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Performance of Constructed Facilities: Pavement Structural Evaluation of William P Hobby Airport in Houston, Texas

Kim, Sung-Hee* · Jeong, Jinhoon** ·Kim, Nakseok***

Abstract

The results of a recent case study for material characterizations and structural evaluation to design asphalt overlay thickness of William P Hobby airport in Houston, Texas are presented herein. The existing runway 12R-30L of Hobby airport consisted of thick asphalt overlay over Portland Cement Concrete (PCC) and the localized surface shoving as evident in the closure of surface groove has been observed recently. Using the field cored asphalt concrete mixtures, measurements of percent air voids, asphalt content and aggregate gradation were conducted to find out the causations of surface shoving and groove closure. The FAA layered elastic program, LEDFAA was utilized to evaluate pavement structural conditions for new asphalt overlay. Two different composition assumptions for existing pavement were made to evaluate the pavement as followings: 1) APC, Asphalt Concrete Overlay over PCC pavement and 2) AC, Asphalt Concrete pavement. Based on laboratory testing results, a ratio of percent passing #200 to asphalt content ranged 1.1 to 2.2, which is considered a high ratio and a tendency of tender mix design was observed. Thus, the localized surface shoving and groove closure of the runway 12R-30L could be attributed to the use of excessive fine contents and tender mix design. Based on the structural evaluation results, it was ascertained that the analysis assuming the pavement structure as AC pavement gives more realistic structural life when the asphalt overlay is thicker enough compared to PCC layer because the existing PCC pavement under asphalt overlay acts more like a high quality base material.

Keywords: Airport Pavement, FAA, PCC, Asphalt Overlay, tender mix, LEDFAA

요 지

본 논문에서는 텍사스 휴스턴에 소재하는 William P Hobby공항의 아스팔트 덧씌우기 포장 두께를 설계하기위한 재료 특성화와 구조평가 연구결과에 관한 최근의 사례결과를 나타내고 있다. Hobby 공항의 12R-30L 활주로는 포틀랜드시멘트 콘크리트 포장위에 두꺼운 아스팔트 덧씌우기 층으로 구성되어 있으며 최근 부분적인 표면 밀림 현상이 관측되었다. 아스팔트 혼합물 현장코아 시료를 사용하여 표면 밀림현상 원인을 분석하기 위하여 공기량, 아스팔트 함량 및 골재 입도 분석이 수행되었다. 미연방 항공우주국의 탄성층 해석 프로그램인 LEDFAA가 새로운 아스팔트 덧씌우기층의 포장구조 상태를 평가하기 위하여 사용되었다. 이를 위하여 두 가지의 포장구성 상태가 존재한다고 가정하였다. 즉 PCC 포장위에 아스팔트 콘크리트 덧씌우기층, 그리고 아스팔트 콘크리트 포장. 실험실 시험결과를 근거로 아스팔트 바인더 함유량에 대한 200번째 체 통과 골재비는 1.1~2.2이며 비율이 높을수록 혼합물은 연성을 보이는 것으로 나타났다. 따라서, 12R-30L 활주로의 표면밀림 현상은 과도한 세립골재 함유율로 인한 연성혼합물이 원인인 것으로 나타났다. 구조 평가결과에 의하면 아스팔트 포장으로 포장구조를 가정한 해석 결과는 PCC층에 비하여 좀 더 두꺼운 아스팔트 층일때 더 실질적인 구조적 수명을 나타내었다. 아스팔트층 하부의 PCC포장은 고급기층재료 역할을 수행하기 때문인 것으로 해석된다.

핵심용어: 공항포장, 미연방 항공우주국, 포틀랜드시멘트 콘크리트, 아스팔트 덧씌우기

1. Introduction

The pavement sections on Runway 12R-30L at William P. Hobby Airport was originally constructed in the 1940's with 152 mm Portland Cement Concrete (PCC) on a 152 mm shell base. Between the original construction date and the 1970's, the runway received a series of hot mix asphalt (AC) overlays, resulting in a nominal pavement section of 229-584 mm AC/152 mm PCC/152 mm shell base.

