UTW AND SASW FOR GENERAL AVIATION AIRPORT PAVEMENT REHABILITATION

By:
Norbert Delatte and Shen-en Chen
The University of Alabama at Birmingham
and
N. Mike Jackson
The University of North Florida

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Abstract

Ultrathin Whitetopping (UTW) is a proven technique for rehabilitating asphalt pavements with a thin concrete overlay. Although some UTW projects have been constructed at General Aviation (GA) airfields, the vast majority have been on highways, streets, and intersections. The oldest UTW overlays are now approximately ten years old. Typical UTW pavement thickness is 2 to 4 inches, with the pavement divided into blocks using early-entry saws at 2 to 4 foot spacing.

Potential benefits of UTW for GA airfields include a durable wearing surface, resistance to fuel spills, economy, improved visibility and enhanced safety, and a reduction in the heat island effect around the airfield. The chief barrier to the use of UTW for GA airfields is that it is not yet proven that these overlays will last for a typical FAA pavement design life of 20 years. Of particular concern is the durability of the concrete-to-asphalt bond under freeze-thaw cycling.

Typical design and construction considerations for UTW include the condition and thickness of the existing pavement, the material properties of the asphalt, the underlying layers (base, subbase, and subgrade), surface preparation, UTW concrete, environmental effects, and pavement drainage. There are some significant differences between highways and airfields for some of these considerations. For highways, UTW is often used to rehabilitate badly rutted pavements. GA airfields generally are susceptible to block cracking, but are highly rut resistant due to stiffer asphalt grades and an angular aggregate structure. Deterioration due to fuel spills is an important issue. Another difference is that pavement drainage is more challenging for airfields, due to wider expanses of pavement and flatter slopes. These differences present challenges for extrapolating successful UTW street and highway experience to airfields.

To date, two GA airfield aprons and one complete airfield have been overlaid with UTW. The Spirit of St. Louis, Missouri, airfield apron, constructed in 1996, was instrumented to determine pavement stresses and strains under aircraft loading. The New Smyrna Beach, Florida, GA airfield apron was overlaid with UTW shortly thereafter. Recently, the Savannah-Hardin County, Tennessee, airport runway, taxiways, and apron were rehabilitated with UTW. Another airport, Centennial, Colorado, was constructed with a 6-inch concrete overlay over asphalt, and incorporated the short joint spacing used with UTW.

The Spectral Analysis of Surface Waves (SASW) method is a powerful nondestructive testing (NDT) tool for estimating the engineering properties of surface layers. For UTW planning and design, SASW may be used to assess the condition and thickness of the asphalt and underlying pavement layers. Following UTW construction, SASW may be used to monitor the overlay condition and investigate potential problem areas. Results of SASW testing on asphalt pavements and UTW overlays are presented. Implications of using this method to plan, control, and investigate UTW for GA airfields are discussed.

Introduction

Ultrathin whitetopping (UTW) is a proven technique for rehabilitating street and highway pavements. However, it has not yet been widely adopted for airfield pavement rehabilitation. The primary concern of the Federal Aviation Administration (FAA) and the aviation community is the durability of the concrete-to-asphalt bond over time and under repeated freeze-thaw cycling. The aviation community concerns may be stated as follows:

- Will the concrete-to-asphalt bond last for the 20-year design structural life of a light-duty airport, particularly in an environment with many freeze-thaw cycles?
- What is the impact of concrete-to-asphalt bond of unsealed sawcut joints? Is sealing required, and if so, what is the impact on durability, performance, and maintenance cost?
- Most UTW experience has been on streets and highways. Airfields have slower surface drainage than highways due to larger areas and more gentle slopes. How will the presence of moisture affect durability and performance, in light of the concerns raised above?

Benefits of UTW for airports

Light duty airport pavements are typically designed for 20-year structural life. These pavements normally receive an overlay at about 12 ½ years, which extends structural life to 30 years. There are many potential benefits of UTW for these airports.

Durable wearing surface

The main reason to use UTW for airports and parking aprons is to provide a durable wearing surface. UTW has been very successful for rehabilitating rutted asphalt pavements. However, rutting is generally not a problem for airfields and parking aprons. The intent of UTW is to provide this durable wearing surface and eliminate the need for future overlays. Asphalt overlays over cracked asphalt or concrete pavements often develop reflective cracking over time. This does not occur with UTW.

