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ADVANCED, MODERN AND INNOVATIVE TECHNOLOGIES USED AT THE HOUSTON AIRPORT SYSTEM (STABILIZED SUBGRADES AND STABILIZED BASES)

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ABSTRACT

The technical paper and presentation will give the audience at the conference an exhilarating surf ride of some of the leading edge of technologies in airport engineering.

We have been using these advanced, modern and innovative technologies at the three airports in the Houston Airport System for the last twenty-three years. This should blend beautifully with the theme and title of the conference.

The following topics among numerous others used should be enough to whet one's appetite for advance, modern and innovative technologies in airport engineering. 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.

- Novophalt asphalt (polymer modified asphalt) concrete technology used on runways and taxiways.
- 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.
- Stress Absorbing Membrane Interlayer (SAM) for reflective cracking of pavements.
- Lime/cement/fly ash/crushed concrete stabilized base used on runways and taxiways.
- New concrete pavement on runways and taxiways using cement, fly ash and blast furnace slag.
- Cement/fly ash crushed concrete base for runways and taxiways.

INTRODUCTION

Lime – Fly ash Soil Stabilization

The addition of lime to a fine-grained soil, like clay, initiates several reactions. Cation exchange and flocculation – agglomeration reactions can take place rapidly and produce immediate changes in soil plasticity, working and immediate uncured strength, and load-deformation properties. Depending on the chemical composition of the soil being stabilized, a soil lime-pozzolanic reaction may occur. The pozzolanic reaction results in the formation of various cementing agents which increase mixture strength and durability. Pozzolanic reactions are time-dependent; therefore, strength development is gradual but continuous for long periods of time amounting to several years in some instances.

In Houston, the great majority of the soil is montmorillonite clays, which are weak clays with a very high organic content. These soils are "non-reactive" with lime. This means that the lime only lowers the Plasticity index of the soils, while barely increasing the compressive strength of the soil by 20 to 50 psi in twenty-eight (28) days. If a soil is "non-reactive", extensive pozzolanic strength development will not be achieved regardless of time, lime percentage or curing conditions of time and temperature.

It may be mentioned that the lime-fly ash used for the soil stabilization of Runway 4-22 at Hobby Airport in 1988 is probably the first runway in the world to use this technique. Attached are some testing laboratory results.

CONTINENTAL EXPRESS APRON PROJECT AT INTERCONTINENTAL AIRPORT – HOUSTON

Soil Stabilization with Cement-Fly Ash Slurry

The construction of this project commenced in October, 1990. It was decided to use a combination of cement and fly ash because results from previous projects on similar soils had indicated that 4% cement + 10% fly ash gave us 50% larger, compressive strength (522 psi) than with 7% cement (350 psi) in 28 days. In addition, the cement + fly ash combination continued to gain strength over a long period, i.e., 5 to 10 years. In two years time, the projected strength of 4% cement + 10% fly ash is twice that of 7% cement. The cost of the 4% cement + 10% fly ash is less than that of 7% cement. This amazing strength gain of cement + fly ash is due to the chemical reactions between cement and fly ash. The fly ash used was class "C" fly ash as produced by Ash Management Systems, Inc. It is obtained from sub-bituminous coal. Since this work was performed in the airfield area, it was essential that we not use dry cement and dry fly ash, as dry cement corrodes the jet engines of the aircraft.

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)

The slurry was produced at the concrete batch plant which was set up on site. The cement, fly ash and water were loaded in the concrete batch plant to produce the cement-fly ash slurry in one operation. The mixing time for this was about 15 minutes. The solids constituted approximately 75% of the total solution. This slurry was subsequently loaded onto ready mix concrete trucks where it was kept in a constant mixing mode just as for concrete. This slurry was discharged within 15 minutes on to a medium size metal buggy with slots cut out in it to distribute the slurry. The size of the slots in the metal buggy was made so that the desired application rate was achieved.

During and after the mixing of the slurry, there was a great deal of swelling due to the clayey particles in the soil. In addition, there was a tremendous amount of fluffiness in the soil. This was due to the chemical reactions of cement, fly ash and soil. It was caused by agglomeration and flocculation. The amount of fluffiness was so large that in order to obtain 8” cement fly ash stabilized subgrade, we had to have 9-1/2” depth of cement-fly ash –soil mixture.

