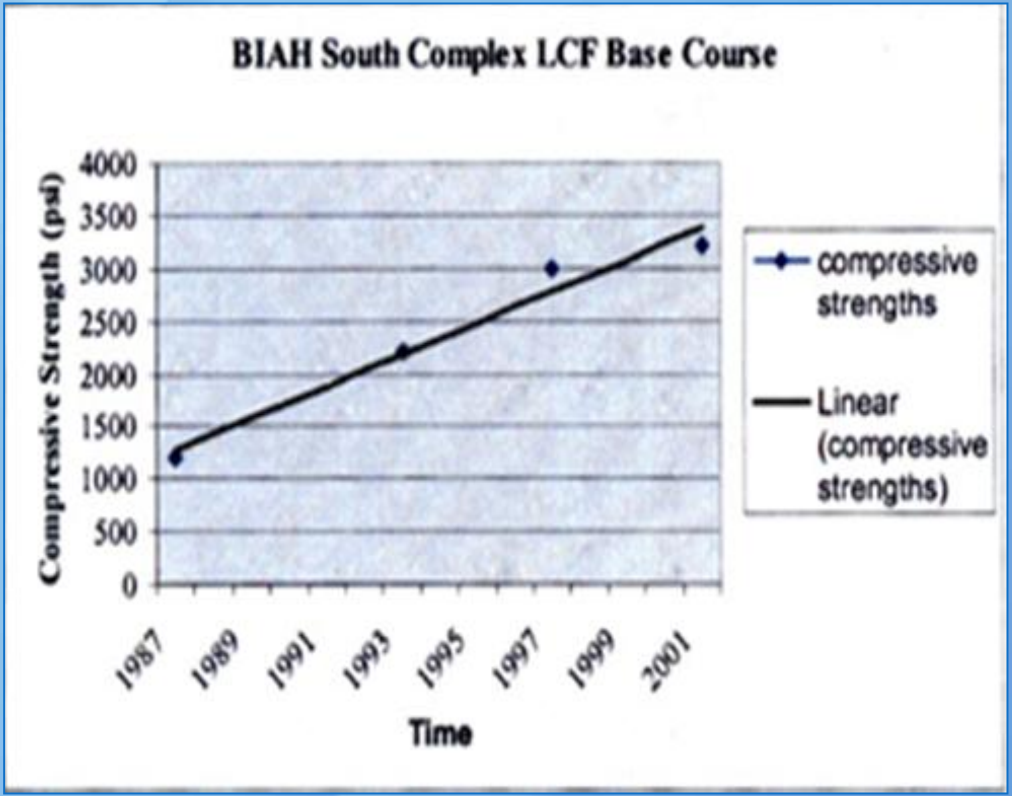
Compressive Strength LCF Stabilized Base - Runway 9-27

LIME-CEMENT FLY ASH (LCF)



Tensile Strength LCF Stabilized Base Runway 9-27

LIME-CEMENT FLY ASH (LCF)



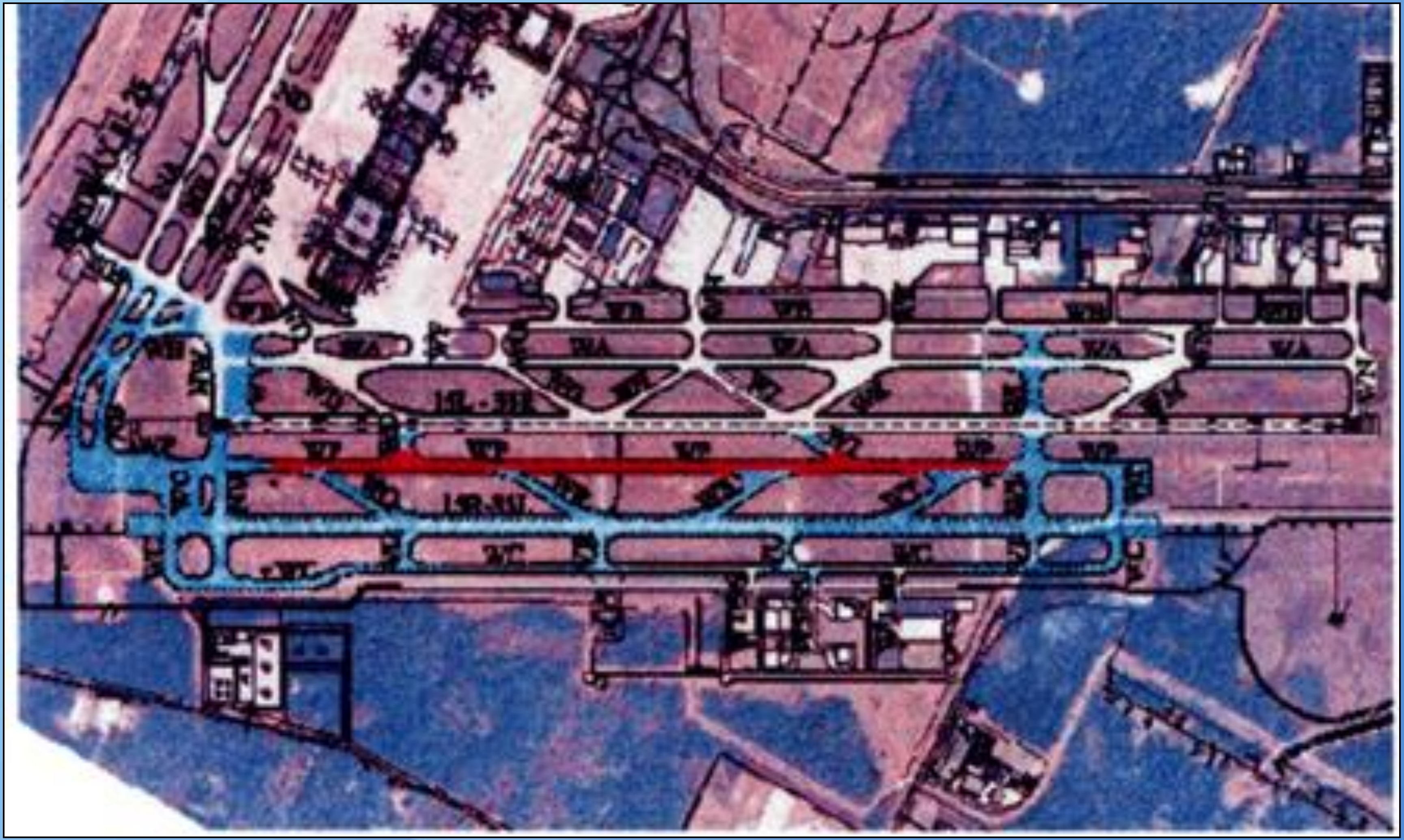
1987	1,200 psi
1993	2,200 psi
1997	3,000 psi
2001	3,200 psi
2008	3,500 psi

- Long-term Strength Gain
- Autogenous Healing of Micro-cracks

LIME-CEMENT FLY ASH (LCF) - TAXIWAY WP

- As a part of improvement program at BIAH, Runway 15R-33L was upgraded
- Category I precision runway, 150 feet wide by 10,000 feet long, capable of handling group V carrier aircraft.
- Approximately 6 miles of new taxiways were built including new parallel taxiway WP, total construction cost was approximately $81 Million.