Resistance to fuel spills

It has been noted that asphalt pavements for parking aprons are particularly vulnerable to fuel spills. Current FAA requirements for hot mix asphalt surfacing state that "Whenever a hot mix asphalt surface is subject to spillage of fuel, hydraulic fluid, or other solvents; such as at aircraft fueling positions and maintenance areas, protection should be provided by a solvent resistant surface." (p. 31, FAA, 1995). Fuel spills on asphalt aprons often lead to durability problems. This was observed at the Savannah-Hardin County Airport. It would still be possible for fuel spills to seep into unsealed joints between UTW panels.

Economy

The chief barrier to the use of concrete pavements for airports has been cost. However, typical FAA concrete designs for this class of airport require 5 or more inches of concrete. When concrete is used as an overlay over asphalt, a higher modulus of subgrade reaction support (k up to 500 pci) may be used (FAA, 1995). However, this procedure does not allow the use of the asphalt as part of a composite section to reduce the stresses in the concrete for design.

With the use of UTW, stresses can be considerably reduced, and thinner overlays may be used. Therefore, UTW may become competitive even on a first cost basis with asphalt overlays. UTW estimates for Savannah-Hardin County airport were lower than several asphalt alternatives, and bids came in up to 22 % lower than the estimate. This is on a first cost basis, and not life cycle cost – life cycle costs would be lower, due to the longer projected life of UTW.

Improved visibility and enhanced safety

Pilots have remarked that the new Savannah-Hardin County Airport, with its light colored concrete surface, is easier to spot from the air. This will enhance safety, particularly in inclement weather.

Reduced heat island effect

Of secondary concern, except perhaps to airfield workers, is the considerable reduction in temperatures in warm climates with the use of concrete pavements rather than asphalt. Temperature reductions of up to 10 º F have been noted (pp. 4-5, ACPA, 1998). The reduced heat island effect helps to retard the production of ground-level ozone, which contributes to smog and poor air quality in urban and congested areas.

Barriers to use of UTW for airports

UTW is a relatively new technology, and even now the oldest overlays of this type on streets and highways are only about a decade old. Therefore, the long-term durability of UTW has not been proven in the field. The aviation community is concerned with the loss of bond with time, particularly with repeated freeze-thaw cycles. Loss of bond would potentially lead to corner cracking. Of particular concern, corner breaks and loose concrete could lead to Foreign Object Damage (FOD) and possible damage to aircraft. UTW typically uses unsealed joints. At the Centennial airport, which was built with some similarities to UTW, the 1/8-inch joint between panels was sealed with silicon. This introduces additional cost, as well as possible maintenance problems.

Another potential barrier is that curing time must be provided for UTW, in contrast to asphalt pavement. Therefore, reconstruction with UTW could have pavements out of service longer than HMA overlays. However, with current UTW technology it is possible to put traffic on pavements in 24 to 48 hours.

Background

Existing pavement

Typically FAA asphalt pavement is highly resistant to rutting – stiff binders are used, some of which are latex modified. Using an angular aggregate skeleton also improves rut resistance. Typical distress is block cracking, which applies to aprons and channelized taxiways. This is illustrated in figure 1. The pavement may also be damaged by fuel spills, as shown in figure 2.

Base, subbase, and subgrade

Layers under the existing asphalt are important from two standpoints – structural support for the pavement and drainage. It is necessary to consider both when evaluating existing pavement and designing overlays.

Figure 1: Runway with cracking

Figure 2: Fuel spill damage

Condition and thickness

Condition and thickness of the existing asphalt is of concern. Current ACPA recommendations require at least 3 inches of asphalt after milling (ACPA, 1998). Figure 3 shows cores with less than 3 inches of asphalt. Deficient thickness should be corrected before constructing UTW.

