Research

Ultra-Thin Whitetopping for General Aviation Airports in New Mexico

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16. Abstract

Whitetopping is a pavement rehabilitation construction practice where portland cement concrete (PCC) is placed over an existing asphalt concrete pavement as an overlay. Ultra-thin whitetopping (UTW) is generally a thin overlay with a thickness between 2 and 4 inches. UTW is usually of high strength and made with fibers for improved tensile strength, ductility and enhanced fatigue life. UTW differs from conventional whitetopping because of the design and construction procedures that ensure substantial bonding between the UTW and the underlying asphalt. UTW also employs much closer joint spacing than conventional whitetopping; this reduces the load-induced stresses within the UTW. UTW does not make use of steel reinforcement. A literature and technology review found that UTW is a proven means of asphalt pavement rehabilitation for improved serviceability. The mechanistic design concepts for UTW are clearly established. The construction methodologies have been developed and are in place. The material technology for fiber reinforced high strength PCC is available. Specifications have been written and successfully used on numerous highway and airport pavement projects. The initial cost of UTW is more than the common asphalt concrete pavement rehabilitation used in New Mexico. However, life cycle costs of UTW compared to asphalt overlays are considered competitive. It is recommended that the NMSHTD design and construct UTW test sections at an appropriate selected airport in the state of New Mexico. Such a project will allow for the determination of the relative initial costs of the UTW versus asphalt rehabilitation, and long term monitoring will allow for the determination of the life cycle costs and long-term performance of UTW versus asphalt.

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FOR GENERAL AVIATION AIRPORTS IN NEW MEXICO

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PREFACE

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INTRODUCTION

Whitetopping is a pavement rehabilitation construction practice where portland cement concrete (PCC) is placed over an existing asphalt concrete (AC) pavement as an overlay. The thickness of the whitetopping dictates the nomenclature defining the type of whitetopping employed. Convention. Ultra-thin whitetopping (UTW) is the term applied for a PCC overlay thickness between 2 and 4 inches. Some define "thin" whitetopping overlays for a PCC thickness between 4 and 7 inches. One might conclude that "thick" whitetopping applies for a thickness greater than 7 inches.

Ultra-thin whitetopping is generally a thin layer of concrete pavement. The concrete is usually of high strength and made with fibers for improved tensile strength, ductility and enhanced fatigue life. In addition to the thinness, UTW differs from conventional whitetopping because of the design and construction procedures that ensure substantial bonding between the UTW and the underlying asphalt. UTW also employs much closer joint spacing than conventional whitetopping; this closer spacing reduces the load-induced stresses within the UTW concrete overlay. UTW does not make use of any type of steel reinforcement as with some types of conventional whitetopping.

Whitetopping overlays date back to 1918 and have been used on highway pavements, primary and secondary roads, city streets, intersections, and parking areas. They have also been used on airport pavements for runways, taxiways, and apron areas (see NCHRP Syntheses 99 and 204 (Ref. 1 & Ref. 2, respectively)). The following, Table 1, is a fairly complete listing of airport pavements where whitetopping has been employed. The contents of Table 1 were obtained form the above cited NCHRP Syntheses and the American Concrete Paving Association's (ACPA) Engineering Bulletin on Whitetopping (Ref. 3). This table shows a predominance of Jointed Plain Concrete Pavements (JPCP) used for whitetopping with only a few reinforced concrete pavements.

TABLE 1 Partial Listing of Airport Whitetopping, and UTW Projects (1918-1996) (Ref. 1, 2 & 3)

		Whitetopping Overlay			Existing Flexible Pavement				
No.	Location & State	Yr. Built	Thick., in.	Type	Yr. Built	Thick., in.	STATUS	Syn. 99 Proj. No.	Syn. 204 Proj. No.
1	Runway, Offut AFB, IN	1944	7 & 9	JPCP	1941	N/A	Reconstructed in 1958	84	8
2	Apron, Davis-Monthan AFB, AZ	1945	12	JPCP	N/A	N/A	No Info.	89	10
3	Craig AFB, AL	1954	8	JPCP	N/A	11.5	Excellent Cond. in 1964	161	12
4	Runway, Dover, AFB, DE	1954	16	JPCP	1941-43	29	In Service after 27 yr	165	13
5	Baton Rouge Municipal Airport, LA	1954	10	JPCP	N/A	10	Good Cond. after 9 yr, some cracking	162	14
6	Apron, Taxiway, Castle AFB, CA	1955	16 & 18	JPCP	1942	10	In Service after 26 yr	177	15
7	Taxiway, Columbus AFB, MS	1956	16	JPCP	N/A	17	Excellent Cond. after 10 yr, in service 1992	188	18
8	Runway, O'Hare Int. Airport, IL	1958	9 & 11	JPCP	N/A	24	Good Cond. after 6 yr	199	19
9	Runway, Selfridge AFB, MI	1958	13	JPCP	1951	34	N/A	205	20
10	Taxiway, Glasgow AFB, MI	1958	15	JRCP	N/A	55	In Service after 22 yr	203	21
11	Runway, Kincheloe AFB, MI	1958	12	JRCP	1942	9	No Info.	201	22
12	Runway, Los Angeles Int. Airport, CA	1960	10.5 & 15	JPCP	N/A	N/A	Excellent Cond after 4 yr	217	24
13	Midway Airport, Chicago, IL	1967	8	CRCP	N/A	N/A	Overlaid in 1988-1992	237	29
14	**Storm Lake Airport, IA**	**1971**	**5**	**JPCP**	**1963**	**2 to 4**	**In Service 1992**	**250**	**31**
15	Taxiway, Moody AFB, BA	1974	6	CRCP	N/A	N/A	No Info.	290	43
16	Newark Int. Airport, NJ	1976	4	FRC	N/A	N/A	Overlaid in 1980 RW 22R (see No. 28 below)	307	49
17	Apron, McCarran Field, Las Vegas, NV	1976	6	FRC	N/A	18	Excellent Cond. after 5 yr, replaced by 1992	306	50
18	Apron, La Guardia Int. Airport, NY	1977	6	FRC	N/A	N/A	Replaced prior to 1992	315	58
19	**Centerville Airport, IA**	**1979**	**5**	**JPCP**	**1966**	**2.5**	**In Service 1992**	**333**	**61**
20	Apron, McCarran Field, Las Vegas, NV	1979	7	JPCP	N/A	14	Excellent Cond. After 2 yr	334	62
21	Apron, Stapleton Airport, Denver, CO	1981	4 & 7	FRC	N/A	N/A	N/A	375	68
22	Apron, Salt Lake City Airport, UT	1981	8	FRC	N/A	N/A	Excellent Cond. in 1982	373	81
23	**Clairon Airport, IA**	**1982**	**5**	**JPCP**	**1965**	**2**	**In Service 1992**	**N/A**	**84**
24	**Waverly Airport, Bremer County, IA**	**1983**	**5**	**JPCP**	**N/A**	**N/A**	**In Service 1992**	**N/A**	**96**
25	**Corning Airport, IA**	**1987**	**5**	**JPCP**	**N/A**	**4**	**In Service 1992**	**N/A**	**129**
26	Dane County Airport, WI	1987	15	JRCP	N/A	N/A	In Service 1992	N/A	142
27	**Carroll Airport, IA**	**1988**	**5**	**JPCP**	**1972**	**2**	**In Service 1992**	**N/A**	**147**
28	Taxiways, R & D, Newark Int., NJ	1989	10	FRC	1968	4	Excellent Cond. 1992	N/A	158
29	**Fort Madison Municipal Airport, IA**	**1991**	**5**	**JPCP**	**1958**	**5**	**In Service 1992**	**N/A**	**178**
30	**Apron, New Smyrna Beach Airport, GA**	**1996**	**2 & 3.5**	**UTW**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
31	**Apron, Spirit of St. Louis Airport, MO**	**1994**	**3.5**	**UTW**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
32	**Allentown Bethlehem Easton Airport, PA**	**1994**	**3**	**UTW**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

NOTES:

1) Project Nos. 1 through 29 from Table 1, Listing of Whitetopping Projects, of ACPA Engr. Bulletin (EB210.02P)
2) Project Nos. 30 through 32 from Table 12, List of UTW Projects (1991-1996), of ACPA Engr. Bulletin (EB210.02P)
3) Syn. 99 & Syn. 204 Project Nos. from NCHRP Syntheses dated 1982 and 1994, respectively.
4) JPCP = Jointed Plain Concrete Pavement (non-reinforced)
5) JRCP = Jointed Reinforced Concrete Pavement
6) CRCP = Continuously Reinforced Concrete Pavement
7) FRC = Fiber Reinforced Concrete Pavement
8) N/A = Not Applicable or Not Available
9) Projects highlighted in **Bold (Nos. 14, 19, 23-25, 27, & 29-32)** are considered representative of **UTW** type projects on General Aviation Airports.