Apron Pavement Cross-Section

10” Fly Ash Concrete Pavement
8” Cement-Fly Ash Stabilized Subgrade

CONCLUSIONS

The California Bearing Ratio (CBR) for the average compressive strength of 730 psi of soil amounts to 688. This compares with a CBR of 100 for crushed stone. Therefore, the amazing chemical reactions between cement, fly ash and soil gives us a very strong soil subgrade foundation at an extremely economical value. The cement and fly ash in slurry form for soil stabilization used on this project was probably the first time in the world. As evident from the results, it was a grand success. Subsequently, this combination of cement and fly ash in slurry form has been used extensively at IAH.

The compressive strength is tabulated below for 4% cement and 10% fly ash.

Table 2: Compressive Strength Of Molded Soil Cement Cylinders
Astm D 698 Compactive Energy
28 Day Moisture Cured

SPECIMEN NO.	MOISTURE CONTENT	DRY UNIT WEIGHT	COMPRESSIVE STRENGTH
1	10.6%	118.6 pcf	570 psi (5355 kPa)
2	10.5%	117.9 pcf	590 psi (5635 kPa)
3	9.1%	116.6 pcf	585 psi (5495 kPa)

Table 3: Compressive Strength Of Molded Soil Cement Cylinders
Astm D 698 Compactive Energy
28 Day Moisture Cured

SPECIMEN NO.	MOISTURE CONTENT	DRY UNIT WEIGHT	COMPRESSIVE STRENGTH
1	10.4%	118.5 pcf	460 psi (4795 kPa)
2	10.3%	118.0 pcf	475 psi (4445 kPa)
3	9.1%	117.2 pcf	450 psi (49.00 kPa)

Note: Specified compressive strength of 600 psi @ 90 days has been achieved.

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

Date	Report #	Moisture Content	Ave. Dens. pct:	7 Day Cyl 1 psi	7 Day Cy12 psi	7 Day Average	7 Day Difference psi	7 Day Difference %	28 Day Cyl 1 psi	28 Day Cy1 2 psi	28 Day Average	28 Day Difference psi	28 Day Difference %	90 Day Cyl 1 psi	90 Day Cy1 2 psi	90 Day Average	90 Day Difference psi	90 Day 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%	6S	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-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

INTRODUCTION

In the mid-1980s, the City of Houston Department of Aviation designed a new runway for the then named Houston Intercontinental Airport. This was to be Runway 9-27. A variety of pavement design alternatives were examined and based on the initial construction cost a design was selected that had only been constructed on limited number of air carrier facilities. This was not a traditional rigid or flexible pavement but a stabilized base pavement constructed in a series of layers to form a rigid base to be surfaced with conventional hot mixed asphalt concrete. This stabilized base consisted of five different materials. The coarse and fine aggregate used were a well-graded fine gravelly sand and a fine sand which were termed sand/gravel and bank sand. The additives were lime, Portland cement, and fly ash. The multilayered stabilized base pavement became known as LCF, the acronym for the cementing agents used in the mixture of materials. The pavement section consisted of 6” of compacted subgrade on which 24” of cement stabilized embankment was placed. This was the foundation for the multilayered LCF base. The LCF was surfaced with 3” conventional asphalt concrete. This pavement section was built on Runway 9-27 and Taxiways SC through SK (Figure 1).

Some of the technical particulars of the LCF material including its composition, mixing and placement, finishing and strength were as follows:

LCF Material mix proportions by weight used for a majority of the construction were:

Bank Sand	12.5%
Lime	4.0%
Cement	0.5%
Fly Ash	9.5%

Thirty samples of the LCF base were tested for tensile strength using the split tensile test. A cylindrical specimen is loaded diametrically in compression which causes a uniform tensile stress distribution causing the cylinder to split in half (Ref 2, 5). The mean tensile strength was found to be 360 psi with a range of 137 to 581 psi. The standard deviation on these tests was 102 psi thus resulting in a Coefficient of Variation of 28%.