LIME-CEMENT FLY ASH (LCF) - TAXIWAY WP



Improvement Layout Taxiway WP 15R -33L

LIME-CEMENT FLY ASH (LCF) - TAXIWAY WP

Preliminary Pavement Design

- 12-inches of PCC; 20-inches of LCF; 8-inches of CFA
- 14-inches of PCC; 18-inches of LCF; 8-inches of CFA
- 15-inches of PCC; 15-inches of LCF; 8-inches of CFA
- 16-inches of PCC; 13-inches of LCF; 8-inches of CFA
- 17-inches of PCC; 10-inches of LCF; 8-inches of CFA

LIME-CEMENT FLY ASH (LCF) - TAXIWAY WP

PCC Layer Thickness, Inches (EPCC = 4,000,000 psi	LCF Layer Thickness, Inches (ELCF = 1,000,000 psi)	Load Induced Edge Stress, psi	Load and Curling Edge Stress, psi
8	24	301	401
	18	417	517
	12	611	711
10	24	285	385
	18	364	464
	12	416	516
12	24	252	352
	18	322	422
	12	392	492
14	24	241	341
	18	287	387
	12	323	423

Summary of Load and Curling Stresses Induced in PCC from FEM Analysis

LIME-CEMENT FLY ASH (LCF) - TAXIWAY WP

Final Pavement Cross Section LCFRCCB Taxiway- WP

LIME-CEMENT FLY ASH (LCF) - TAXIWAY WP

- The targeted strength after 6-months of field cure was between 400 and 600 psi. This curing effect was modeled in the laboratory by curing the mixtures at 113^{0}F for 45-days. This correlation between laboratory and field curing was based on previous research and a literature review.
- The target compressive strength after one-year of service was between 800 and 1,200 psi.

LIME-CEMENT FLY ASH (LCF) - TAXIWAY WP

- It is important to remember that a long, steady strength development that will continue well beyond one-year. Such a process will minimize volume change due to shrinkage and will maximize Autogenous healing, which will in turn limit fatigue-cracking damage.
- The goal for the LCF is to provide acceptable strength and load-carrying ability without becoming too rigid. A very rigid sub-base below the PCC slab exacerbates the edge and corner stresses induced by temperature curling and warping of the slab, whereas, a less rigid sub-base provides a “cushion” effect reducing such stresses.

LIME-CEMENT FLY ASH (LCF) - TAXIWAY WP

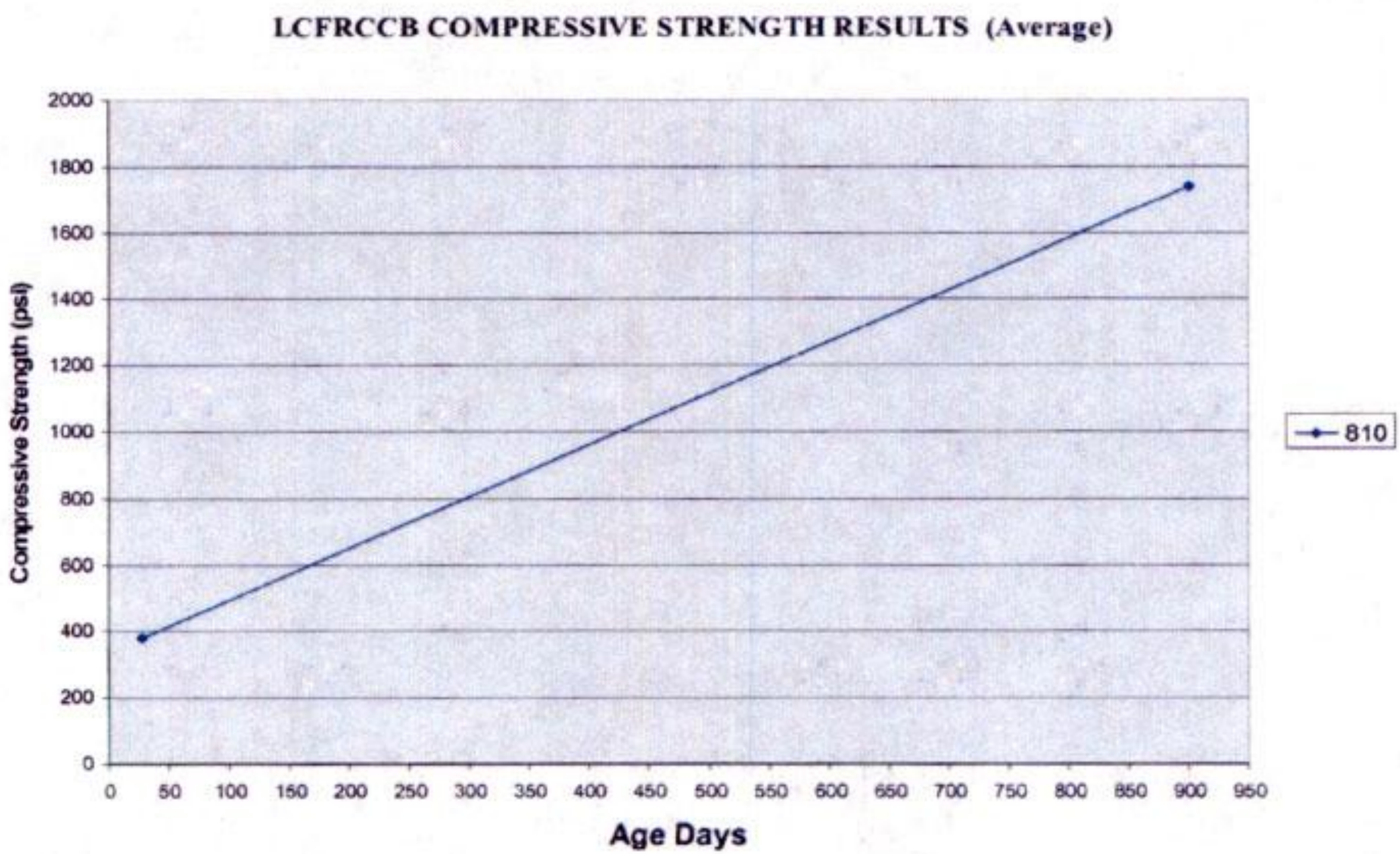


Fig. 7: LCFRCCB COMPRESSIVE STRENGTH RESULTS (Average)

LIME-CEMENT FLY ASH (LCF) TAXIWAY WP

Conclusion:

- A mixture of Lime, Cement, and Fly ash (LCF) was used as a sub base on taxiway WP to support a Portland cement concrete pavement surface.

- The LCF layer was engineered to provide a target strength at the end of one year of service of about 1,000 psi and a concomitant resilient modulus of about 1,000,000 psi.

- The LCF was designed to gain strength in a slow, controlled manner in order to reduce shrinkage cracking and to optimize autogenous healing over the life of the pavement.

- Non destructive test at the end of one year life showed an E value of 900,000 psi for LCF layer

- LCF mixture gained strength in accordance with the trend lines that predict strength gain based on laboratory testing

- The LCF uses recycled crushed concrete as the aggregate source and locally available, Class C fly ash. This was the first use of LCF as a sub base for a PCC pavement in the world.