In 1983-1984, the structural condition of Runway 12R-30L was re-evaluated and it was found the pavements to be understrength for projected traffic. Based on the studies, Runway 12R-30L were milled down to the original 152 mm PCC layer and replaced with a new 229 mm (nominal) PCC layer to the original runway elevation. At the completion of the PCC layer construction, the entire runway width (keel and sides) was

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*Assistant Professor, Division of Engineering Southern Polytechnic State University 1100 S. Marietta Parkway Marietta, GA 30060(E-mail: skim4@spsu.edu)
**Member · Civil & Environmental Engineering Inha University, Korea
***Member · Dept of Civil & Environmental Engineering Kyonggi University, Korea (Corresponding Author)

overlaid with a nominal 102 mm AC layer to a new runway profile. The construction works for this keel rehabilitation were implemented in 1986.

In 1995, the rehabilitations of Runway 12R-30L surface and a pavement overlay was performed. During an analysis in 1998, it was observed that Runway 12R-30L was undergoing unusual deterioration in the form of extensive shrinkage cracking longitudinal, transverse and diagonal. Resultant Pavement Condition Index (PCI) values were 86-93, while still in the “excellent” range, were quite low for a pavement that was only four years old at the time. Due to unusual deterioration, the asphalt overlay was conducted in Runway 12R-30L in 2004.

In 2005, the localized surface shoving and groove closure were observed on the pavement. To figure out the causation of the distresses, the material testings and structural evaluation were conducted. Measurement of aggregate particle distribution, asphalt content, and air void were performed and the pavement structural evaluation was also conducted. The technical approach to the pavement investigation study for the asphalt overlay at Runways 12R-30L consisted following basic elements: 1) Reviews of as-built records, 2) Nondestructive Testing (NDT), 3) Material Testing, 4) Traffic Analysis and 5) Pavement Structural Evaluation. FAA Advisory Circular 150/5320-6D, “Airport Pavement Design and Evaluation”, was used to determine equivalent operations of the design aircraft (FAA, 1998). The processed NDT data, material testing results, and traffic projections were used in comprehensive layered elastic analysis program, LEDFAA to evaluate the structural condition of the pavement according to FAA Advisory Circular 150/5370-11 (FAA, 2004).

2. Material testings and results

Field cores of asphalt concrete were taken and the bulk specific gravity (G_{mb}) was measured using the AASHTO T166-93 procedure. The maximum specific gravity (G_{mm}) was measured using the AASHTO T209-99 procedure. Then, the percent air voids was calculated using Equation (1):

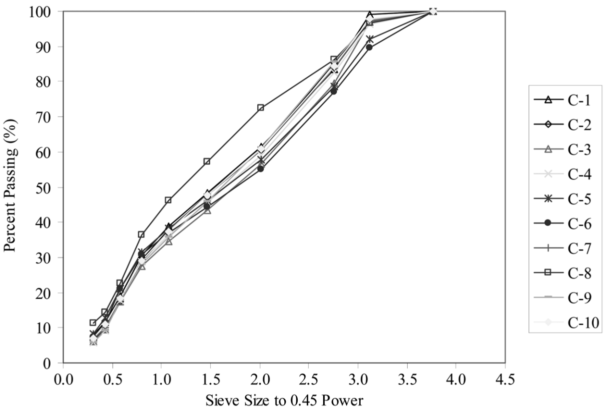

Fig 1. Particle Size Distributions of Field Cores (0.45 Power Curve)

$$\text{Percent Air Voids (\%)}\left(1-\frac{G_{mb}}{G_{mm}}\right)\times 100\% \qquad (1)$$