UTW concrete overlays are a fairly recent innovation with the first such UTW project being designed and constructed on a Kentucky highway in 1988 (see ACPA Bulletin, Ref. 3). The Iowa DOT has been a leader in the use of whitetopping and UTW design, construction, and performance monitoring (see Smith, Ref. 4). Airport aprons at the Spirit of St. Louis Airport in

Missouri were among the earliest airports to use UTW as it is known and defined today. However, it is clear from reviewing Table 1 that numerous airports have used whitetopping as early as the 1970s using concrete overlays of sufficient thinness with plain concrete to be classified as UTW. Table 1 highlights (in **bold** letters) 10 airport pavements that have performed well and appear to be performing well as of this point in time.

DESIGN OF UTW

The design of UTW differs from conventional pavement design in the following fashion. Bond between the concrete and asphalt creates a composite pavement section with shear flow transfer at the interface between the UTW and underlying asphalt material. This results in an increased section modulus and a lowering of the neutral axis within the UTW with resultant reduction in tensile stress at the bottom fiber of the UTW. This composite action between the concrete and asphalt and concrete is not generally recognized in conventional pavement design where an unbonded interface is often assumed. Conventional whitetopping design procedures also characterize the existing pavement support by using an increased value of the modulus of subgrade reaction (*k*) at the top of the asphalt. For UTW, these assumptions regarding bonding at the interface and increased *k* result in a considerable overestimation of the pavement stresses and required UTW thickness. This is illustrated in Figure 1 where a conventional two-layer model (top) and a three-layer UTW model with composite action (bottom) are compared. For the same loading one can see that the UTW stresses are significantly reduced with the composite three-layer analysis. Note that modest tensile stresses exist in the asphalt; these tensile stresses can be compared with allowable fatigue values. Field measurements of Colorado UTW test sections and airport test sections in St. Louis (Wu et al (Ref. 5), and Mowris (Ref. 6) indicate substantial bond and shear transfer at the interface between the concrete and asphalt of the composite section.

Short joint spacing has been found to substantially reduce load induced stresses within the UTW pavement. Curling stresses caused by temperature differential are also reduced. These stress reductions substantially reduce or eliminate the prospects for slab edge uplift. A mechanistic analysis of UTW clearly shows this effect of slab size relative to slab thickness for a given load. This is illustrated in Figure 2 where it is seen that the tensile stress in the UTW slab decreases as the size of the slab is reduced. A simple analysis of a beam on an elastic foundation will prove this to be true as well (e.g., see Hetenyi, Ref. 7). These resultant stress reductions for these relatively small slab sizes also result in reduced warping and curling stresses caused by moisture gradients and temperature gradients, respectively. While stresses are reduced for theses smaller slab sizes, pavement deflections are found to increase. For thin asphalt and base course sections, vertical strains will be high and resultant deflections greater than allowable. There is clearly an optimum joint spacing for stress reduction and allowable deflections under the specified loading. In general it has been found that slab sizes of 12 to 15 times the UTW slab thickness perform well under the prescribed loadings without failing the UTW slab or underlying asphalt material.

The concrete strength required for UTW is generally higher than that employed for conventional concrete. Unconfined compressive strength requirements of 4500 psi are common. For most specifications, the flexural strength (modulus of rupture) should be specified as well. Also, in general, fibers are used which enhances the tensile strength to some extent, but more importantly improves the fatigue resistance of the concrete. ACPA’s Guide Specification (see Appendix A) suggests the evaluation of the concrete’s residual flexural strength, using a modified modulus of rupture test procedure, when fibers are used in the concrete mix design. This test procedure is described in ASTM C 1399, Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete (Ref. 8). This residual strength is specified as 80 psi in the ACPA Guide Specification.

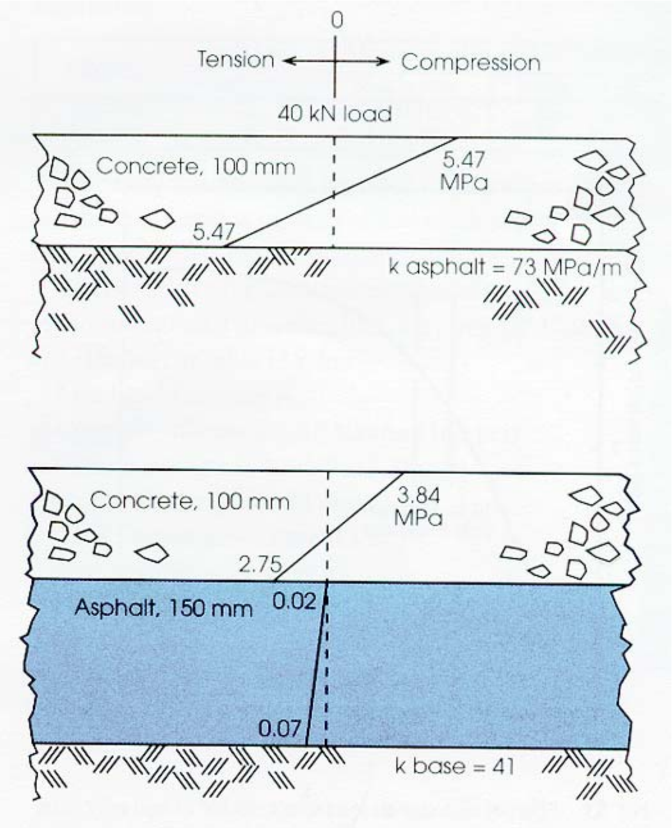

FIGURE 1 Pavement Stress Distribution by Conventional Overlay Design (Top) vs. UTW Composite Design (Bottom) (Ref. 3).

The underlying subgrade and asphalt materials must be of adequate strength and of sufficient structural integrity to provide adequate non-erodible support for the UTW concrete. The structural support provided by the existing subgrade and asphalt pavement is an important component of the thickness design of the UTW. The degree of support from the subgrade is measured in terms of the modulus of subgrade reaction (*k*). This value is determined by the well-known non-repetitive plate bearing load test. This test is expensive and time consuming. Hence, the *k*-value may also be estimated by correlation with other strength and stiffness parameters such as CBR, *R*-value, or cone penetration values. It may also be estimated based on correlations for different soil types. The preferred approach for determining the mechanical properties of the underlying asphalt and subgrade materials for major projects is by the use of nondestructive testing (NDT) (Ref. 2). The falling weight deflectometer (FWD) is a common NDT method for determination of these parameters.

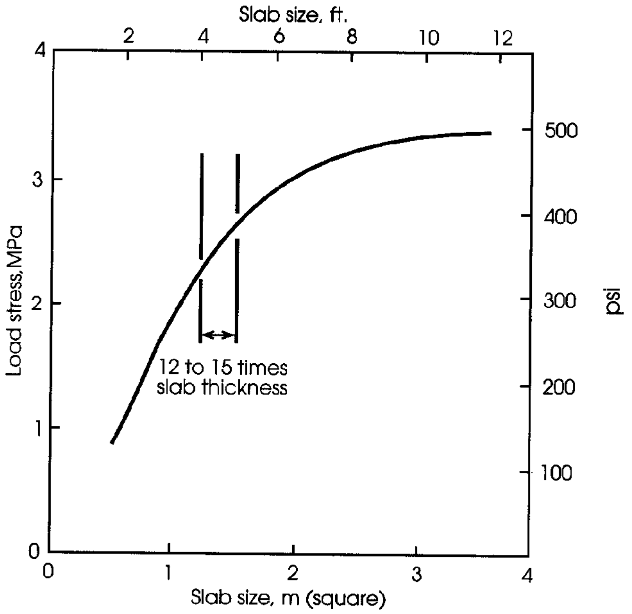

FIGURE 2 Effect of Slab Size on Load Induced Stress (9 kip edge load, 4 in. UTW, 4 in. asphalt, 100 pci subgrade) (Ref. 3).