CEMENT AND SLAG: Composition & Ingredient

Chemical Composition	Percentages for Portland Cement	Percentages for Class "C" Fly Ash	Percentages for Ground Granulated Blast Furnace Slag, Grade 120 (GGBFS)
CaO	65	31	42
SiO_2	20	35	38
AL_2O_3	4	17	8
Fe_2O_3	3	6	Trace
MgO	3	5	7
SO_3	3	3.5	--
S	--	--	1
Na_2O+K_2O	1	1.5	0.4
MnO	--	--	1

CEMENT AND SLAG: Composition & Reaction

- When GGBFS is coupled with cement, a Synergistic combination is formed.

- Each products hydrates on its own, forming strength bearing Calcium

- Silicate Hydrates (CSH).

- Excess Silica from GGBFS and the excess Calcium from Cement react to form additional strength bearing CSH in the pore space of concrete which makes stronger, denser and decreased permeability.

$$\text{Cement} + H_2O = \text{CSH} + Ca(OH)_2$$
$$\text{GGBFS} + H_2O = \text{CSH} + SiO_2$$
$$SiO_2 + Ca(OH)_2 + H_2O = \text{CSH}$$

PORTLAND CEMENT: Composition & Reaction

Concrete Ingredients Portland Cement					
Type of Cement	Description	Composition %			
		C_3S	C_2S	C_3A	C_4AF
I	General Purpose	48-50	24-26	5-13	7-9
II	Modified General Purpose	45-47	28-30	5-7	11-13
III	High Early Strength	55-57	14-16	11-13	7-9
IV	Low Heat	29-31	45-47	4-6	12-14
V	Sulfate Resistant	42-44	35-37	3-5	11-13

Chemical Reactions: Cement and Fly Ash

CaO - Cementitious Materials

MgO

Al_2O_3

SiO_2 - Pozzolanic Materials

Fe_2O_3

$CaO+MgO+H_2O+AI_2O_3/SiO_2/Fe_2O_3$ = Cementitious Paste + $Ca(OH)_2$

$Ca(OH)_2+A1_2O_3/SiO_2/Fe_2O_3$ = Cementitious Paste

CEMENT AND SLAG- Mixed Proportion

Cement, Type I	270 lbs/C.Y.
Class "F" fly ash	135 lbs/C.Y.
Blast furnace slag, Grade 120	135 lbs/C.Y.
Total cementitious materials	540 lbs/C.Y.
Coarse aggregate (1.5" granite)	1,193 lbs/C.Y.
Fine aggregate (siliceous sand)	1,193 lbs/C.Y.
Water	209 lbs/C.Y.
Water/Cementitious materials ratio	0.39
AEA	4.5 ozs/cwt
WRA	22.0 ozs/cwt

Runway 8L-26R Reconstruction
90 Days Concrete Summary

Concrete Statistics

Average Air Content = 4.4%

Average Slump =1.9”

Strength Types	7 Days	28 Days	90 Days
Avg. Flexural Strength	500 Psi (3500 kPa)	701 Psi (4900 kPa)	808 Psi (5650 kPa)
S.D, Flexural Strength	43 Psi	52 Psi	71 Psi
Min. Beam Strength	385 Psi	545 Psi	620 Psi
Max. Beam Strength	610 Psi	800 Psi	940 Psi

Runway 8L-26R Reconstruction

The pavement cross-section selected for the Runway and Taxiways were as follows:

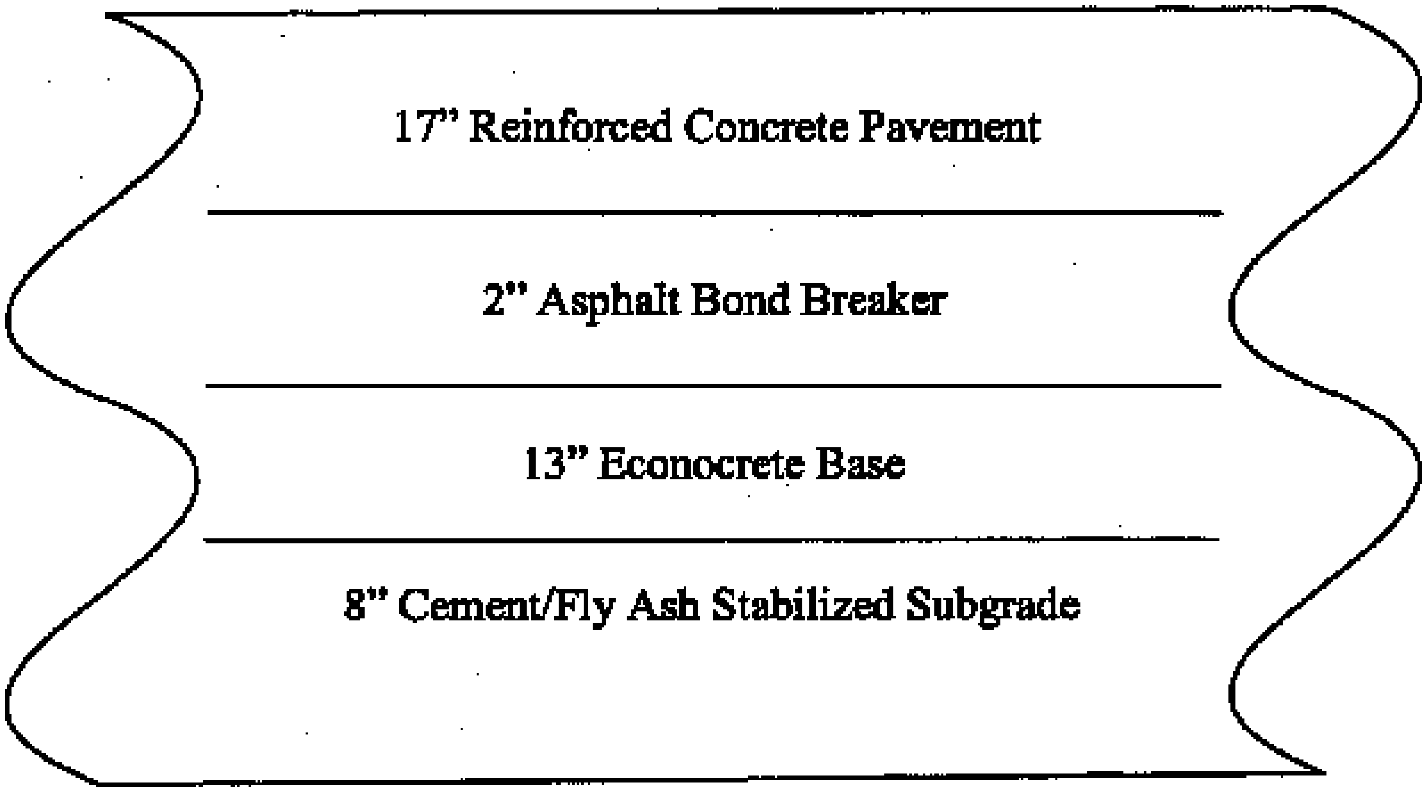


Figure 4: <u>Runway and Taxiway Pavement Cross-Section</u>

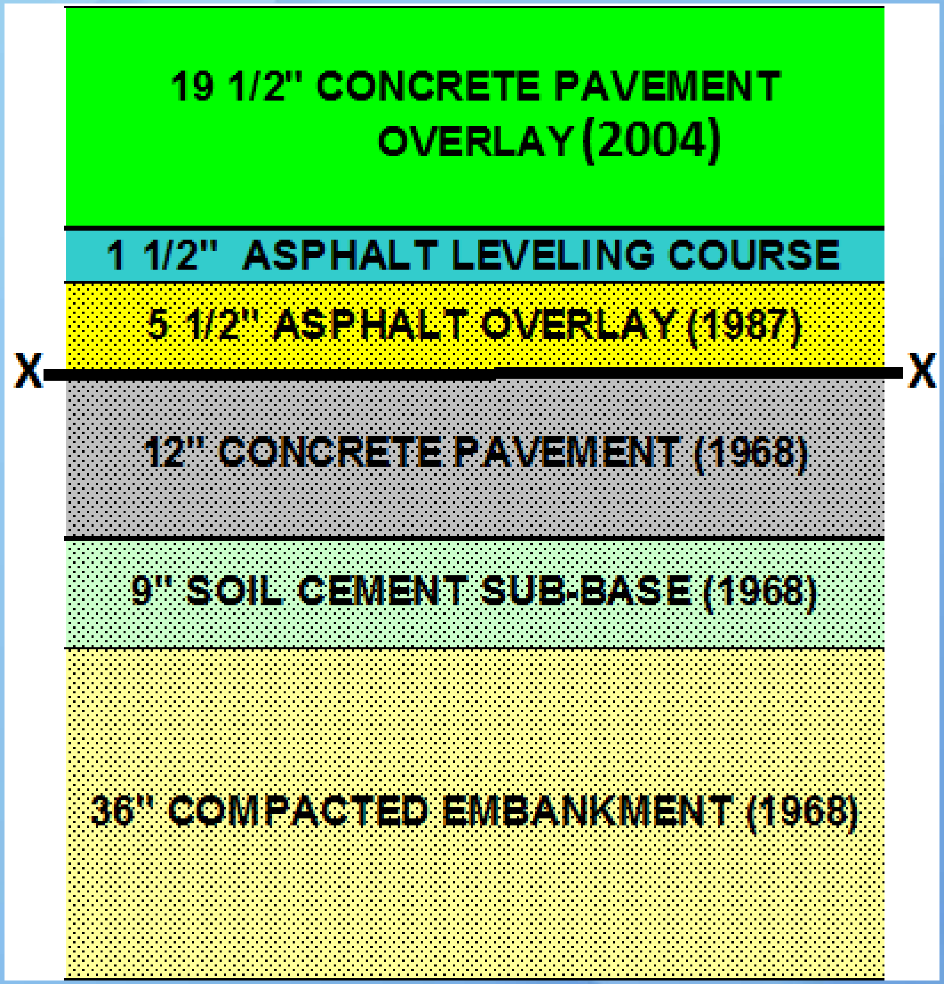
Runway 8L-26R - Reconstruction

Rehabilitation of Runway 8R-26L

NDT Evaluation Updated 2003

- IMPULSE STIFFNESS MODULUS
- 1998 ISM AVERAGED 4000 kips/inch
- 2003 ISM AVERAGED 3000 kips/inch

OVERLAY PAVEMENT CROSS SECTION



- NORMAL STRESS = 20.70 psi
- SHEAR STRESS = 8.2 psi
- PRINCIPLE STRESS = 22 psi
- DISPLACEMENT (DEFLECTIVE) = 0.05"
- NORMAL STRAIN = 0.0000067
- SHEAR STRAIN = 0.0000049
- PRINCIPLE STRAIN = 0.0000072

(ALL FOR X-AXIS)

Advantages of Overlay Solution:

- Reduced affect on airport operations.

  Total reconstruction would require the removal of 1.25 million Tons of materials.

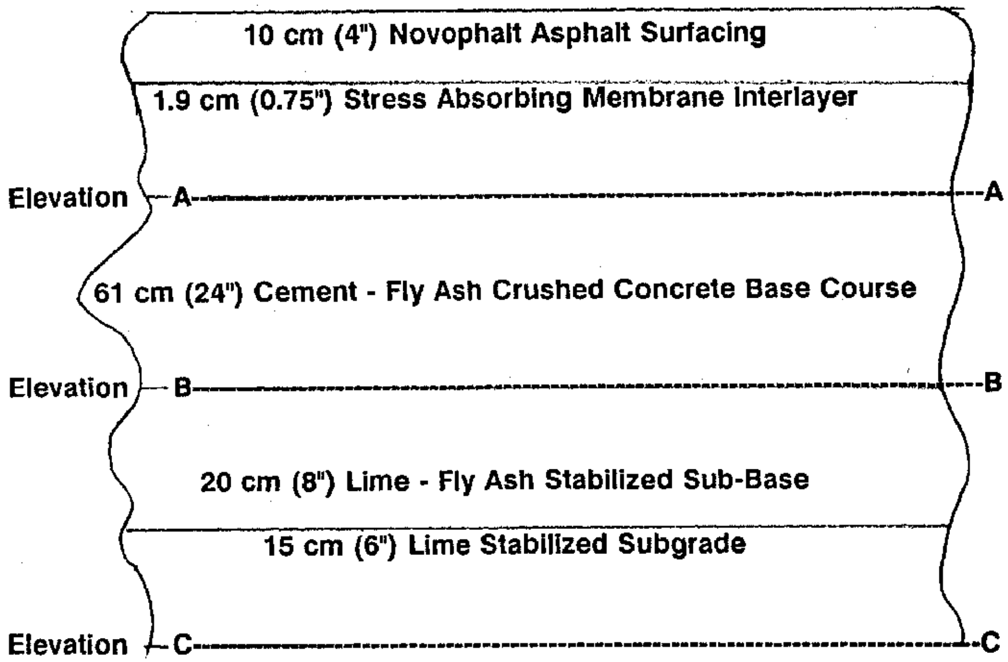
- Reduced construction costs.

  Estimated construction cost of full depth replacement twice as much as rehabilitated. $65 million versus $31 million.

- Reduced construction schedule.

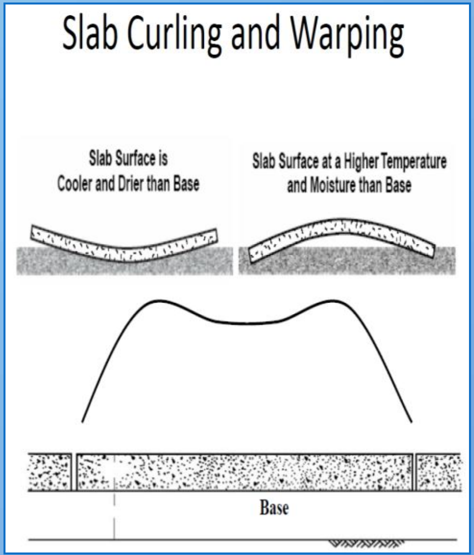
  Estimated construction schedule was 12 months, versus 7 months for rehabilitation option.