As shown in Table 1, the percent air voids ranged from 3.0 to 5.1%. This percent air voids is considered reasonable for an asphalt pavement layer. The asphalt content was determined using the ignition oven according to the AASHTO T308 procedure. As shown in Table 1, the aggregate content ranged between 5.1% and 6.5%. The aggregate gradation was determined using the ASTM C136 procedure. The aggregate gradations are plotted in the 0.45 power chart in Figure 1. The C-8 core had a gradation that is much finer than the other field cores. The percent of material passing sieve #200 for core C-8 was 11.25% which was the highest among all cores. The ratio of material passing sieve #200 to asphalt was between 1.0 and 2.2, which is considered a high ratio as the recommendation of the Superpave for a new mix design to have this ratio between 0.6 to 1.1 (Sung-Hee Kim. et al., 2003).

Asphalt Institute describes a method to check for tender mixes as following: The factor leading to mix tenderness is an excess of the middle-sized sand fraction in the material that passes the 4.75 mm (No. 4) sieve. This condition is characterized by a “hump” in the grading curve that can appear on nearly any sieve between No. 4 and No. 100 sieves. The

Table 1. Gradations and Volumetrics of Field Cores

Sieve Size	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10
1/2"	99.0	97.6	96.9	96.2	91.9	89.5	97.3	96.6	97.6	97.8
3/8"	83.5	85.4	79.6	82.5	78.6	77.1	83.8	86.1	85.5	84.5
No. 4	61.5	60.4	56.5	58.9	57.8	55.0	60.4	72.5	61.1	60.9
No. 8	48.3	47.6	43.4	45.5	46.3	44.2	47.9	57.2	46.0	47.6
No. 16	38.7	37.9	34.6	36.5	38.1	36.9	37.5	46.2	35.8	37.3
No. 30	30.6	29.3	27.5	28.8	31.5	30.8	28.7	36.3	28.1	28.9
No. 50	19.1	17.4	17.4	17.8	21.0	21.0	17.6	22.5	17.6	18.5
No. 100	11.7	9.5	9.6	9.2	12.7	11.3	10.0	14.5	9.3	11.1
No. 200	7.8	6.4	6.1	5.9	8.2	7.2	6.6	11.2	5.7	6.9
G_{mm}	2.390	2.410	2.412	2.409	2.400	2.440	2.380	2.421	2.419	2.400
G_{mb}	2.289	2.314	2.338	2.322	2.327	2.361	2.268	2.299	2.310	2.279
% Air Voids	4.2	4.0	3.1	3.6	3.0	3.2	5.1	5.0	4.5	5.0
% Asphalt	6.5	6.0	5.8	5.5	6.0	5.5	6.1	5.1	5.9	6.1

hump typically occurs near the No. 30 sieve. Problem gradations can usually be detected on the 0.45 power gradation chart. Studies have indicated that if there is a deviation exceeding 3 percent upward in the gradation curve from a straight line drawn from the origin of the chart to the point at which the gradation curve crosses the No. 4 sieve line, a tender mix problem is likely.

Table 2 compares the percent passing at No. 30 sieve between straight line and upward point. It was found that the deviations exceed at least 27 percent upward in all the gradation curves from straight lines. The result clearly shows the evidence of tender mix.

3. Input for structural evaluation

The Nondestructive Testing (NDT) was performed to determine the structural input of pavement subgrade. The load response data resulting from the dynamic force simulates the effect of moving aircraft loads. This data can be used as reliable input for computer analysis which utilizes both conventional and elastic theories for pavement design and evaluation.

The test involves measuring deflections at the center of the machine loading plate and also at fixed distances from center. After pavement thickness and composition was established, back-calculation procedures were used to reduce the NDT data for structural evaluation purposes. Corps of Engineers' and FAA research found good correlation between the subgrade elastic modulus determined from NDT and that determined from laboratory resilient modulus testing (FAA, 2004). Sensitivity analyses also found the subgrade modulus from layered elastic to be relatively insensitive to minor variations in base course and surface course moduli or thickness. Thus, the subgrade modulus from NDT is believed to be an accurate representation of the in-situ subgrade elastic modulus.