Figure 3: Existing pavement thickness

Asphalt aging

Mechanical properties of asphalt change considerably as asphalt ages. Factors that affect asphalt aging include:

- Oxidation – reaction of oxygen with asphalt cement
- Thixotropy – formation of harder structure within asphalt cement
- Synerisis – loss of thin oily constituents
- Separation – selective absorption of constituents by porous aggregates) (pp. 42 – 44, Roberts et al., 1996)

The actual mechanisms are not important – what is important is that, over time, the stiffness of asphalt increases. As a result, its resistance to cracking decreases, although its resistance to rutting increases. Aging proceeds more rapidly at the pavement surface, since the surface is exposed to oxygen and provides a path for lighter, more volatile fractions to escape.

Historically, the grade of asphalt used has varied throughout the United States. Softer asphalt is more susceptible to rutting at high temperatures, but less susceptible to cracking at low temperatures. As a result, softer asphalts have historically been used in northern states, and harder asphalts were used in the south.

Surface preparation

The above discussion refers to the aging of the surface of the asphalt. However, asphalt surfaces are prepared for UTW by cold milling. Therefore, the surface that the UTW actually bonds to has been buried under the surface asphalt, and therefore has not aged as much. Milling leaves a rough surface, with some fractured aggregate particles, which facilitates bond.

UTW concrete

UTW concrete varies somewhat from typical paving concrete. Higher cementitious material contents and a low water to cementitious materials (w/cm) ratio are used to attain higher flexural strength (700 to 800 psi) at earlier ages. Synthetic fibers are generally used, at a rate of about 3 pounds per cubic yard. ACPA notes that "The need for fibers and the optimum content have not been established" (p. 45, ACPA, 1998). The entrained air content is about 6 %, and water reducing admixtures or superplasticizers are often used.

Concrete of this strength, with proper air entrainment, may be expected to be highly resistant to freeze-thaw damage. However, it remains to be seen whether the concrete-to-asphalt bond will be similarly resistant.

Early age behavior

Concrete undergoes volume changes at early ages due to shrinkage and thermal expansion and contraction. These volume changes can lead to significant stresses at the interface between an overlay and the base pavement, and may lead to debonding. Experience with concrete overlays bonded to concrete has shown that if debonding occurs, it generally occurs within about 48 hours of placement. Often, debonding has been associated with poor curing practices (Delatte, 1998). Although debonding has been observed in some cases for concrete overlays over concrete, it has not been reported for UTW. However, the extensive corner cracking observed on I-20 near Jackson, Mississippi (Delatte and Webb, 2000) may have been associated with slab corner debonding.

Curling and long-term performance

Concrete slabs curl upward and downward with daily temperature cycles. Two extreme conditions occur. Extreme downward curling occurs when the top of the slab is significantly warmer than the bottom, and generally occurs in mid to late afternoon. The expansion of the top of the slab may also close up and lock together thin sawcut joints, increasing overall pavement stiffness.

Upward curling is of more concern because of the tendency of slab corners to lift up, debond, and become unsupported. That, in turn, may lead to corner breaks. Upward curling occurs when the top of the slab is significantly cooler than the bottom, and generally occurs in early morning hours. The slab contraction also results in joints opening up. This is the best time to investigate possible UTW debonding in the field, and to evaluate loss of pavement stiffness.

The amount of curling is directly related to the slab dimensions, and this is why short joint spacing is used for UTW. As a general rule of thumb, joint spacing in feet is roughly equal to slab thickness in inches, to reduce the curling stresses (ACPA, 1998). The ACPA design procedure allows for more load repetitions if joint spacing is reduced. Much of the corner cracking on I-20 in Mississippi occurred where joint spacing had been increased well beyond the ACPA recommendation.

Concrete-to-asphalt bond

The nature of concrete-to-asphalt bond is fundamental to UTW performance. Bond of concrete to any material (concrete, reinforcing steel, asphalt) relies on chemical adhesion and mechanical interlock. In order to maintain bond, the stresses induced at the interface between the overlay and the existing pavement due to loading and curling must remain less than the strength of the bond.

An unsealed UTW joint allows water to sit at concrete slab edges and corners, on top of a relatively impermeable layer. Theoretically, a dangerous situation may occur – this water may freeze, enlarging the gap, thus allowing more water in. In time, the freezing water would pry the overlay away from the base. Because this phenomenon would occur well within the pavement structure, it would be difficult to observe. The first manifestation would probably be corner cracking, although it might be possible to detect debonding through nondestructive testing (NDT) prior to crack forming. Therefore, the fact that this has not yet been documented does not mean that it does not occur.