Figure 3. Distribution of Stresses and Strains in the Various Layers of the Pavement on Taxiways



	Elevation A-A	Elevation B-B	Elevation C-C
Normal Stress	1,033 kPa (150 psi)	1,047 kPa (152 psi)	6.13 kPa (0.89 psi)
Shear Stress	35.83 kPa (5.2 psi)	4.82 kPa (0.70 psi)	0.34 kPa (0.05 psi)
Principal Stress	1,033 kPa (150 psi)	1,040 kPa (151 psi)	6.13 kPa (0.89 psi)
Displacements	1.11 cm (0.44")	1.11 cm (0.44")	1.09 cm (0.43")
Principal Strain	0.00057	0.00031	0.00040
Normal Strain	0.00057	0.00031	0.00040

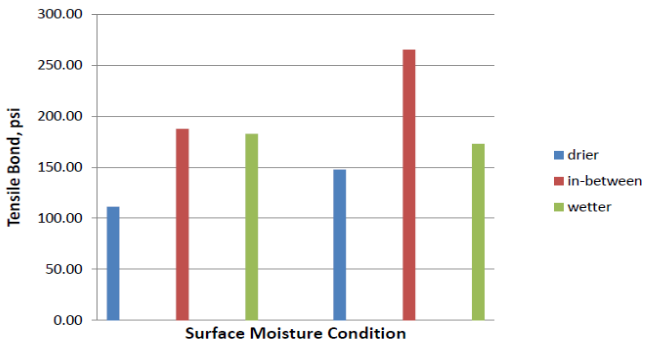
Slab Cracking/ Delamination Study: TW- WB



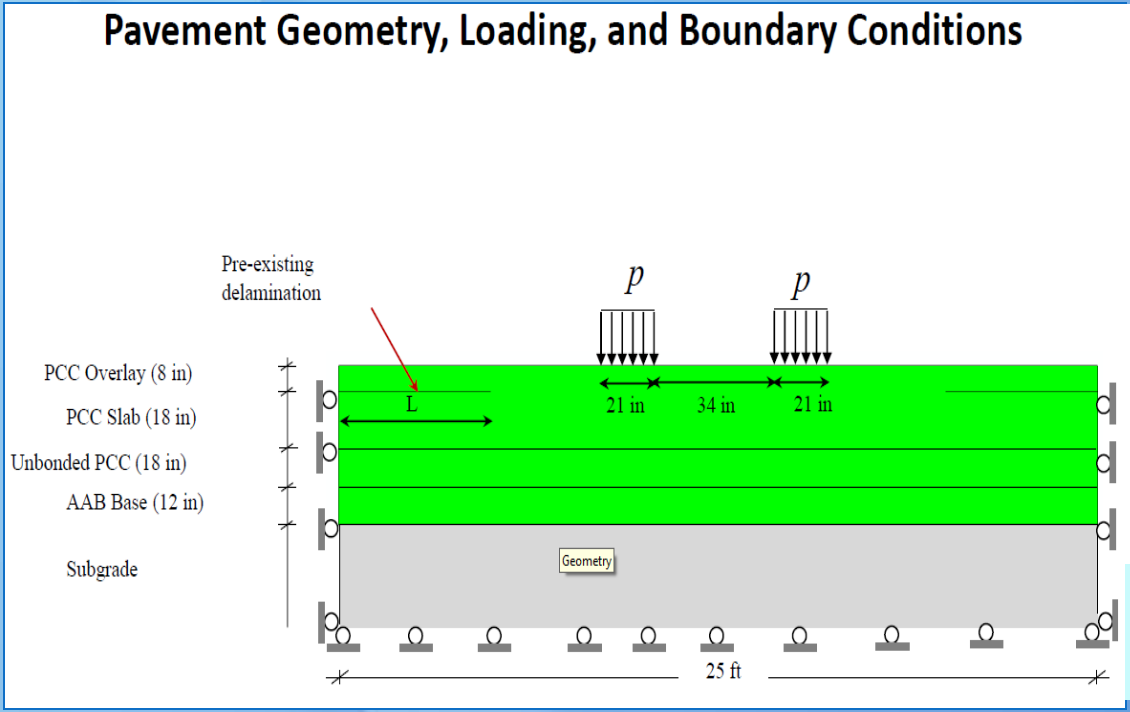
Field Bond Testing

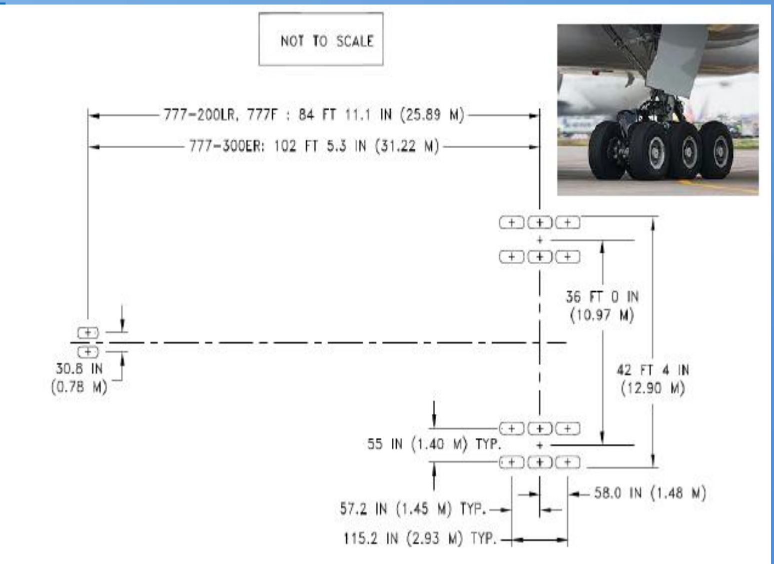
Type	Degree of Bond	Strength	Location
Pulloff	Full	183 psi	83+00
	Partial	19 psi	82+75
Torsion	Full	219 psi	82+25
	Full	178 psi	82+25