Heavy Falling Weight Deflectometer (HWD) was used for the testing program. The machine is well capable of exceeding the minimum pavement deflection referenced in U.S. Federal Aviation Administration (FAA) and Department of Defense (DOD) publications, and is capable of performing deflection basin and ISM test sequences. The HWD is capable of producing impulse loads up to 245 kN and utilizes seven response-monitoring sensors for data recordation. The sensors were placed at the center of the loading plate and at radial offsets of 203, 457, 610, 914, 1219, and 1,524 mm. For this study, the tests were conducted at maximum nominal force amplitude of 67 kN.

After the NDT, the Corps of Engineers WESDEF computer program was used to backcalculate pavement layer and subgrade resilient modulus (Van Cauwelaert. et al., 1989). WESDEF provides a layered elastic solution, whereby the elastic modulus for each layer is fitted such that the theoretically computed deflection basin matches the one measured by NDT. Based on NDT, the subgrade modulus generally ranged between 137,895 kPa to 206,843 kPa. Finally, subgrade moduli of 137,895 kPa and 165,474 kPa were selected for Runway 12R-30L Stations 8+00 to 50+00 and for Stations 50+00 to 76+00, respectively.

Aircraft operations forecasts and fleet mix projections were prepared by Hobby Airport. In the traffic forecast report, the connecting scenario, which reflects the assumptions that Hobby airport would increasingly be relied upon as a central U.S. transfer point for passengers traveling between city pairs on the East and West Coasts, was utilized. The increase in domestic air carrier airline operations in the connecting scenario represents an annual compounded growth rate of 2.1% during the 20year forecast period. The Year 2017 operations were used as the average year to estimate aircraft departures over the planning horizon. The mixed fleet traffic data used for the design of Runway 12R-30L is summarized in Table 3.

5. Structural analysis and discussion

The existing pavement structural compositions from field coring were used to develop models of existing pavement thickness and composition for the structural evaluations. The thickness and composition of the developed models are summarized on Table 4. A review of the coring data showed that new runway profile resulted in AC overlay layer thicknesses ranging from approximately 152 mm to 483 mm. PCC layer ranged 229 to 533 mm. The weakest pavement section was

Table 3. Design Traffic

Aircraft	Gross Taxi Weight (kg)	Departures
		Total Departure Connecting Scenario (2017)
Narrow-Body Jets		
A320	68,039	2,876
B717	53,977	2,615
B737-300	63,502	15,889
B737-500	60,781	11,543
B737-700	69,400	23,247
B737-800	78,471	2,354
B757	113,398	4,236
Domestic Regional/Commuter Aircraft		
Dual Wheel-45	20,411	6,465
General Aviation/Other Air Taxi Departure		
Dual Wheel-60	27,216	50,100

Table 2. Percent upward at #30 sieve from Straight Line

	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10
Straight Line	23.25	21.3	20.48	20.73	23.16	21.43	21.69	27.95	21.31	22.65
Upward Point (#30)	30.6	29.3	27.5	28.8	31.5	30.8	28.7	36.3	28.1	28.9
% Upward	31.6	37.5	34.3	39.0	36.0	43.7	32.3	29.9	31.8	27.6

Table 4. Pavement Structural Design Life (Station is in Feet)

Facilities	Station		Thickness (mm)			Expected Design Life (years)	
	From	To	P401	P501-1	P501-2	Assumed as APC	Assumed as APC
RW12R	8 + 00	19 + 00	229	229	152	10	>20
	19 + 00	22 + 00	229	254	152	10	>20
	22 + 00	24 + 00	254	533	178	>10	>10
	24 + 00	27 + 00	152	533	152	>10	>10
	27 + 00	29 + 50	305	356	127	>10	>10
	29 + 50	31 + 00		406	152	>10	>10
	31 + 00	36 + 50	330	330	178	>10	>10
	36 + 50	50 + 00	279	229	152	>10	>10
	50 + 00	55 + 75	305	330		>10	>10
	55 + 75	56 + 60	483	406		>10	>10
	56 + 60	63 + 75	432	330		>10	>10
	63 + 75	71 + 75	279	330		>10	>10
	71 + 75	72 + 65	203	610	203	>10	>10
	72 + 65	76 + 00	203	330		>10	>10

turned out to be Station 8+00 to 19+00.