In addition to the compressive and tensile strength tests performed on the LCF base material, five samples were tested for Modulus of Elasticity. The mean value of the modulus of elasticity was found to be 3,520,000 psi in a range of 3,280,000 to 3,920 psi. The modulus of elasticity is thus similar to that of a “lean” concrete mix.

CONCLUSION / SUMMARY

The investigation did demonstrate that the LCF component of the pavement was very sound and exhibited an extraordinary strength gain over it s 10-year life. The pavement as a whole has reached a point in its total life cycle where its serviceability level needs to be restored. When the runway was constructed in 1986, a 10-year surface renewal was expected to be needed. The LCF base pavement has proven to be a successful alternate to Portland cement concrete pavement, which was a much more expensive original alternate, bid. The pavement performed very satisfactorily as expected.

The pavement surface rehabilitation strategy selected was one that included removing 1” of the existing HMAC surface by milling and overlaying with 5” of Novaphalt asphalt with a SAMI in between the old and new asphalt layers. This strategy is projected to last 12-14 years. This technique is an excellent example of a long term perpetual pavement, whereby the LCF base supports all the loads. The asphalt surfacing is merely a wearing surface.

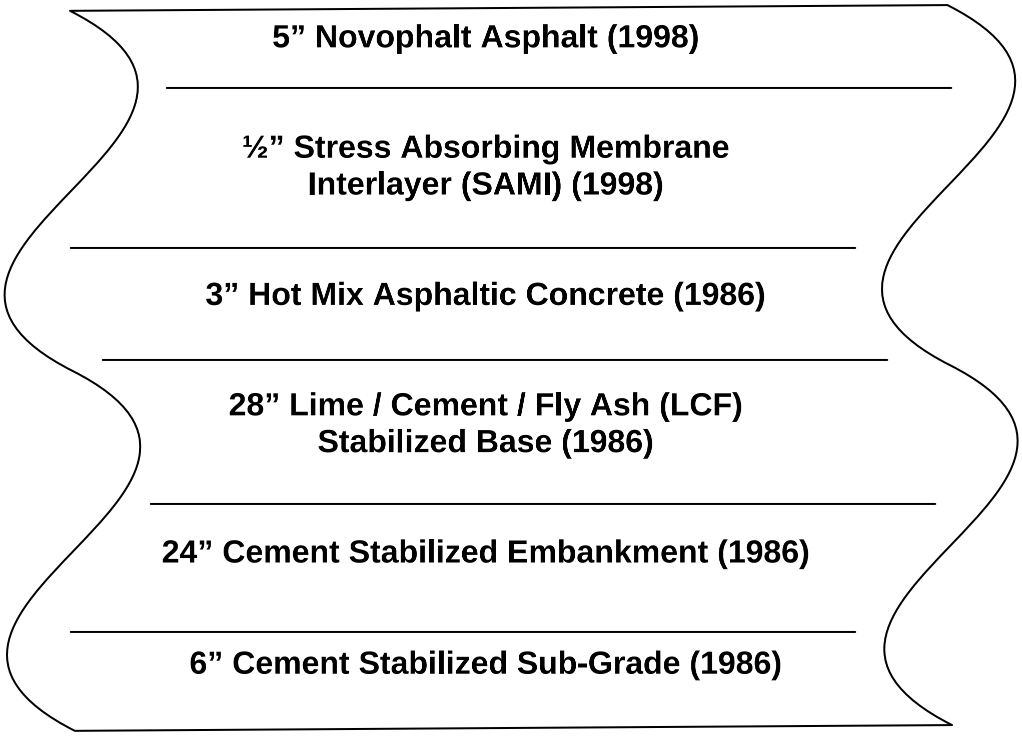


Fig. 1: Runway 9-27 Pavement Cross-Section

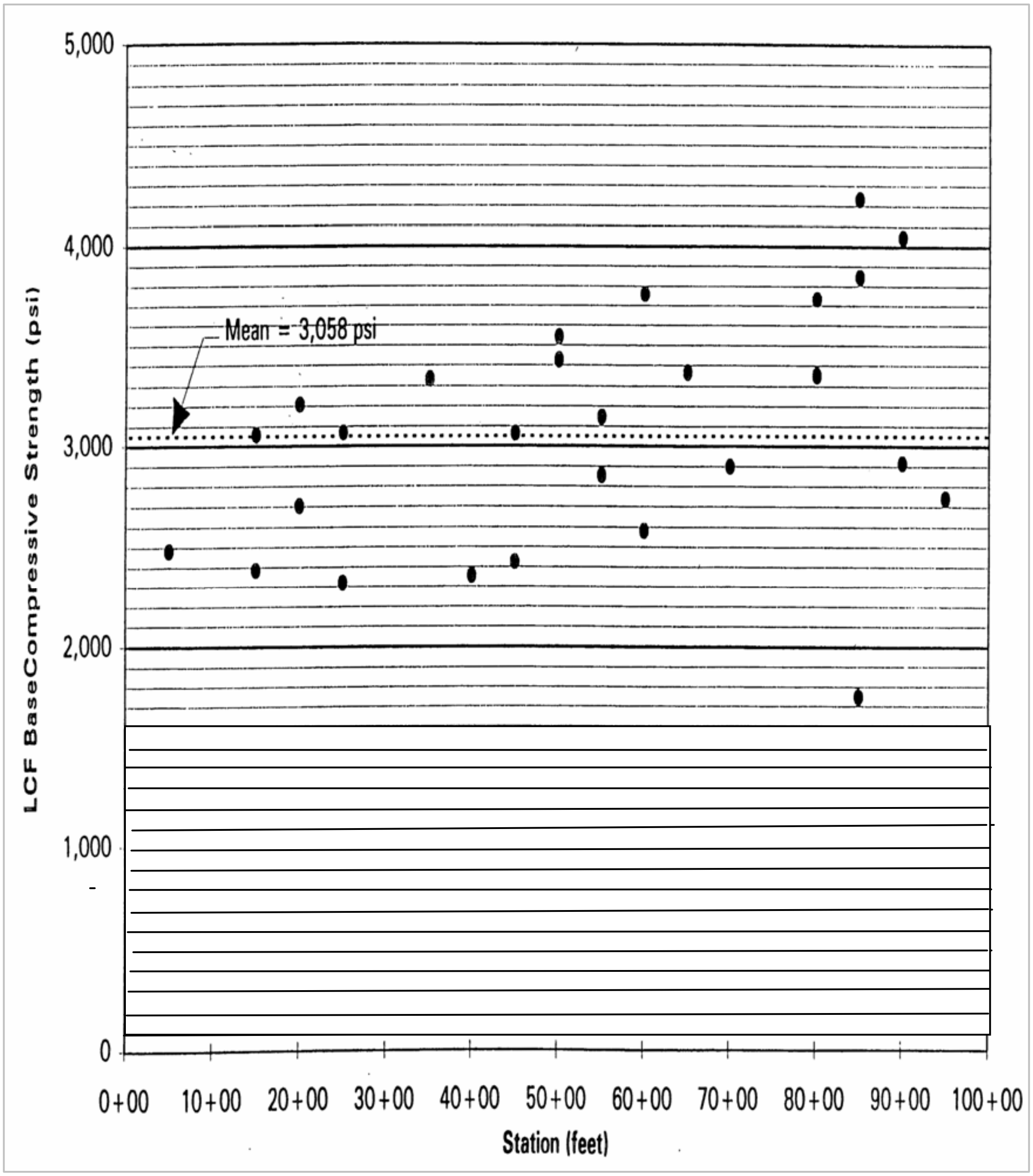


Fig. 2: RUNWAY 9-27 LCF BASE
COMPRESSIVE STRENGTH

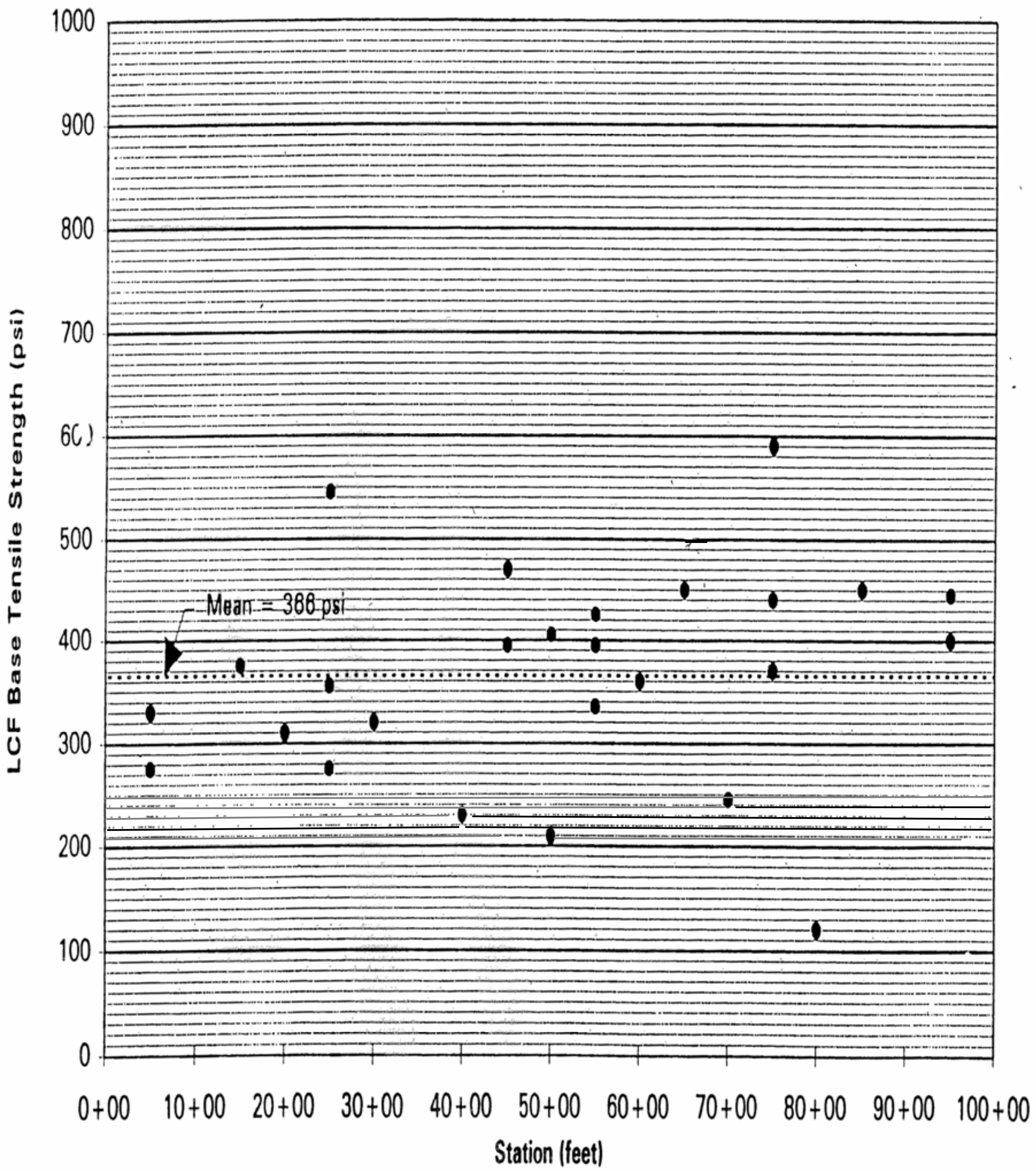
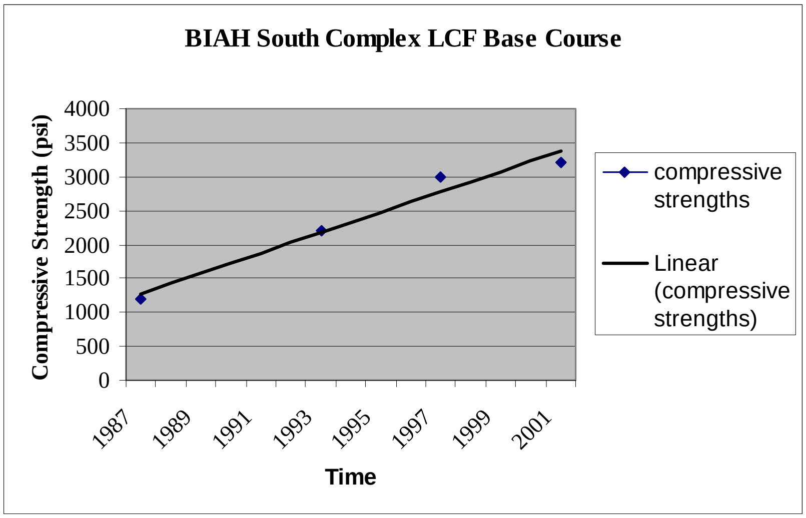