Laboratory Bond Testing



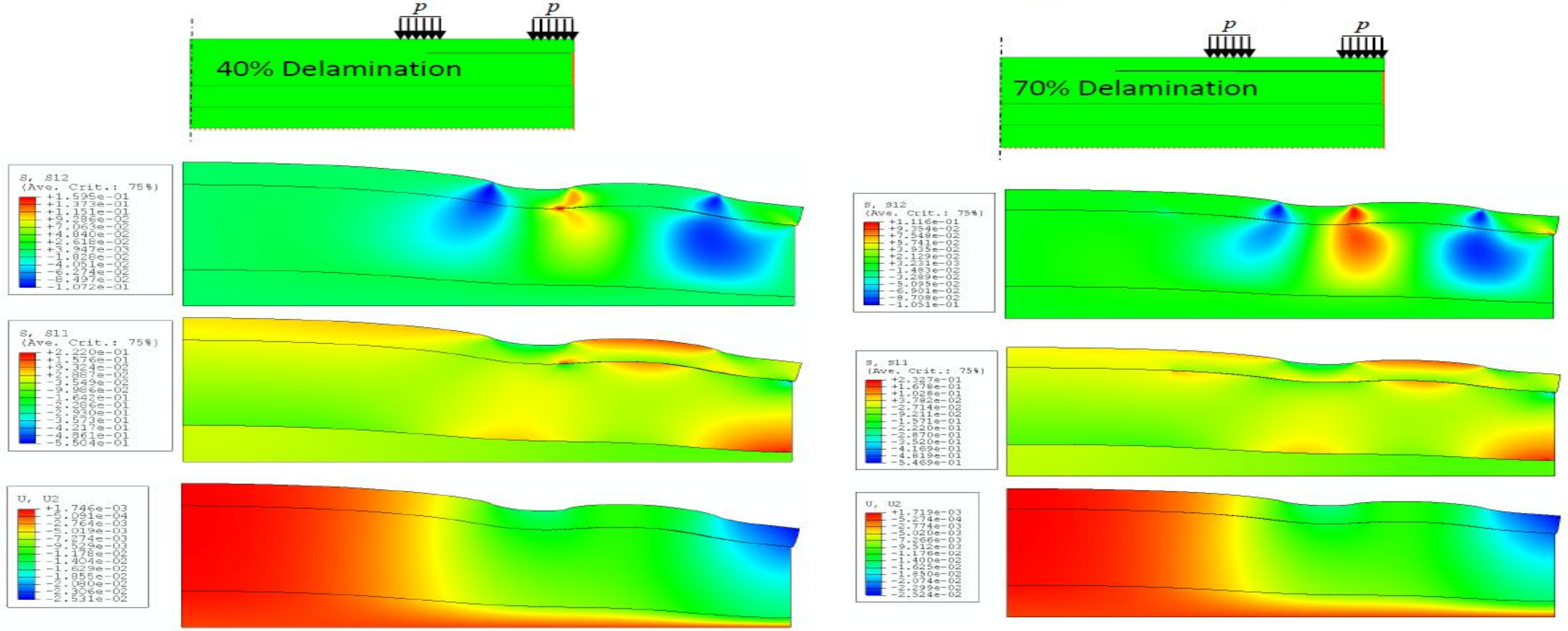
Finite Elemental Analysis: Delamination

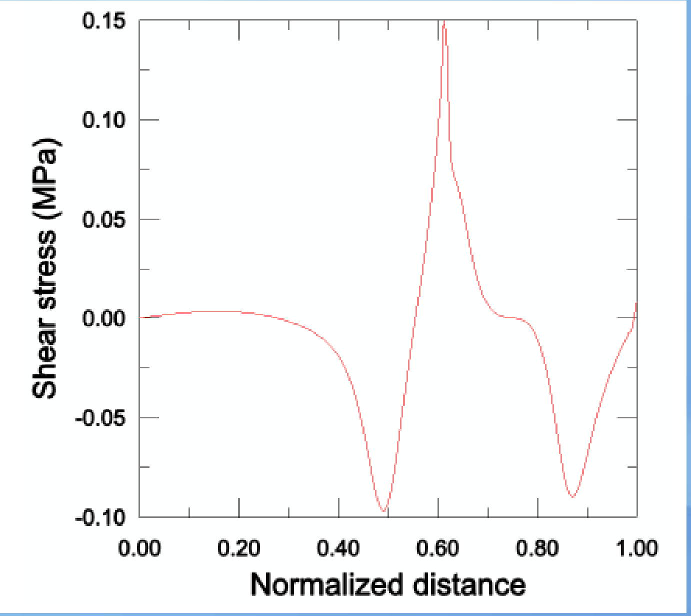


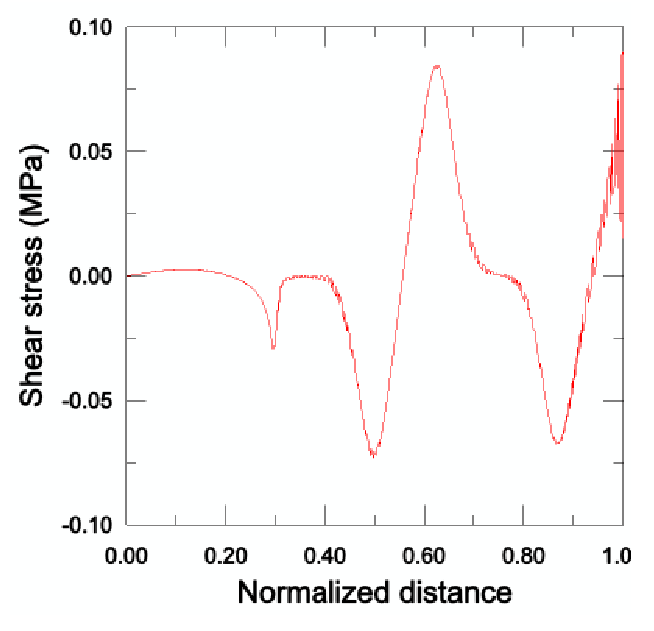


Geometry and Weight from the Main Gear

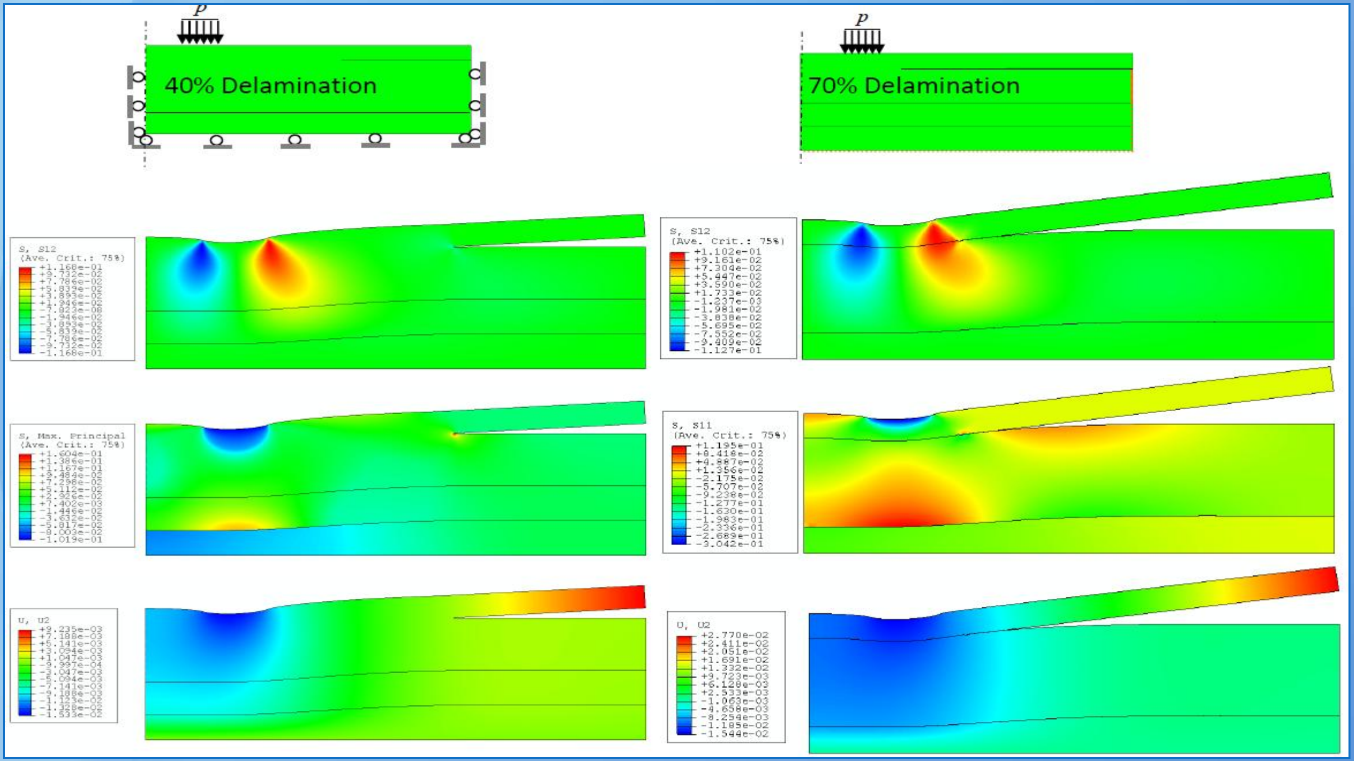
40% and 70% Delaminations – Edge Loading