The American Concrete Pavement Association has developed design tables for UTW design for various aircraft weights and gear configurations that cover most types of aircraft found in the general aviation category. These tables, from ACPA's Engineering Bulletin on Whitetopping (Ref. 3), are shown below as Tables 2 through 5. These tables estimate the allowable number of channelized passes of aircraft for the service life of the pavement. Many general aviation aircraft are quite light in weight (less than 5000 lb) and do not affect the concrete UTW thickness requirements. This applies to all single-engine aircraft and some twin-engine aircraft. Note that the allowable traffic values shown in these tables are a function of the concrete flexural strength, the modulus of subgrade reaction, the UTW thickness, the asphalt thickness, and the spacing of the contraction joints. These tables were developed based on the developed design approach described in Wu et al (Ref. 5).

TABLE 2 Allowable Number of Channelized Passes of Aircraft (12,000 lb gross weight aircraft w/dual gear, or 9,000 lb gross weight aircraft w/single wheel gear, k = 100 pci)

		Ultra Thin Whitetopping Thickness, *c* (in.)					
		2 in.		3 in.		4 in.	
	Joint Spacing	3 ft	2 ft	4 ft	3 ft	6 ft	4 ft
Avg. Flexural Strength, *MOR* (psi)	Asphalt Thickness, *a* (in.)	Allowable Number of Channelized Passes of Aircraft 12,000 lb Gross Weight Aircraft w/ Dual Wheel Gear, or 9,000 lb Gross Weight Aircraft w/ Single Wheel Gear, *k* = 100 pci					
700	3	42000	84000	118000	161000	297000	396000
700	4	102000	190000	223000	302000	483000	Unlimited
700	5	233000	426000	437000	Unlimited	Unlimited	Unlimited
700	6 or More	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
800	3	51000	96000	143000	189000	361000	475000
800	4	116000	211000	260000	346000	Unlimited	Unlimited
800	5	259000	468000	498000	Unlimited	Unlimited	Unlimited
800	6 or More	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited

Unlimited: For practical purposes, 500,000 is taken as the upper limit of channelized passes of aircraft that are heavy enough to affect thickness requirements of general aviation airport pavements.

(Ref. 3)

TABLE 3 Allowable Number of Channelized Passes of Aircraft (12,000 lb gross weight aircraft w/dual gear, or 9,000 lb gross weight aircraft w/single wheel gear, k = 200 pci) (Ref. 3.)

		Ultra Thin Whitetopping Thickness, *c* (in.)					
		2 in.		3 in.		4 in.	
	Joint Spacing	3 ft	2 ft	4 ft	3 ft	6 ft	4 ft
Avg. Flexural Strength, *MOR* (psi)	Asphalt Thickness, *a* (in.)	Allowable Number of Channelized Passes of Aircraft 12,000 lb Gross Weight Aircraft w/ Dual Wheel Gear, or 9,000 lb Gross Weight Aircraft w/ Single Wheel Gear, *k* = 200 pci					
700	3	112000	236000	272000	380000	Unlimited	Unlimited
700	4	246000	487000	472000	Unlimited	Unlimited	Unlimited
700	5	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
700	6 or More	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
800	3	136000	269000	326000	430000	Unlimited	Unlimited
800	4	282000	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
800	5	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
800	6 or More	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited

Unlimited: For practical purposes, 500,000 is taken as the upper limit of channelized passes of aircraft that are heavy enough to affect thickness requirements of general aviation airport pavements.

TABLE 4 Allowable Number of Channelized Passes of Aircraft (20,000 lb gross weight aircraft w/dual gear, or 14,500 lb gross weight aircraft w/single wheel gear, k = 100 pci) (Ref. 3)

		Ultra Thin Whitetopping Thickness, *c* (in.)					
		2 in.		3 in.		4 in.	
	Joint Spacing	3 ft	2 ft	4 ft	3 ft	6 ft	4 ft
Avg. Flexural Strength, *MOR* (psi)	Asphalt Thickness, *a* (in.)	Allowable Number of Channelized Passes of Aircraft 20,000 lb Gross Weight Aircraft w/ Dual Wheel Gear, or 14,500 lb Gross Weight Aircraft w/ Single Wheel Gear, *k* = 100 pci					
700	3	4000	11000	15000	23000	44000	65000
700	4	13000	29000	32000	46000	75000	107000
700	5	35000	70000	67000	95000	133000	188000
700	6 or More	81000	157000	138000	193000	242000	340000
800	3	6000	15000	21000	31000	60000	84000
800	4	17000	34000	41000	57000	97000	134000
800	5	41000	79000	81000	112000	164000	227000
800	6 or More	93000	175000	162000	221000	289000	401000

Table 5. Allowable Number of Channelized Passes of Aircraft (20,000 lb gross weight aircraft w/dual gear, or 15,500 lb gross weight aircraft w/single wheel gear, k = 200 pci) (Ref. 3)

		Ultra Thin Whitetopping Thickness, *c* (in.)					
		2 in.		3 in.		4 in.	
	Joint Spacing	3 ft	2 ft	4 ft	3 ft	6 ft	4 ft
Avg. Flexural Strength, *MOR* (psi)	Asphalt Thickness, *a* (in.)	Allowable Number of Channelized Passes of Aircraft 20,000 lb Gross Weight Aircraft w/ Dual Wheel Gear, or 14,500 lb Gross Weight Aircraft w/ Single Wheel Gear, *k* = 200 pci					
700	3	8000	31000	32000	52000	83000	126000
700	4	31000	73000	64000	98000	132000	195000
700	5	74000	158000	126000	183000	218000	316000
700	6 or More	158000	321000	241000	342000	365000	Unlimited
800	3	15000	39000	46000	69000	113000	162000
800	4	39000	85000	83000	121000	169000	241000
800	5	87000	178000	153000	216000	266000	379000
800	6 or More	181000	354000	276000	390000	430000	Unlimited

Unlimited: For practical purposes, 500,000 is taken as the upper limit of channelized passes of aircraft that are heavy enough to affect thickness requirements of general aviation airport pavements.

It is worth noting that the above tables include asphalt depths as thin as 3 inch and *k*-values as low as 100 pci. On going research by the Construction Testing Laboratories (CTL) on Colorado thin whitetopping projects is currently evaluating the appropriateness of these lower bounds for thickness and subgrade reaction (Ref. 9). CTL is evaluating whether asphalt depths less than 5 inches and *k*-values less than 150 pci are problematic for UTW applications. These concerns may also be an issue for UTW on general aviation airport pavements.

Wu et al (Ref. 5) in the development of their UTW design procedure found, based on experimental observation of airport test sections at the Spirit of St. Louis Airport (also see Mowris, Ref. 6), that the critical stresses imposed by 18 kip single axle loads were not necessarily at the bottom middle of the slab. They found that the critical stresses in the asphalt occurred when the UTW slabs were loaded at the slab joint and the critical stresses in the UTW occurred when the UTW slabs were loaded at the slab corner.

They developed the following equations for *load-induced stresses* based on their mechanistic analysis coupled with field observations where they observed incomplete bonding between the UTW and the asphalt interface. These equations include an increase in such load-induced stresses of 36% in order to account for the observed lack of 100% bonding at this interface. The following defines the tensile strain (ε_{JT}) at the bottom of the asphalt layer due to slab edge loading:

$$\log \varepsilon_{JT} = 5.267 - 0.927 \log k + 0.299 \log\left\{ \frac{12}{l_e} \left[8 - \frac{24}{\left(\frac{L}{12} + 2 \right)} \right] \right\} - 0.037\, l_e \qquad \text{(Eq. 1)}$$

where

$\varepsilon_{JT} =$ the tensile strain at the bottom of the asphalt layer, microstrain ($\mu\varepsilon$)

$k =$ the modulus of subgrade reaction, pci

$L =$ the UTW slab length, in., and

$l_e =$ the effective radius of relative stiffness, in., defined in the following equation;

$$l_e = \left\{ \frac{E_c}{k\left(1-\nu_c^2\right)} \left[\frac{t_c^3}{12} + t_c \left(\bar{y} - \frac{t_c}{2} \right)^2 \right] + \frac{E_a}{k\left(1-\nu_a^2\right)} \left[\frac{t_a^3}{12} + t_a \left(t_c - \bar{y} + \frac{t_a}{2} \right)^2 \right] \right\}^{0.25} \qquad \text{(Eq. 2)}$$

where

E_c & $E_a =$ Young's modulus of elasticity of the UTW concrete and asphalt, respectively, psi,

ν_c & $\nu_a =$ Poisson's ratio of the UTW concrete and asphalt, respectively,

t_c & $t_a =$ the respective thickness of the UTW slab and the underlying asphalt, in., and

$\bar{y} =$ the location of the neutral axis from the top of the UTW slab, in., defined as follows;

$$\bar{y} = \frac{\dfrac{E_c t_c^2}{2} + E_a t_a \left(t_c + \dfrac{t_a}{2} \right)}{E_c t_c + E_a t_a} \qquad \text{(Eq. 3)}$$

Note that the computed tensile strain, of Equation 1, can be used to compute the corresponding tensile stress in the asphalt (σ_{JT}) by simply multiplying the tensile strain by the elastic modulus of the asphalt (E_a).