Environmental effects

Environmental changes in pavement moisture and temperature can induce stresses in pavements, and interact with other damage mechanisms. In order for freeze-thaw damage to occur, moisture must be present, and the pavement must alternately freeze and thaw – pavements that rarely freeze, or freeze once a year and stay frozen, are not highly susceptible.

The Strategic Highway Research Program Long Term Pavement Performance (SHRP LTPP) database divides pavement environmental regimes into wet and dry, and freeze and no-freeze. There are four climate combinations: wet freeze, wet no freeze, dry freeze, and dry no freeze. Detailed climate information is available for a large number of pavement sections in the SHRP LTPP program. This information may be used to review environmental conditions for nearby airports.

It should be noted that locations close to the boundaries of these regimes should be evaluated based on local experience. For example, the SHRP LTPP database identifies Tennessee as a wet/no-freeze environment, whereas the Savannah-Hardin County, Tennessee project will most likely experience significant freeze-thaw cycles.

Obviously, the wet freeze environmental regime poses the greatest danger of freeze-thaw damage. Two existing UTW airfield pavements, Spirit of St. Louis and Savannah-Hardin County, are in or close to the wet freeze region. Over time, the performance of these overlays will provide valuable information about environmental effects on UTW.

Pavement drainage

As noted previously, drainage presents more of a problem for airfields and aprons than it does for highways and streets. Due to wider expanses of pavements and more gentle slopes, it is more difficult to carry water away from the pavement. A pavement even in a dry desert area may have high moisture content underneath. As a result, designers generally assume that the subgrade is saturated.

Therefore, an airfield pavement may be more susceptible to freeze-thaw deterioration than a highway pavement in the same climate, because the airfield pavement would retain more moisture in the subgrade. This is another factor that makes it difficult to extrapolate successful street and highway UTW experience to airfields.

UTW and whitetopping airfield projects

The vast majority of UTW projects have been on highways and streets, particularly intersections. However, some airfield projects have been built, as documented below.

Spirit of St. Louis, Missouri

The Spirit of St. Louis (Missouri) airport apron received a 3.5-inch UTW overlay in 1996 (p. 48, ACPA, 1998). The pavement was cut into 4-foot squares, and carries aircraft loads up to

12,500 lb. This airport has been well documented in a number of research reports, and is situated in an area where freeze-thaw cycling occurs.

Centennial, Colorado

The Centennial airport near Denver, Colorado, is not UTW, but is a relatively thin (about 6 inch thick) concrete overlay on asphalt, cut into small panels. This pavement is currently around 4 years old, 6 inches thick, and carries aircraft loads of up to 72,000 lb. The 1/8-inch sawcut joints were sealed with silicon, which is in contrast to typical UTW practice.

New Smyrna Beach, Florida

The New Smyrna Beach General Aviation airport apron received 2 and 3.5-inch UTW overlays in 1996. This apron overlay received a Florida Aviation Award for 1997 Outstanding Airport Project. Freeze-thaw cycling is not an issue for this airport. Most of the asphalt surface was not milled. Several test variables were investigated – three methods of surface preparation, and four variations of fiber content in concrete (ACPA, undated, Scherling, 1997).

Savannah-Hardin County, Tennessee

The existing pavement at the Savannah-Hardin County airport was badly deteriorated asphalt, with extensive cracking, oxidation, raveling, and some patches due to fuel spillage (shown in figures 1 and 2.). Project goals were to extend the useful life of the runway and provide a durable surface with a fast, economical overlay alternative. The project location in Tennessee, the single biggest user of UTW for streets and highways, meant that contractors familiar with the technology were available. A 4-inch thick overlay was built, with joints approximately 4 feet apart. Joints were not sealed. Total joint sawcutting added up to 45 miles. Because the bids were lower than cost estimates, a contract extension of nearly $ 250,000 for additional apron and taxiway resurfacing was added.

Considerable information is available for this project in a recent paper by Saeed and Hall (2001). The existing asphalt thickness was an average of 4 inches, with a one-inch standard deviation, based on seven cores. The thinnest asphalt core was just less than 2 ¾ inches thick, which may be of concern. Considerable variation was also found for base and subgrade properties. Bending stress analysis using the finite element program Illi-slab led to a predicted pavement fatigue life of 30 years. Two slabs were instrumented to evaluate bond between the UTW and existing pavement.