Fig. 3: RUNWAY 9-27 LCF BASE
TENSILE STRENGTH



- **1987 1,200 psi**
- **1993 2,200 psi**
- **1997 3,000 psi**
- **2001 3,200 psi**
- **Long-term strength gain**
- **Autogenous healing of microcracks**

Fig. 4: SOUTH COMPLEX—RUNWAY 9-27 AND ASSOCIATED TAXIWAYS

LIME / CEMENT / FLY ASH (LCF) STABILIZED BASE FOR TAXIWAY “WP”

Introduction

As a part of the overall improvement program at BIAH Runway 15R-33L is being upgraded to a Category I precision runway, 150-feet wide by 10,000-feet long, capable of handling Group V carrier aircraft. In support of the upgraded runway approximately 6 miles of new taxiways are being built including a new parallel Taxiway WP; taxiway extensions; high speed exits; aircraft hold areas; and necessary drainage, utility, and service road improvements (see figure 5 for layout of improvements). The total construction cost of the Runway 15R-33L extension, widening, and associated taxiways is approximately $90 million.

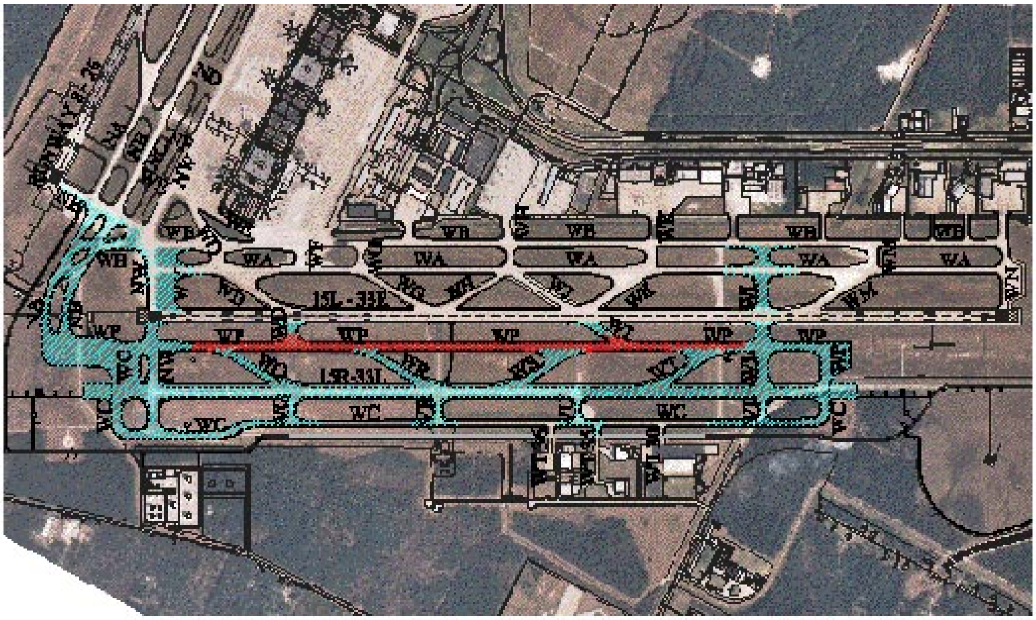


Figure 5. General Layout of Improvements at BIAH

This paper describes the application of a lime-cement fly ash (LCF) subbase used in taxiway WP, the parallel taxiway for runway 15R-33L. The engineering evaluation that accompanied rehabilitation consisted of an extensive analysis of the LCF, and the evaluation proved that the LCF was in excellent condition and had functioned as designed over the 10-year period.