The load induced stress in the concrete caused by the corner loading takes on the following form:

$$\log \sigma_{COR} = 5.025 - 0.465 \log k + 0.686 \log \left\{ \frac{12}{l_e} \left[8 - \frac{24}{\left(\dfrac{L}{12} + 2 \right)} \right] \right\} - 1.291 \log l_e \qquad \text{(Eq. 4)}$$

where

$\sigma_{COR} =$ tensile stress at the top of the concrete slab due to corner loading, psi.

Wu and his co-authors also ascertained the contribution caused by thermal stresses using their analysis and field observations. They arrived at the following respective equations for *thermal-induced stresses* in the asphalt concrete:

$$\log \varepsilon_{JT} = -28.698 + 2.131\alpha_c \Delta T + 17.692\left\{\frac{12}{l_e}\left[8 - \frac{24}{\left(\frac{L}{12}+2\right)}\right]\right\} \qquad \text{(Eq. 5)}$$

and

$$\sigma_{COR} = 28.037 - 3.496\alpha_c \Delta T - 18.382\left\{\frac{12}{l_e}\left[8 - \frac{24}{\left(\frac{L}{12}+2\right)}\right]\right\} \qquad \text{(Eq. 6)}$$

where

$\alpha_c =$ the coefficient of thermal expansion of the UTW concrete, in./in./°F, and

$\Delta T = T_{bottom} - T_{top} =$ the temperature differential across the UTW slab from bottom to top, °F.

Note that the product $\alpha_c \Delta T$ is unitless and must be expressed as microstrain ($\mu\varepsilon$).

The total effect of load and temperature induced strains in the asphalt is simply the sum of the computed strains from Equations 1 and 5. Similarly, the total stress in the UTW concrete is the sum of the load and temperature stresses computed from Equations 4 and 6.

Wu (Ref. 5) chose to use fatigue equations developed by the Portland Cement Association for the UTW concrete and Asphalt Institute equations for asphalt pavement to ascertain the allowable traffic passes (N). The governing equations for the PCC UTW are:

$$\log N = \frac{0.97187 - SR}{0.0828}\ ; \qquad SR > 0.55$$

$$N = \left(\frac{4.2577}{SR - 0.43248}\right)^{3.268}\ ; \qquad 0.45 \le SR \le 0.55 \qquad \text{(Eqs. 7)}$$

$$N = \infty\ ; \qquad SR < 0.45$$

where

$N =$ the number of allowable load repetitions, and

$SR =$ the stress strength ratio defined as the ratio of the computed total concrete stress (load plus temperature) to the flexural strength of the concrete (the modulus of rupture (MOR)), i.e.,

$$SR = \frac{\sigma_{COR}}{MOR} \qquad \text{(Eq. 8)}$$

Gucunski (Ref. 10) suggests that the stress ratio of the UTW slab be kept below 0.45 to ensure infinite or unlimited fatigue life.

The fatigue relation for the existing asphalt pavement is assumed to have the following form:

$$N = \frac{0.0795}{\varepsilon_{JT}^{3.291} E_a^{0.854}} \qquad \text{(Eq. 9)}$$

where the tensile strain in the asphalt is the sum of the load-induced strain and the temperature induced strain. The form of Equation 9 is similar to that used by Gucunski (Ref. 10).

For an assumed whitetopping design and anticipated traffic, Equations 7 and 9 must yield values of N close to but less than the anticipated design traffic. Wu et al provide a very adequate example for dealing with mixed traffic loadings that will satisfy the above fatigue criterion.

Wu’s equations (Ref. 3) are based on an 18 kip single axle with dual tires. As such, it is the opinion of this report’s authors that Wu’s equations are reasonable for estimating the strains and stresses for general aviation aircraft of 20,000 pound gross aircraft weight with dual wheel gear. Appendix C provides a simple spreadsheet with example that can be used for UTW design. This spreadsheet should only be used by an experienced pavement design engineer familiar with this report and associated references.

CONSTRUCTION CONSIDERATIONS

UTW is generally constructed with fixed forms or via slipform operations in the same fashion as for conventional whitetopping or PCC pavement construction. The essential steps are asphalt surface preparation, concrete placement, concrete finishing, surface texturing, curing, and sawing of the contraction joints.

Milling followed by cleaning with compressed air is the preferred method for preparing the asphalt surface. The surface must be allowed to dry if water blasting or washing operations are used after milling. A clean dry surface is absolutely necessary to ensure bonding between the UTW and the underlying asphalt. Note that sealers or bonding agents should not be applied to the asphalt surface prior to UTW paving construction.

Finishing can be accomplished by conventional concrete pavement finishing machines, or by vibrating screed or roller screed. This finishing operation consolidates and strikes off any excess concrete. A uniform head of concrete must be maintained ahead of the screed to ensure adequate consolidation and to prevent low spots. Surface vibration results in good consolidation. Floating follows the screeding operation as necessary, but should be kept to a minimum. Excessive floating suggests needed modifications to the concrete mix or to the finishing processes or equipment.

Plastic shrinkage cracks caused by rapid evaporation of water from the thin UTW slabs is of extreme importance, especially on hot, dry, and windy days (quite common in New Mexico). Such excessive evaporation while the concrete is in a plastic or semi-plastic states will result in such shrinkage crack development. The following factors influence this rate of evaporation: air temperature, relative humidity, wind velocity, and concrete temperature. Increased evaporation tends to occur when the concrete temperature exceeds the air temperature. Figure 3 provides the well-known ACI nomograph for estimating evaporation from the concrete UTW surface (Ref. 11). When the evaporation exceeds 0.2 $lb/ft^2/hr$, plastic shrinkage is likely. Hence, many agencies specify that this limit not be exceeded (e.g., see the NMSHTD Standard Specifications, Ref. 12). Evening or night paving operations or the use of evaporative retardant on the concrete surface may be necessary to ensure low evaporation rates from the concrete surface.

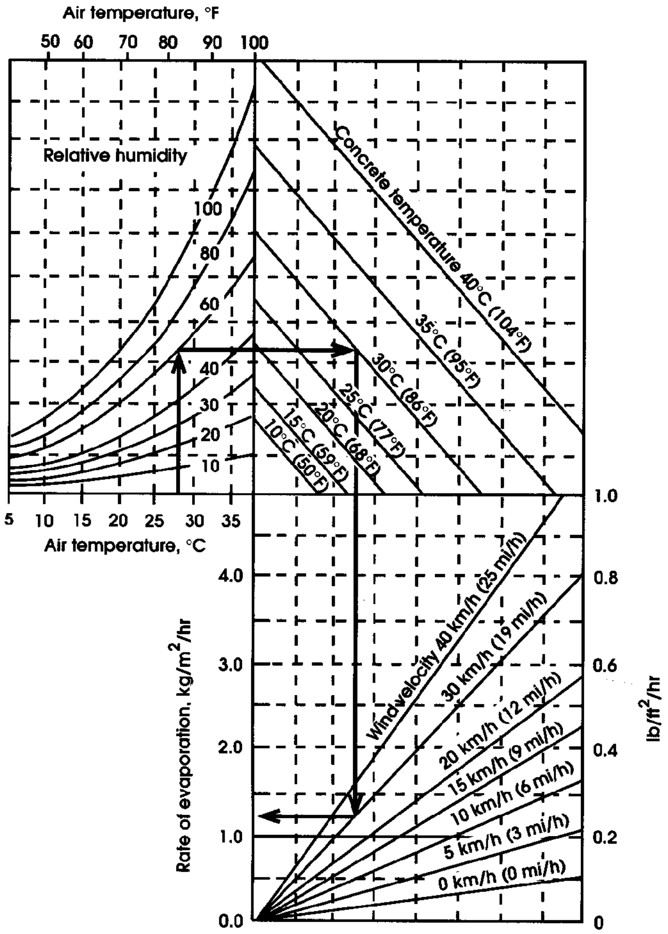

FIGURE 3 ACI Evaporation Rate Nomograph for Prevailing Environment and Concrete Temperature Conditions (Ref. 11).