UTW field and laboratory testing

It has been noted the performance of UTW has been considerably better than would be expected for thin slabs. Some laboratory and field testing has been performed, along with finite element modeling (Delatte and Webb, 2000).

Although UTW technology is only about a decade old, the research record for concrete overlays bonded to concrete pavement is much longer (Delatte et al., 1996). These are commonly termed bonded concrete overlays, or BCO. Therefore, this section addresses not only UTW testing, but also established BCO testing procedures.

Laboratory testing

A number of laboratory test methods have been developed that are applicable to investigating long-term bond performance. The most widely used methods rely on interface shear (e.g. the Iowa bond tester) or direct tension (Dynatest, for example). These are shown in figures 4 and 5.

Figure 4: Interface shear test (Iowa type)

Li et al. (1999) used a composite prism test to investigate the freeze-thaw durability of bond of rapid setting repair materials to concrete. In this test, a cube of repair material bonded to concrete is made, the specimen is cycled in a freeze-thaw chamber, and then the specimen is compressed with knife-edges along the bond interface. The loading is similar to that of the Brazilian splitting tension test (ASTM C 496).

Both methods of testing at the interface, the Iowa test and the Li et al. procedure, have a significant limitation. These tests are much easier to do on a smooth bond interface. However, BCO and UTW surface preparation methods (cold milling, etc.) are intended to provide a rough interface to improve bond. Therefore, when investigating more realistic overlays, the test becomes harder to perform, and results are highly variable.

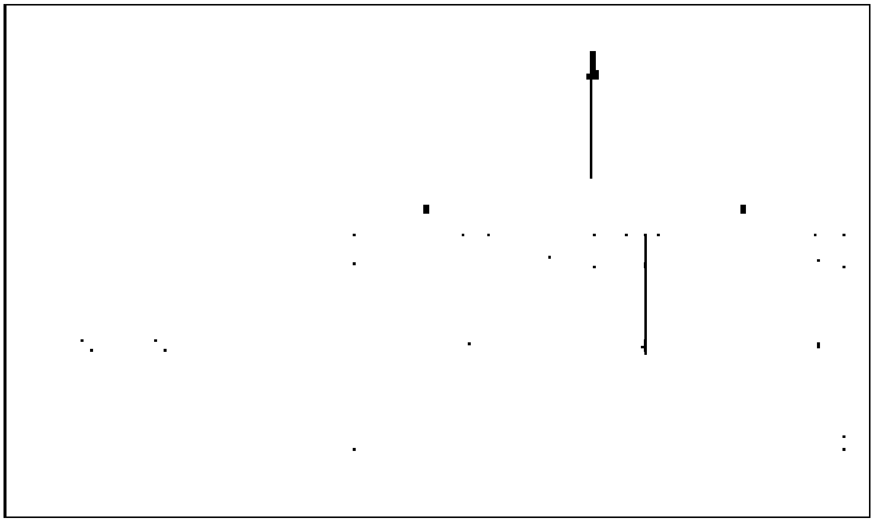

Figure 5: Interface tension test

In contrast, direct tension methods are not dependent upon the roughness of the interface. Typically, a specimen of base concrete with an overlay is prepared. Next, a diamond coring bit drills through the overlay into the base concrete. An aluminum cap is attached to the overlay with epoxy. Finally, the pull-off tester is attached to the aluminum cap, and tension is applied until failure. This method may also be employed in the field.

One disadvantage of this method is that failure does not necessarily occur at the interface. However, this problem may be overcome. Failure may occur at the interface, in the base pavement, within the overlay, or where the cap is attached to the surface, with the first and last modes being the most common. In the past, failures frequently occurred where the cap was attached to the overlay with epoxy (Delatte et al., 1996).

However, use of a weaker epoxy has a useful application to field-testing, where it is desirable to avoid damage to the pavement. If a core is drilled into an in-service pavement, it will be easy to see if it is debonded – the core will be loose. If not, a pull-off cap may be attached with epoxy, to provide a proof test – once the epoxy fails, a lower bound estimate of bond strength is obtained (Delatte et al., 1996). In either case, the epoxy may then be used to glue the core back into the hole, or to seal the gap around the core. The water tightness of the overlay surface is then restored.