This paper described the role of LCF in taxiway WP. The paper specifically discusses the maximization of the use of recycled materials in the mixture design, target strengths and moduli of the design LCF mixture, and the expected performance of the LCF layer in taxiway WP.

Adapting LCF to Taxiway WP

Several options were considered for the design of taxiway WP including the use of a LCF subbase. This design is only attractive if it results in cost savings. Designers decided to use readily available recycled crushed concrete (RCC) as the aggregate in the LCF mixture. Large volumes of RCC had been stockpiled less than ten miles from the runway project by Southern Crushed Concrete. The RCC is widely used by both the Houston Airport System and the Texas Department of Transportation, TxDOT.

In the design of runway 9-27, the LCF performed as the major structural layer with only a 3-inch HMA surface. The 28-inch LCF functioned well for this purpose. The application of LCF in taxiway WP has a very different application. While it does function as a structural subbase, it is not the major structural layer. That, of course, is the PCC surface. Furthermore, very stiff subbases can actually exacerbate the curling and warping stresses induced in the PCC surface as they form a rigid sublayer below the deformed PCC slab. Therefore, it is appropriate to design LCF with enough strength and a high enough elastic modulus to provide the necessary structural support and still not be overly rigid so as to exacerbate curling and warping stresses. Based on these considerations, the pavement team designed for a target elastic modulus of 1,000,000 psi for the mature LCF, with an interim (6-month) target modulus of approximately 400,000 psi.

Preliminary Pavement Design

A preliminary design was performed for the design traffic mix using FAA's layered elastic computer program, LEDFAA. The materials selected for the analysis were PCC surface, LCF subbase (with a modulus of 400,000 psi from the initiation of traffic until one year of service and 1,000,000 psi thereafter), and cement fly ash (CFA) stabilized subgrade (with a modulus increasing from 30,000 psi between the initiation of traffic and gradually increasing to 150,000 after 2-years). The natural subgrade is a sandy silt with an average annual design resilient modulus of approximately 10,000 psi. According to the LEDFAA analysis for an unbonded condition, the candidate pavement sections were:
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

The LEDFAA candidate sections were further analyzed using a finite element model (FEM). In this analysis, the critical aircraft, a Boeing 737-800, was used. The FEM was used to calculate interior, corner and edge stresses for 20-feet by 20-feet PCC panels, which were used in lieu of the more typical 25-feet by 25-feet panels to minimize curling and warping stresses over the stiff subbase. As would be expected, edge stresses were critical. Table 2 summarizes the stresses calculated in the FEM analysis for the mature pavements, e.g., when LCF has developed a resilient modulus of 1,000,000 psi at maturity of at one year of service.