The texturing operation is important. If performed too early or late, adequate skid and friction resistance of the pavement surface will not be obtained. Texturing operations should be performed just after the surface water sheen has disappeared, before the concrete becomes non-plastic. For low speed operations (< 50 mph), texture the surface with a burlap drag, turf drag, or broom. For high-speed operations (> 50 mph), tining operations are required. Note that NMSHTD specifications using concrete grooving operations to achieve adequate texture are deemed appropriate in lieu of tining operations. The ACPA Guide Specification provides a detailed description of the texturing requirements (see following section).

After the concrete is placed, finished, and textured, a curing compound should be applied at twice the normal rate because of the thin UTW slab's tendency to lose water rapidly due to evaporation and absorption by the underlying asphalt. If the initial coat of curing compound results in surface runoff of the compound, then a second coat should be applied.

The contraction joints should be sawn before the internal stresses of cement hydration begin to develop. Therefore, the use of "green cut concrete saw equipment" should be used as soon as possible. Generally sawing operations commence as soon as the concrete is firm enough to stand upon. It should also be firm enough to prevent excessive dislodging of aggregate at the sawed joints. Note that aggregate interlock at the sawn joints is an important and necessary feature of a properly constructed UTW project. Depth of the sawed joints is specified in the attached Guide Specification (see following section). Joints are generally not sealed because of the short slab lengths and widths used for UTW. Appropriate straightedge equipment should be used to verify conformance with smoothness specifications.

UTW pavement overlays do not make use of dowel bars, tiebars, or keyways, as they are deemed impractical for such thin pavement sections. Load transfer is provided by the aforementioned aggregate interlock, which is enhanced by the short slab joint spacing and the support of the underlying asphalt and subgrade materials. Load transfer is not as critical for UTW because of this underlying support of the existing asphalt pavement. For UTW pavements, extra concrete is required at the transitions to existing asphalt pavement or adjacent paving and soil materials. A suggested transition detail is shown in Figure 4. This detail is applicable for both longitudinal and lateral transitions.

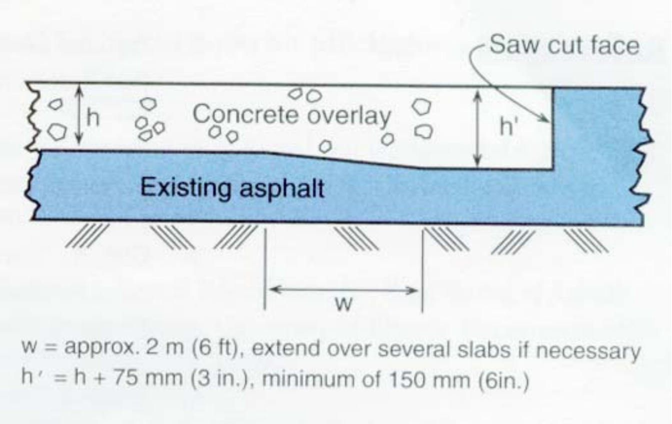

FIGURE 4 Suggested Transition Detail from UTW to Adjoining Paving Materials (Ref. 3).

TECHNICAL SPECIFICATIONS

The American Concrete Pavement Association (ACPA) has developed a Guideline Construction Specification for Ultra-Thin Whitetopping. This guide specification is attached herein as Appendix A. This guide specification should be modified as necessary by the contracting agency for local conditions, preferences and construction practices. Such modifications must be compliant with current NMSHTD specifications and any special provisions required by other state and local agencies such as the Federal Aviation Administration (FAA).

The ACPA guide specification includes recommendations for material specifications and construction specifications. Included are specifications for joint spacing as a function of slab size and tolerances for UTW thickness, milling operations, and joint spacing, width and depth. Requirements for hot weather and cold weather construction are included. Submittal requirements, testing and inspection requirements and the basis of payment are also included.

Appendix B shows an example specification for ultra-thin whitetopping based on a New Jersey DOT specification (Gucunski, Ref. 10). This specification provides some detail and includes suggested specifications for New Mexico from the NMSHTD Standard Specifications for Highway and Bridge Construction (see appropriate sections of Ref. 12). Included are specifications for materials, concrete mixture requirements, equipment, surface preparation, concrete placement and finishing, joint construction and curing requirements.

COST ANALYSIS

Ultra-thin whitetopping is essentially a maintenance strategy, not unlike the use of milling and overlays with hot mix asphalt. In contrast to a complete reconstruction with new pavement, UTW design and construction is constrained by existing pavement factors, and is not necessarily designed for a 20-30 year service life. In general, concrete pavement and concrete overlays are acknowledged to have higher initial costs than hot mix asphalt initial costs. However, it can be argued that concrete whitetopping provides superior service, longer life and lower maintenance cost with associated reduced life cycle costs. The ACPA argues improved serviceability as a benefit of whitetopping. In general, asphalt overlays exhibit a more rapid loss of serviceability than concrete whitetopping, and whitetopping requires less maintenance. Concrete surfaces reduce time and delays accompanying the frequent maintenance requirements of an asphalt surface. Rutting, shoving, temperature cracking, fatigue cracking, and weathering require more frequent attention with crack sealing and surface treatments for asphalt surfaces.

The use of ultra-thin whitetopping is a relative new concept and long-term pavement performance is still being evaluated. For cases where field monitoring has been conducted, UTW thin slab performance has been outstanding (Mack et al, Ref. 13).

Typically the cost of whitetopping construction is paid for in three parts: by the square yard for asphalt surface preparation (milling), by the cubic yard for furnished concrete, and by the square yard for the expense of placement. Extensive experience in Iowa (see Smith, Ref. 4) found that the costs for concrete furnished and placed, in 1993, averaged $36.40 per cubic yard and $2.56 per square yard, respectively. Cost data, for 2001, obtained from the NMSHTD Materials Bureau indicates that the average costs for milling and complete placement of plant mix bituminous pavement (PMBP) were $0.53 per square yard and $28.67 per ton, respectively.

In order to compare these, the 1993 Iowa costs must be converted to 2001 dollars. The consumer price index (CPI) from 1993 to 2001 increased at a rate of 2.6% per annum (Ref. 14). Using this interest rate over the 8-year period from 1993 to 2001, the 2001 estimated costs for whitetopping are $0.53 per square yard for milling (same as PMBP), $44.70 per cubic yard of furnished concrete, and $3.14 per square yard for concrete placement. Assume that a 4 inch UTW and a 4 inch PMBP are of equal design and that the in place density of the PMBP is 140 pcf. The relative initial costs of the in place UTW and PMPB pavements are $8.64 per square yard and $6.55 per square yard, respectively. The estimated initial costs of UTW are roughly one-third higher than that for a PMBP overlay.

CONCLUSIONS AND RECOMMENDATIONS

Whitetopping and more recently ultra-thin whitetopping are proven means of asphalt pavement rehabilitation and improved serviceability. The mechanistic design concepts for UTW are clear. The construction methodologies and practices are in place. The material technologies for fiber reinforced high strength concretes are available. Specifications have been written and successfully used on numerous highway and airport pavement projects. The initial cost of UTW is more than the common asphalt concrete pavement rehabilitation commonly used in New Mexico. However, the life cycle costs of UTW compared to asphalt overlays are considered competitive.

It is recommended that the NMSHTD design and construct UTW test sections at an appropriate selected airport in the state of New Mexico. These test sections should be constructed at the time when an asphalt overlay is being placed at the selected airport. The asphalt overlay will serve as a control or reference section for comparison of the UTW. It is recommended that a short test section be placed on an active runway just past the threshold. This test section does not need to be lengthy, perhaps 150 feet in length for the full width of the runway. Beyond this test section will be the newly placed asphalt overlay. The UTW and the asphalt sections should see the same traffic and essentially the same environmental conditions.

UTW should also be placed in a well-trafficked apron area at this same airport. Again, this area need not be large, perhaps 75 feet by 75 feet. Such a project will allow the determination of the relative initial costs of the UTW versus the asphalt rehabilitation, but more, importantly, long term monitoring will allow for the determination of the life cycle costs and long-term performance of UTW versus asphalt overlays.