The accepted standard for evaluating the freeze-thaw durability of concrete is the ASTM C 666 freeze-thaw test. This test has also been used to evaluate the freeze-thaw durability of bond between overlay and base concrete (Li et al., 1999). Prisms 3 by 4 by 16 inches are placed in an automated freeze-thaw cabinet and subjected to up to 300 freeze-thaw cycles. Damage is evaluated by loss of sample mass, and reduction in modulus of elasticity as measured by a sonometer.

Nondestructive field testing

An important paper on investigating BCO debonding was published by Delatte in 1998. In this paper, a number of nondestructive testing (NDT) technologies were used to attempt to find known debonding in a BCO field test strip. The technologies investigated included spectral analysis of surface waves (SASW), impact-echo, impulse-response, the falling weight deflectometer (FWD) and the rolling dynamic deflectometer (RDD). SASW, impact-echo, and impulse-response all showed potential for detecting debonding. Rebar sounding is also useful, although somewhat subjective. Impulse-response showed the greatest promise (Delatte et al., 1998).

Slabs tend to debond from the corners (Delatte et al., 1996). It is important to investigate possible debonding when the slabs are in an upward curled condition, in the early morning. If the testing is carried out when slabs are curled downward, a debonded interface may be compressed, and would not be detected by NDT methods – although it could still be detected by coring.

SASW and FWD are also useful for estimating engineering properties of layered pavement systems. The SASW is light, portable equipment, and gathers data that may be used to estimate layer stiffness (through shear wave velocity) as well as thickness. It measures properties at low strains. The method provides estimates of the stiffness (based on shear wave velocity) and thickness of each layer. Over the last two years, Delatte and Chen have employed the SASW method with considerable success to investigate soil deposits up to 100 feet deep. It has been possible to measure seasonal moisture-related stiffness variations in layers.

SASW testing was carried out recently at a UTW project about one year old in Selma, Alabama. Figure 6 illustrates the results obtained and processed with University of Alabama at Birmingham (UAB) equipment.

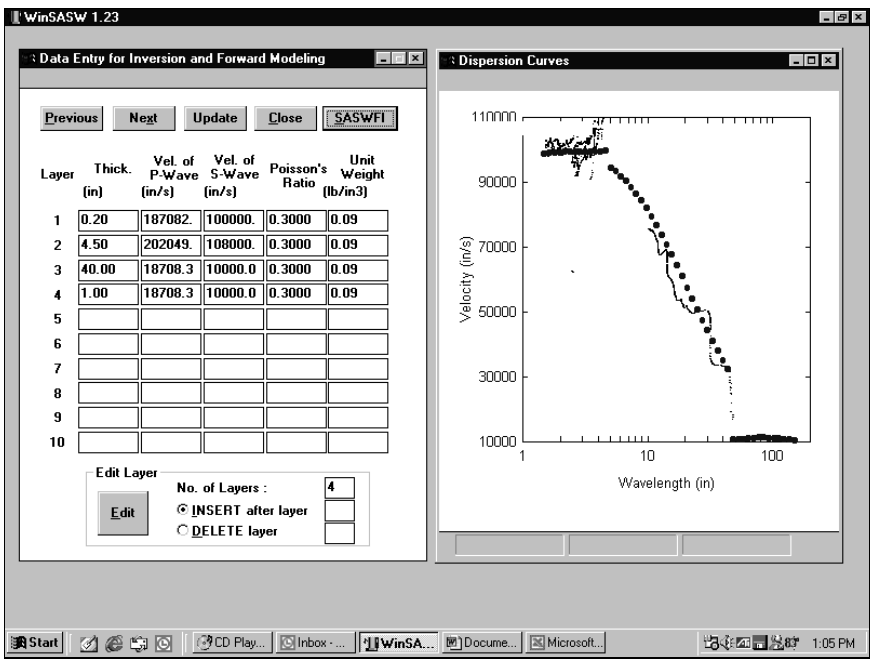

Figure 6: SASW testing results on UTW, Selma, Alabama

It is easy to observe three distinct stiffness regimes – the concrete, with a shear wave velocity of about 100,000 inches per second, the asphalt and other flexible pavement layers with a velocity varying from 30,000 to 70,000 inches per second, and an underlying soil layer with a shear wave velocity of 10,000 inches per second. The field testing layout is shown in figure 7.