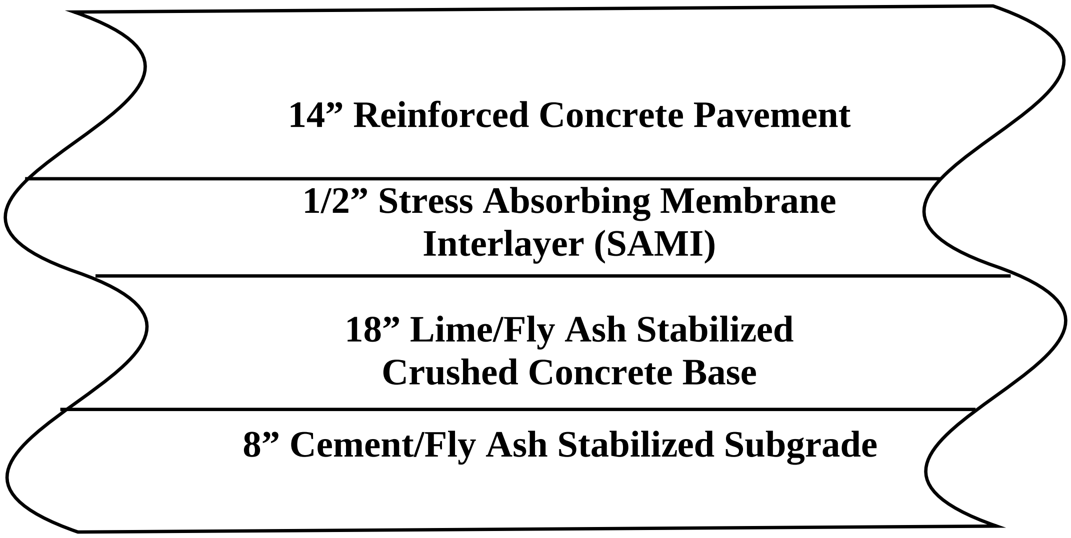


Fig. 6: Final Pavement Cross Section for Taxiway "WP"

Table 5. Summary of Load and Curling Stresses Induced in PCC from FEM Analysis.

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

DESIGN OF LCF MIXTURE TO ACHIEVE REQUIRED STRUCTURAL PROPERTIES

Mixture Design Approach

Recycled crushed concrete was selected as the aggregate for the LCF based on availability, proximity to the construction site, and cost. The RCC aggregate is required to meet P-209 aggregate gradation specifications with a target gradation as mid-line of the P-209 gradation curve. Class C fly ash was added to the aggregate as a filler to produce a durable (low permeability) yet strong (utilizing internal friction among aggregate particles) aggregate matrix. The Class C fly ash was also added as the primary component of pozzolanic strength. Hydrated lime was added as an activator for the fly ash to maximize the pozzolanic reaction. Several trial mixtures were prepared at a design compaction energy of 98 percent of ASTM D 1557. The selected mixture deign consisted of 86.5 percent RCC, 10 percent Class C fly ash, 3 percent hydrated lime, and 0.5 percent Portland cement, which is used to assist in nucleating the pozzolanic and cementitious reactions within the mixture.

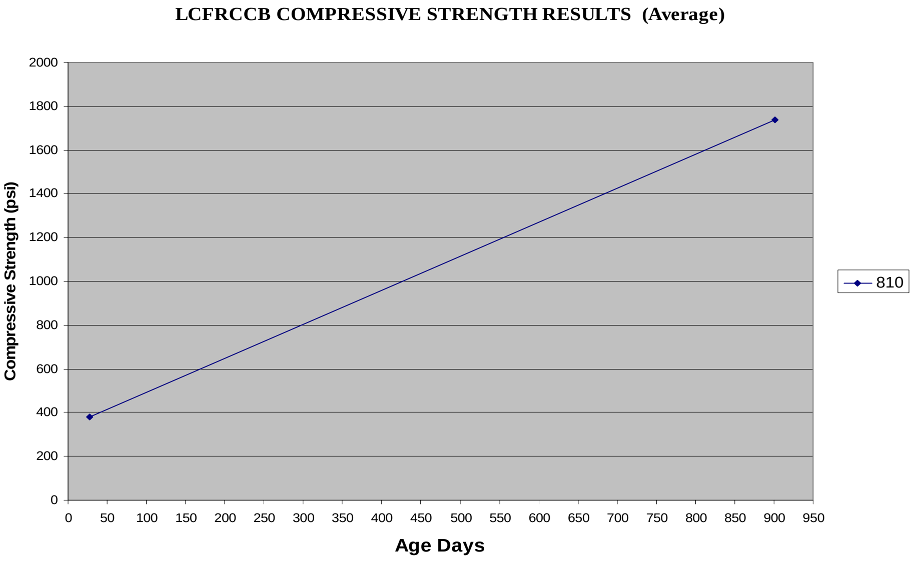


Fig. 7: LCFRCCB COMPRESSIVE STRENGTH RESULTS (Average)

CONCLUSION

A mixture of lime, cement, and fly ash (LCF) was used as a subbase 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. Since the LCF is a subbase to support a PCC surface, an overly rigid subbase was considered undesirable in the design phase. . The non-destructive tests at the end of one year life showed an E-value of 900,000 psi for LCF layer.

The mixture design approach used achieved the desired results based on field core test data. The 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 is the first use of LCF as a subbase for a PCC pavement in the world. The project is expected to save money and perform well.