Such a study will have implications beyond the New Mexico aviation industry. Such a study will provide invaluable information that may allow for the NMSHTD to perhaps pursue UTW for eventual highway applications. UTW has proved to be successful elsewhere and there is no reason that it should not also be a successful alternative for asphalt rehabilitation in New Mexico.

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14. http://research.stlouisfed.org/fred/data/cpi/cpiaucsl

APPENDIX A

CONSTRUCTION SPECIFICATION GUIDELINE FOR ULTRA-THIN WHITETOPPING

(American Concrete Pavement Association, ©1999)

American Concrete Pavement Association

CONCRETE INFORMATION

Construction Specification Guideline for Ultra-Thin Whitetopping

Ultra-Thin Whitetopping

Ultra-thin whitetopping (UTW) is a process where a thin layer of concrete [50 to 100 mm (2 to 4 in.)], usually with fibers and often of high strength, is placed over a prepared surface of distressed asphalt pavement. In addition to the thinness of the concrete overlay, other factors differentiate UTW from conventional concrete overlays of existing asphalt pavement (conventional whitetopping). These are: (1) a substantial degree of bond between the concrete overlay and the prepared asphalt surface, and (2) much closer joint spacing.

UTW Applications

Ultra-thin whitetopping provides a durable wearing surface for pavements. Since the first experimental project when a landfill access road near Louisville Kentucky was overlaid with UTW in 1991, about 200 UTW projects have been built through 1998. The predominant use has been to rehabilitate distressed asphalt pavement at intersections where rutting and washboarding was a recurring problem. Other uses include: city streets, general aviation airfields, automobile parking lots, bus lanes, and rural highways.

For More Information

For more information about UTW, including applications, history and use, material requirements, project selection criteria, load-carrying capacity, research and performance, joint design, construction procedures and repair, obtain these publications from the American Concrete Pavement Association:

- Ultra-thin Whitetopping (IS100P)
- Whitetopping – State of the Practice (EB210P)

Foreword to Guideline

This document provides guideline specifications useful for developing concrete project specifications for ultra-thin whitetopping pavement. These guidelines should not be used as a specification by reference in contract documents. A contracting agency must modify these guidelines for local conditions, preferences and construction practices.

Project specifications denote specific requirements for construction. They are not intended to provide general or educational information about material, equipment or construction procedures. Therefore, the language in these guidelines is generally imperative and terse as would be used in project specifications.

A contracting agency must specify items designated in the "Mandatory Specification Checklist" portion of this document. The contracting agency may also choose from the provisions in the "Optional Specification Checklist" portion of this document. Checklists are to assist in properly choosing and specifying requirements for the project specifications. These checklists should not be part of the final project specifications.

This document references appropriate material standards, test methods and specifications of the American Society of Testing and Materials (ASTM), American Association of State Highway and Transportation Officials (AASHTO), and Canadian Standards Association (CSA). These references assume that the contractor and the engineer will use the applicable standards or methods that are in effect when bids are solicited for the project or at the time of construction. It also assumes that the specification writer will choose the standard or test most suitable for their agency and project. These guidelines are written in the three-part section format of the Construction Specifications Institute.

MANDATORY SPECIFICATION CHECKLIST	
Section/Part/Article	**Action Required by Engineer**
Section 1 - General 1.7.2 Testing and inspection	Review for compliance with Project Specifications. Designate the Contracting Agency representatives for "Testing and Inspection."
Section 2 - Products 2.1.2 Concrete air content	Specify expected exposure condition (mild, moderate, or severe).
2.1.4 Fibers	Specify type and amount, when used.
Section 3 - Execution 3.1.1 Asphalt surface preparation	Specify depth of milling on Project Drawings.
3.4.6, 3.5.4 Overlay thickness	Specify Ultra-thin Whitetopping thickness on Project Drawings.
3.12 Jointing	Specify joint locations, depths, and dimensions on Project Drawings [3.12.1], or review and accept drawings from the Contractor describing jointing requirements [3.12.2].

OPTIONAL SPECIFICATION CHECKLIST	
Section/Part/Article	**Optional Action by Engineer**
Section 1 - General 1.7.5 Testing	Specify other than ASTM C 94 (AASHTO M I57, CSA A23.1) for concrete testing, inspection and remedy for concrete failing to meet strength requirements, when permitted.
Section 2 - Products 2.1 Concrete	Specify cement specifications and type when other than ASTM C 150, C 595, or C 1157 (AASHTO M 85 or M 240, CSA A5 or A 362)
2.1.1 Concrete strength	Specify strength when other than 31.0 MPa (4500 psi) compressive strength at 28 days is required.
2.1.2 Concrete air content	Specify total required air content when other than those listed in Table 2.1.2 is required.
2.1.5 Slump	Specify slump other than required in Section 2.1.5, when permitted
Section 3 - Execution 3.7 Final surface texture	Specify the final surface finish (broom, burlap-drag, turf drag or tined) if a particular texture is desired. (Otherwise the final surface finish will be the Contractor's option for roadways designed for vehicle speeds less than 80 km/h (50 mph). Tining will be required for higher speed roadways.)
3.9 Curing	Specify curing method other than membrane-forming curing compound, when permitted.
3.14 Opening to traffic	Specify other than 20.7 MPa (3000 psi) compressive strength, when permitted.

SUBMITTAL CHECKLIST	
Section/Part/Article	**Notes to Engineer**
Section 2 - Products 2.1.6 Concrete mix proportions	Required.
Section 3 - Execution 3.10 Hot weather construction	When required.
3.11 Cold weather construction	When required.
3.12.2 Jointing	When required.

Contents

Section 1 – General

Section 2 – Products

Section 3 – Execution

Section 1 – General

1.1 – Scope

This Specification covers the requirements for the construction of Ultra-thin Whitetopping of existing asphalt pavement.

1.2– Definitions

These definitions are to assist in interpreting the provisions of this specification.

Accepted – Accepted by or acceptable to Engineer.

Cold Weather – A period when for more than 3 successive days the average dialy outdoor temperature drops below 4° C (40° F.) The average daily temperature is the average of the highest and lowest temperature during the period from midnight to midnight. When temperatures above 10° C (50° F) occur during more than half of any 24-hr duration, the period shall no longer be regarded as Cold Weather.

Contractor – The person, firm, or corporation with whom the Contracting Agency enters into an agreement for construction of the Work.

Contract Documents – Documents including Project Drawings and Project Specifications covering the required Work.

Contracting Agency – The corporation, association, partnership, individual, or public body or authority with whom the Contractor enters into an agreement, and for whom the Work is accomplished.

Engineer – The engineer or engineering firm issuing Project Drawings and Project Specifications, or administering the Work under the Contract Documents.

Hot Weather – Any combination of the following conditions that tend to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration or causing concrete cracking at locations other than joints:

a. High ambient temperature.
b. High concrete temperature.
c. Low relative humidity.
d. Wind velocity
e. Solar radiation.

Isolation Joint – A full-depth joint which isolates or separates the pavement from fixed objects within or abutting the newly paved area.

Moderate Exposure Condition – Exposure in a climate where freezing is expected but where the concrete will not be continually exposed to moisture or free water for long periods prior to freezing and will not be exposed to deicing agents or other aggressive chemicals.

Panel – A section of concrete pavement between joints.

Project Drawings – The drawings which, along with the Projects Specifications, complete the descriptive information for constructing the Work required or referred to in the Contract Documents.

Permitted – Permitted by the Engineer.

Project Specifications – The written documents which specify requirements for a project in accordance with service parameters and other specific criteria established by the Contracting Agency.

Reference Standards – Standards of a technical society, organization, or association, including the building codes of local or state authorities, which are referenced in the Contract Documents.

Severe Exposure Condition – Exposure to deicing chemicals or other aggressive agents or where the concrete may become highly saturated by continued contact with moisture or free water prior to freezing.

Submitted – Submitted to the Engineer for review.

Ultra-thin Whitetopping – A concrete overlay, 50-mm to 100-mm (2 in. to 4 in.) thick with closely spaced joints bonded to an existing asphalt pavement.

Work – The entire construction of separately identifiable parts thereof which are required to be furnished under the Contract Documents. Work is the result of performing services, furnishing labor, and furnishing and incorporating materials and equipment into the construction, all as required by the Contract Documents.