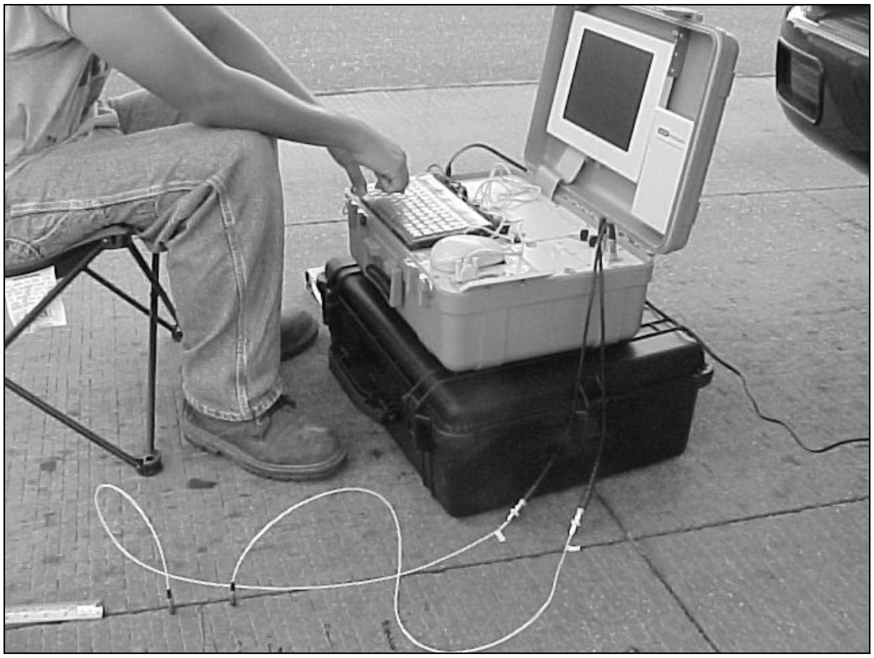

Figure 7: Selma UTW testing

This is a sample of the extensive results obtained during a day of testing, illustrating that the engineering properties of the UTW and underlying layers may be investigated with this method. Shear wave velocity decreases rapidly with depth, representing the decreasing stiffness of the asphalt and underlying layers.

FWD is much heavier, trailer-mounted equipment, and can apply much heavier loads and strains. Thus, pavement response to FWD is much closer to the response to actual traffic loads. However, the FWD has a key limitation – layer properties are calculated based on assumed layer thickness. If the assumed thickness is not correct, layer property estimates will have considerable error. SASW, on the other hand, may be used directly to estimate the layer thickness.

Recommendations for future research

The best approach to pavement evaluation is to compare SASW and FWD results. By using both methods, a more accurate assessment of the pavement structure may be developed. FWD has the important property of being able to evaluate overall pavement stiffness under realistic loading levels – in other words, the actual deflection under aircraft loads approaching 30,000 lb. can be determined. This is important for evaluating the effects of sawcut joints on overall pavement stiffness. It may also be possible to evaluate loss of stiffness due to debonding.

The advantage of the SASW system is its portability. Clearly, SASW has a lot to offer when integrated into a comprehensive testing and quality control for UTW construction. Further research is needed to gather data and refine the analysis for evaluating airfield pavements before UTW construction. Field validation would also be useful for refining methods of using SASW to monitor quality and performance of UTW construction.

Summary and conclusions

Although UTW is a promising technique for airfield pavement rehabilitation, a number of barriers to implementation remain. The concerns of the aviation community are well founded, and need to be addressed. One means of addressing the concerns would be through a comprehensive NDT evaluation of existing UTW airfield pavements. It is recommended that SASW and FWD testing be used in combination to perform such an evaluation.

This paper has reviewed some of the concerns, outlined the benefits of UTW for light-duty airfield pavements, and discussed some of the key testing and quality control considerations. With cautious and appropriate implementation of the technology, UTW is likely to become an economical and viable rehabilitation alternative for airfields.

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