Layered elastic analysis was employed to evaluate the structural condition of Runway 12R-30L. Layered elastic computations utilize the elastic moduli of pavement and subgrade layers with traffic inputs in sophisticated design procedures to compute pavement stresses and strains at critical locations in the pavement structure. The computed values are compared to limiting stresses and strains that are based on requirements to limit pavement roughness and cracking.

Layered elastic stress and strain criteria are described in FAA Research Report RD-74-199, “Development of a Structural Design Procedure for Flexible Airport Pavements”, RD-77-81, “Development of a Structural Design Procedure for Rigid Airport Pavements”, and DOT/FAA/PM-87/19,” Design of Overlays for Rigid Airport Pavements” (FAA, 2001; FAA, 2003; DOT/FAA, 2000). A more complete description of layered elastic analysis and its theoretical basis is contained in the references. Version 1.3 of FAA’s LEDFAA program included in FAA Advisory Circular 150/5320-6D was used for the layered elastic computations (FAA, 1996).

Standardized pavement material property defaults, such as fixed concrete modulus (27,579 MPa) and unbounded interface condition between concrete slab and subbase (frictionless slip), were used in the FAA design procedures.

The expected structural life is essentially the remaining time to programmed rehabilitation (i.e. theoretical fatigue life) and is computed by dividing the total allowable number of load repetitions of the design aircraft by the estimated current yearly load repetitions of the design aircraft. The expected life estimate is used to prioritize and program repairs on a relative basis and does not necessarily indicate the time to structural failure or facility inoperability. The expected life analysis gives a realistic indication of pavement needs and rehabilitation priorities.

It is believed that as the overlay thickness becomes greater at some point, the existing rigid pavement will tend to act more like a high quality base material. When this condition is reached, the overlay can be designed as a flexible pavement with the existing pavement treated as a high quality base course. Since the thickness of existing asphalt overlay is thicker enough compared to PCC layer, the original 152 mm PCC was modeled as both concrete and aggregate base to compute structural lives, which results the pavement structure in APC (Asphalt overlay over PCC pavement) and AC (Asphalt Concrete pavement). Structural life estimates for the various sections of Runway 12R-30L are summarized in Table 4.

As a result, the pavement evaluation when the pavement was assumed as APC gave longer design life. This is more realistic thickness requirements from a capacity standpoint since the Pavement Condition Index (PCI) on Runway 12R-30L ranged 86 to 96.

6. Conclusions

To investigate the causation of surface shoving and groove closure and to evaluate the structural condition of Runway 12R-30L of William P Hobby Airport, the field cores were taken for measurements of aggregate particle size distribution, asphalt content, and air voids. The ratio of material passing sieve #200 to asphalt ranged 1.0 and 2.2, which describe the excess of fines. A tender mix design was also observed. It is ensured that the localized surface shoving and groove closure are attributed to the mix design problem.

The LEDFAA procedure has special rules for AC over PCC overlay design to protect the overlay from reflective cracking. For the subject pavement sections, these special rules resulted in excessive overlay requirements. Thus, when analyzing the AC over PCC sections, the PCC was modeled in LEDFAA as a high quality aggregate base as allowed for in Section 406 of the FAA AC 150/5320-6D. This method of Section 406 gives more realistic thickness requirements from a capacity standpoint but may not protect the overlay from reflective cracking. Based on the computed structural lives, Runway 12R-30L is structurally adequate for the projected traffic. Although pavement strengthening is not indicated for several sections, this does not mean that some form of rehabilitation should not be considered for these areas. It was recommended that the overlay and rehabilitation for these areas should be driven by functional, rather than structural requirements.

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