1.3 – Reference organizations

AASHTO – American Association of State Highway and Transportation Officials
444 N. Capitol Street, NW, Suite 249
Washington D. C. 20001

ACI – American Concrete Institute
P. O. Box 9094
Farmington Hills, MI 48333

ASTM – American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

CSA – Canadian Standards Association
178 Rexdale Boulevard
Etobicoke (Toronto), ON, Canada M9W 1R3

1.4– Reference standards

1.4.1. ACI standards:

117. Standard Specifications for Tolerances for Concrete, Construction and Materials

306.1. Standard Specification for Cold Weather Concreting

1.4.2. ASTM standards:

C 94. Standard Specification for Ready-Mixed Concrete

C 150. Standard Specification for Portland Cement

C 309. Standard Specification for Liquid Membrane Forming Compounds

C 595M. Standard Specification for Blended Hydraulic Cement

C 1116. Standard Specification for Fiber-Reinforced Concrete and Shotcrete

C 1157M. Standard Performance Specification for Blended Hydraulic Cement

C 1399. Test Method for Obtaining Average Residual Strength of Fiber-Reinforced Concrete

D 1751. Standard Specification for Preformed Expansion Joint Filler for Concrete Paving Structural Construction (Nonextruding and Resilient Bituminous Types)

D 1752. Specification for Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction

1.4.3. AASHTO standards

M 85. Standard Specification for Portland Cement

M 148. Standard Specification for Liquid Membrane–Forming Compounds for Curing Concrete

M 153. Standard Specification for Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction

M 157. Standard Specification for Ready-Mixed Concrete

M 213. Standard Specification for Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction

M 240. Standard Specification for Blended Hydraulic Cements

1.4.4. CSA standards

A 5. Portland Cement

A 23.1. Concrete Materials and Methods of Concrete Construction

A 362. Blended Hydraulic Cement

1.5 – Submittals

1.5.1. Submit drawings and documentation as required in this specification.

1.5.2. Obtain written acceptance of submittals before using the material or methods requiring acceptance.

1.6 – Storage and handling

Store construction material in a clean, dry location.

1.7 – Testing and Inspection

1.7.1. Tests required to document submittals, certify product compliance with this specification prior to construction, establish concrete mixture proportions, provide acceptability of changes requested by the Contractor, or appeal rejection of material found defective by Contracting Agency test, shall be performed by accepted laboratories.

1.7.2. The Work in progress will be inspected and materials, equipment, and procedures will be evaluated for quality and acceptability by representatives of the Contracting Agency or as designated in the Contract Documents.

1.7.3. Permit and facilitate access of the Contracting Agency's representatives to the construction sites for the performance for all inspection and testing.

1.7.4. Failure to detect defective work or material shall not prevent later rejection when the defect is discovered nor shall it obligate the Contracting Agency for final acceptance.

1.7.5. Test concrete in accordance with ASTM C 94 or C 1116 (AASHTO M 157, CSA A23.1). Concrete failing to meet strength requirements shall be remedied in accordance with ASTM C 94 or C 1116 (AASHTO M 157, CSA A23.1), unless otherwise specified.

SECTION 2 – PRODUCTS

2.1 – Concrete

Comply with ASTM C 94 or C 1116 (AASHTO M 157, CSA A 23.1) and the following requirements:

2.1.1 Strength. Use concrete with a compressive strength of 31.0 MPa (4500 psi) at 28 days unless otherwise specified.

2.1.2 Total air content. Comply with Table 2.1.2 unless otherwise specified.

Table 2.1.2 - Required total air content

Nominal maximum aggregate size, mm (in.)	Total air content, percent		
	Mild exposure	Moderate exposure	Severe exposure
9.5 (3/8)	4.5	6.0	7.5
13 (1/2)	4.0	5.5	7.0
19 (3/4)	3.5	5.0	6.0
25 (1)	3.0	4.5	6.0

2.1.3 Aggregates. Use a maximum aggregate size of one-third of the pavement thickness.

2.1.4 Fibers. If fiber-reinforced concrete is specified, use fibers of the type and in the amount shown in the Contract Documents, and comply with ASTM C 1116. When fibers are used, use fibers providing a residual strength of at least 0.6 MPa (80 psi) as measured by ASTM C 1399, unless otherwise specified.

2.1.5 Slump. Use concrete with a maximum slump of 100 mm (4 in.) for pavements placed by other than slipform equipment or 25 mm (1 in.) for concrete placed with slipform equipment. Concrete with different slumps may be used when accepted.

2.1.6 Submittal. Submit documentation describing concrete mixture proportions in accordance with Section 1.5 – Submittals.

2.2 – Membrane-forming curing compounds

Comply with ASTM C 309 (AASHTO M 148), Type 2, Class A.

2.3 – Isolation joint material

Comply with ASTM D 1751 or ASTM D 1752 (AASHTO M 213 or M 153).

2.4 – Forms

Use forms made of steel or wood or other material capable of supporting mechanical concrete placing equipment without settling vertically, bowing inward or outward, or crushing. Use forms, with sufficient rigidity to maintain specified tolerances, that are clean and free of dirt, rust, and hardened concrete.

Section 3 – EXECUTION

3.1 – Asphalt surface preparation

3.1.1. Mill existing asphalt surface to the depth indicated on the Project Drawings using self-propelled milling equipment having an effective means for preventing dust from escaping into the air. All removed material becomes the property of the Contractor unless otherwise designated in the Contract Documents.

3.1.2. Remove all loose foreign material from asphalt surface with compressed air, by brooming or other methods immediately prior to placing concrete.

3.2 – Setting forms

3.2.1. Set, align, and brace forms so that pavement will meet the tolerances specified in Section 3.8 – Tolerances.

3.2.2. Apply form release agent to inside face of forms prior to placement of concrete. The vertical edge of previously placed concrete may be used as a form. Do not apply form release agent to previously placed concrete. Do not apply form release agent to prepared asphalt surface.

3.3 – Batching, mixing, and transporting concrete

Comply with ASTM C 94 or C 1116 (AASHTO M 157).

3.4 – Placing fixed-form pavement

3.4.1. Deposit concrete directly from the transporting equipment onto the prepared dry asphalt surface. Other methods of conveying the concrete may be used when accepted by the Engineer.

3.4.2. Do not place concrete when the asphalt surface temperature is less than 0° C (32° F).

3.4.3. Deposit concrete between the forms to a uniform height.

3.4.4. Vibrate concrete to remove voids and air pockets. Do not move concrete horizontally with vibrator.

3.4.5. Strike off concrete between forms using a form-riding paving machine or vibrating screed. Vibrate the surface of the concrete at a frequency of no less than 3500 vibrations/minute. Other strikeoff devices may be used when accepted.

3.4.6. Construct concrete overlay to the thickness shown on Project Drawings within tolerances required in Section 3.8-Tolerances.

3.5 – Placing slipform pavement

3.5.1. When accepted, slipform equipment may be used. Furnish machines capable of spreading, consolidating, screeding and finishing concrete in one pass.

3.5.2. Deposit concrete in accordance with Sections 3.4.1 and 3.4.2.

3.5.3. Produce a dense and homogeneous concrete overlay requiring minimal hand finishing by vibrating the surface of the concrete with a pan vibrator operating at a frequency of no less than 3500 vibrations/minute.

3.5.4. Construct concrete overlay to the thickness shown on Project Drawings within tolerances required in Section 3.8-Tolerances.

3.6 – Surface finishing

3.6.1. Check the surface of the fresh concrete with a long-handled straightedge that is 3 m (10 ft) or longer. Remove high areas indicated by the straightedge. Overlap each successive pass of the straightedge by about 1.5 m (5 ft).

3.6.2. Hand-float the surface only as needed to produce a uniform surface and sharp corners. Do not use excess mortar to build up slab edges or round the slab corners.

3.6.3. Edge each side of transverse Isolation Joints, formed joints, transverse construction joints, and fixed forms to produce a 6-mm (1/4-in.) continuous radius and a smooth, dense mortar finish.

3.7 – Final surface texture

3.7.1. After surface finishing, texture all concrete surfaces that will be used by traffic. Use either hand-operated or mechanical tools to produce a uniform texture.

3.7.2. For roadways designed for vehicle speeds of less than 80 km/h (50 mph), texture the surface with a burlap drag, turf drag or broom.