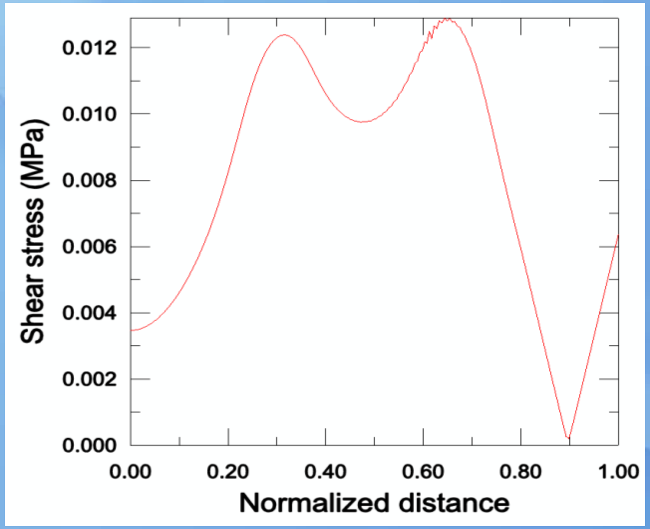


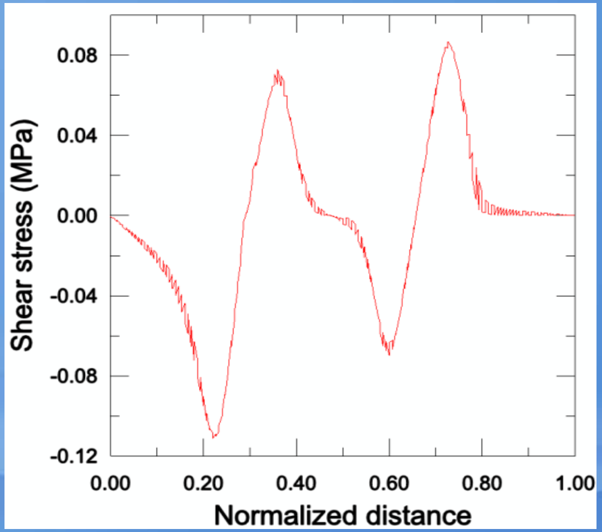




40% and 70% Delaminations – Middle Loading





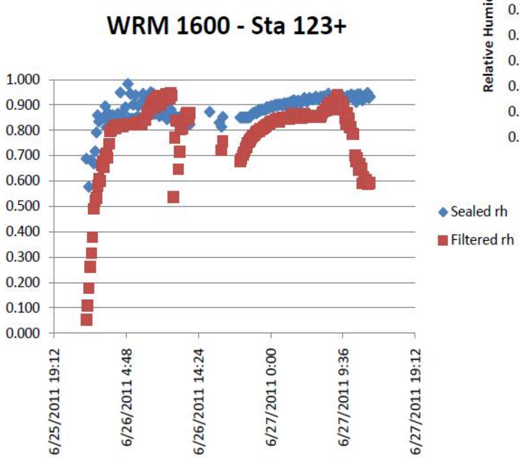


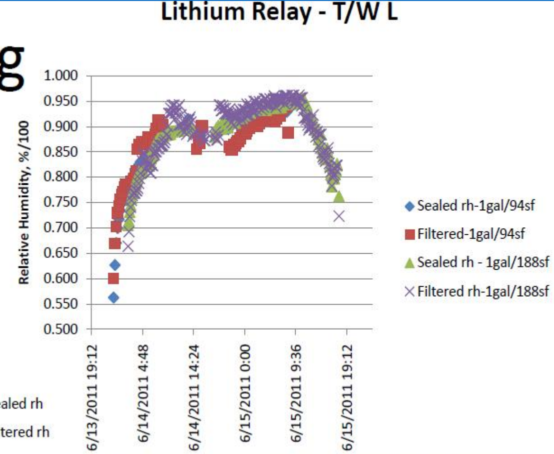
Curing Monitoring and Evaluation

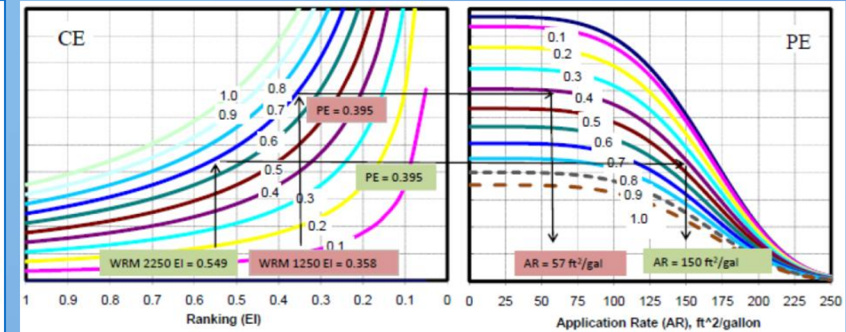
Field Monitoring

Laboratory Monitoring

Field Monitoring

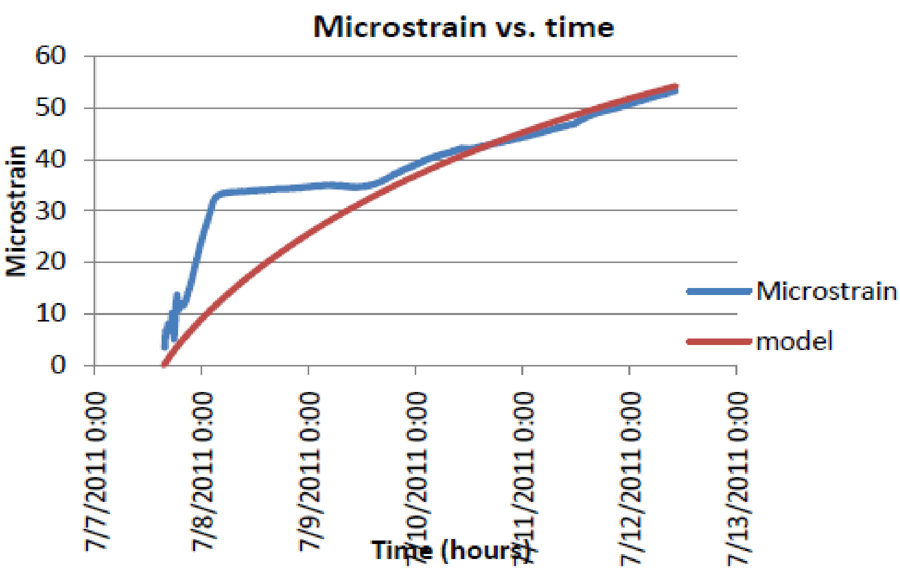


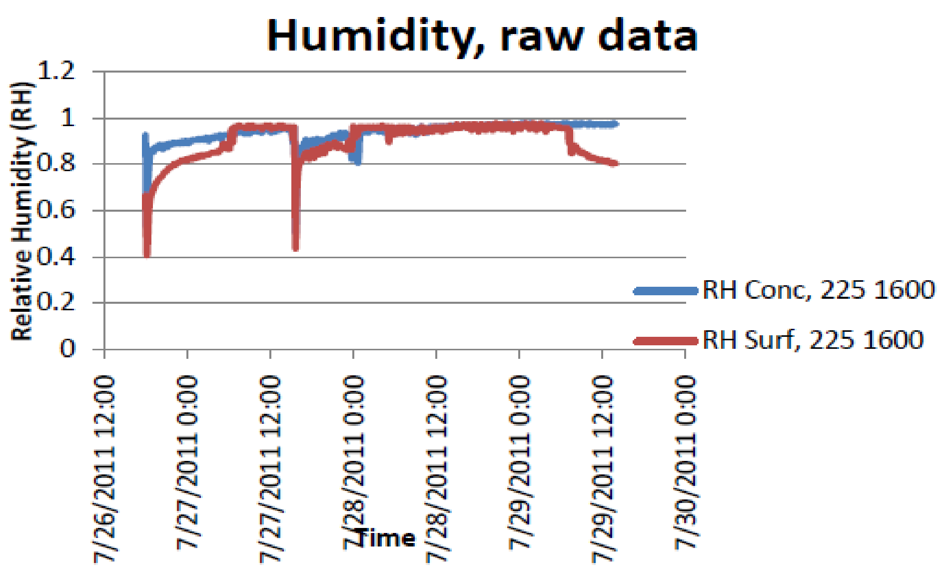


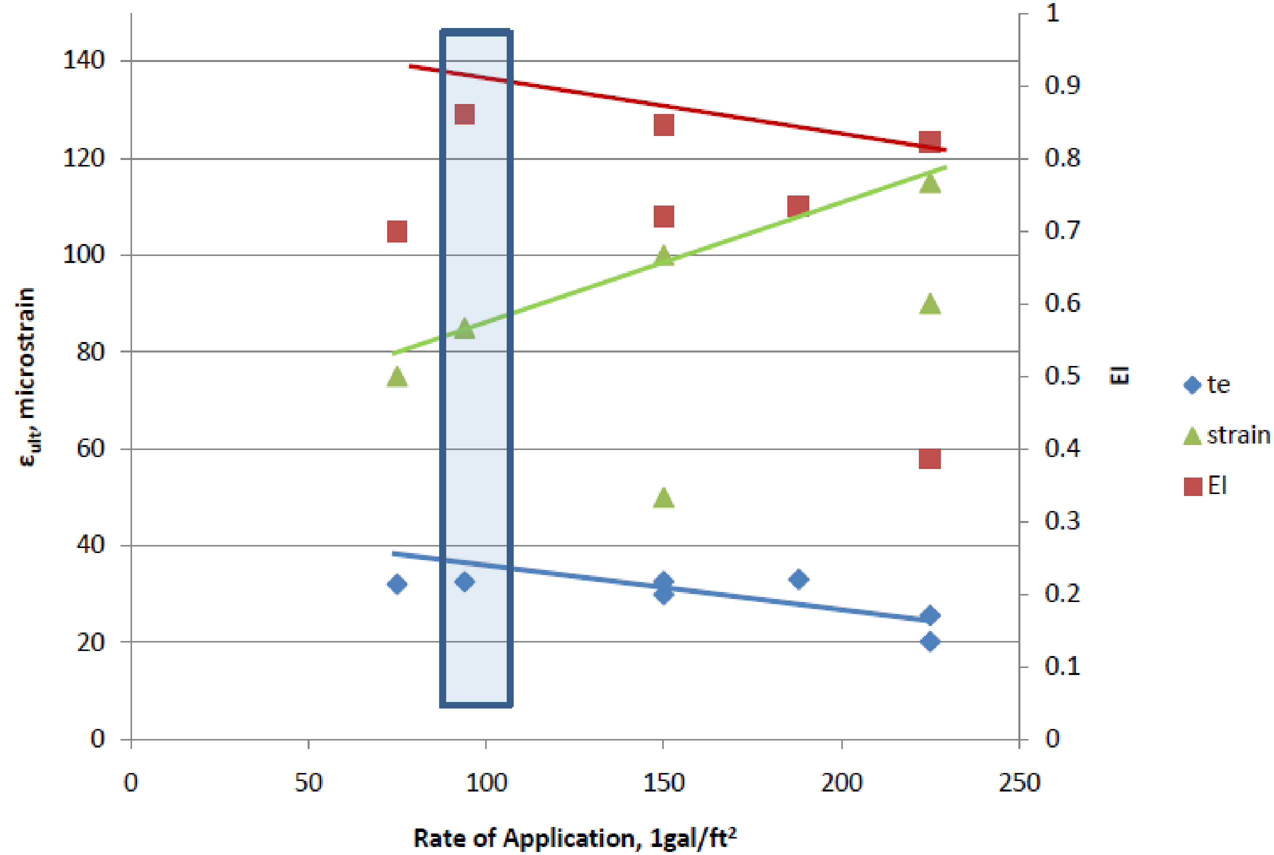


$$EI = \frac{t_{e-filtered} - t_{e-open}}{t_{e-sealed} - t_{e-open}} ; t_e = \beta_{rh} \sum e^{\frac{E}{R}\left(\frac{1}{T} - \frac{1}{T_r}\right)} \Delta t$$

Curing Evaluation Index







Date	EI	%Cracking	Cure
Mar 5th	0.814	5.6%	WMR
Jun 26th	0.785		WMR- 1g/150 ft^2
Jun 15-16	0.734		Lithium Relay – 1g/188 ft^2
	0.861		Lithium Relay – 1g/94ft^2

Possible Causes:

- Dry and Windy Weather Conditions
- Surface wetting behind the paver
- Quality of the Cure
  - Compound
  - Time of placing
  - Configurations associated with an overlay

Assessment:

- Structural Condition is ok.
- Grouting/Anchoring the interface can minimize the potential problem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•Godiwalla, A. (2011). “Advanced, Modern and Innovative Technologies Used at Houston Airport Systems, Stabilized Sub-grade and Stabilized Bases Pavement Surfaces”, Airfield Engineering & Asset Maintenance Summit, Singapore Expo & Convention Center, Singapore.

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