For a burlap-drag texture, drag two layers of moistened burlap along the pavement in the direction of paving. The burlap must be sufficiently long and wide enough to cover the entire pavement width and produce a uniform texture with corrugations about 1.5 mm (1/16 in.) deep. Clean the burlap periodically to remove encrusted mortar or replace with new burlap.

For a turf-drag texture, drag plastic turf along the pavement in the direction of paving. The plastic turf must be sufficiently long and wide enough to cover the entire pavement width and produce a uniform texture with corrugations about 1.5 mm (1/16 in.) deep. Use turf with a blade density of 77500 blades/m^2 (7200 blades/ft^2) with blades at least 20 mm (0.75 in.) long.

For a broom texture, use a stiff-bristled broom, drawing it from the pavement center to the edges. Overlap strokes slightly to produce a uniform texture with corrugations about 1.5 mm (1/16 in.) deep.

3.7.3. For roadways designed for vehicle speeds greater than 80 km/h (50 mph), tine the surface in the transverse or longitudinal direction to a depth of 3 to 6 mm (1/8 to 1/4 in.) and individual tine width of 2.5 to 3.5 mm (0.10 to 0.14 in.)

When tining transversely, space tines randomly at a minimum spacing of 13 mm (1/2 in.) apart, a maximum spacing of 38 mm (1-1/2 in.) apart, with no more than 50% of the tines apart by more than 25 mm (1 in.).

When tining longitudinally, texture parallel to the pavement centerline with tines spaced uniformly at 18 mm (3/4 in.).

3.8 – Tolerances

Construct pavement within the following tolerances:

Concrete overlay thickness ....
+13mm; – 6 mm (+ 1/2 in.; – 1/4 in.)

Asphalt surface after milling ....
+ 13 mm; – 6 mm (+ 1/2 in.; – 1/4 in.)

Joint spacing ....
± 75 mm (± 3 in.)

Contraction joint depth ....
+ 6 mm; – 0 mm (+ 1/4 in., – 0 in.)

Joint width ....
± 3 mm (± 1/8 in.)

Surface: In the principal direction of vehicle travel, the gap below a 3 m (10 ft) straightedge resting on highspots shall not exceed....3 mm (1/8 in.).

Exceptions: Areas within 3 m (10 ft) of fixtures such as manholes, drainage inlets and catch basins and in areas where the UTW meets existing curb and gutter, crossroads, side-roads and driveways.

3.9 – Curing

Apply membrane-forming curing compound to all exposed surfaces at a maximum coverage rate of 2m^2/ liter (100 ft^2/gal). Apply curing compound immediately after final surface texture has been obtained and water sheen has disappeared. Apply curing compound to pavement edges after forms have been removed. Alternate curing methods may be used when specified or accepted.

3.10 – Hot weather construction

In Hot Weather, protect finished concrete with windbreaks, shading, fog spraying, ponding, or wet covering to prevent cracking at locations other than contraction joints. If required, submit detailed procedures for the production, transportation, placement, protection, curing, and temperature monitoring of concrete during Hot Weather.

3.11 – Cold weather construction

In Cold Weather, comply with ACI 306.1, Standard Specification for Cold Weather Concreting. This defines the conditions for which concrete shall be protected from freezing, and describes the operations of placement and protection of concrete during Cold Weather. If required, submit detailed Cold Weather procedures for the production, transportation, placement, protection, curing, and temperature monitoring of concrete.

3.12 – Jointing

3.12.1. Construct joints at the locations, depths, and with dimensions indicated on the Project Drawings or accepted drawings submitted by the Contractor.

3.12.2. If Project Drawings do not indicate jointing requirements or if submittals are required, submit drawings describing jointing requirements in accordance with Section 1.5 – Submittals, and the following requirements:

3.12.2.1. Indicate locations of all contraction joints, construction joints, and Isolation Joints. Locate joints at spacings shown in Table 3.12.2.1.

Table 3.12.2.1 – Spacing between joints

Pavement thickness, mm (in.)	Approximate spacing, m (ft)
50 (2)	0.6 - 1.0 (2 - 3)
63 (2.5)	0.75 - 1.1 (2.5 - 3.5)
75 (3)	0.9 - 1.2 (3 - 4)
88 (3.5)	1.1 - 1.5 (3.5 - 5)
100 (4)	1.2 - 1.8 (4 - 6)

3.12.2.2. The larger dimension of any Panel shall not exceed 125 percent of the small dimension.

3.12.2.3. The minimum angle between any two intersecting joints shall be 80 degrees.

3.12.2.4. Joints shall intersect pavement free edges at a 90-deg angle and shall extend straight for a minimum of 0.3 m (1 ft) from the pavement edge.

3.12.2.5. Align joints of adjacent Panels.

3.12.2.6. Describe joint depths and widths.

3.12.2.7. Minimum contraction joint depth shall be one-fourth of the UTW thickness.

3.12.2.8. Use Isolation Joints only where pavement abuts buildings, existing curbs, manholes, and other fixed objects.

3.12.3. Construct contraction joints by one of the following methods:

3.12.3.1. Tool contraction joints in fresh concrete after concrete has set sufficiently to maintain the formed joint to the specified depth and width.

3.12.3.2. Saw-cut concrete after concrete has hardened sufficiently to prevent excessive aggregate being dislodged and soon enough to control pavement cracking. If contraction joint sawing causes a crack, discontinue sawing that contraction joint and continue sawing other contraction joints.

3.13 – Protection

Protect pavement from damage.

3.14 – Opening to traffic

Open the pavement to vehicular traffic after the concrete compressive strength exceeds 20.7 MPa (3000 psi) or when accepted for opening to traffic.

3.15 – Method of measurement

3.15.1. Asphalt Surface Preparation. The area of asphalt surface preparation, will be computed by the Engineer in square meters (square yards) from measurements of the locations.

3.15.2. Concrete, Furnish Only. The amount of concrete will be measured by the Engineer in cubic meters (cubic yards).

3.15.3. Concrete, Placement Only. The area of concrete overlay placement will be computed by the Engineer in square meters (square yards) from measurements of the locations.

3.16 – Basis of payment

3.16.1. Asphalt Surface Preparation. Payment will be made at the contract price per square meter (square yard) for asphalt surface preparation. This will include full compensation for removal and disposal of material.

3.16.2. Concrete, Furnish Only. For the concrete incorporated, payment will be made at the contract price per cubic meter (cubic yard) of concrete. This will be full compensation for furnishing all materials, and for proportioning, mixing and delivery of concrete to the paving site.

3.16.3. Concrete, Placement Only. For the concrete overlay constructed (placement only), payment will be made at the contract price per square meter (square yard). This will be full compensation for furnishing all labor, equipment and materials to place, finish, texture, cure the concrete, and to saw or form the joints, in accordance with the Contract Documents.

APPENDIX B

EXAMPLE SPECIFICATION

ULTRA THIN CONCRETE OVERLAY

(Modified New Jersey DOT Specification, Ref. Gucunski, 1998, Ref. 10)

ULTRA THIN CONCRETE OVERLAY

SPECIFICATION

DESCRIPTION

This work shall consist of the placement of a special Portland Cement Concrete Surface Course, containing a number 8 size aggregate, over an existing cleaned and milled flexible pavement.

MATERIALS

Materials used in this construction shall meet the following requirements:

Materials	Requirements
Portland Cement	ASTM C 150, Type II, Low Alkali and NMSHTD 510.21
Water	NMSHTD 510.24
Aggregates	NMSHTD 510.25
Air-Entraining Admixtures	NMSHTD 510.22
High Range Water Reducer	ASTM C 194, Type F
Synthetic Fibers	ASTM C 1116
Curing Compound	NMSHTD 451.24

Synthetic fibers shall be added at the plant at a rate of three (3) pounds per cubic yard. At the direction of the engineer, Type F high range water reducing (HRWR) admixture may be used. However, the slump, achieved with water, shall not exceed three (3) inches before the HRWR admixture is added to the mix. The HRWR admixture is added to the mix at the plant to increase the desired workability during placement. Type A and Type D water reducers are prohibited because their combination with Type F water reducers cause undesired retardation. Admixtures shall be incorporated into the concrete mix in accordance with the manufacturer's recommendations, at the direction of the engineer. Only one addition of the HRWR will be permitted at the jobsite, unless otherwise approved by the engineer.

PROPORTIONING

The contractor shall furnish a mix design in accordance with NMSHTD 510.41 and 510.42 meeting the following requirements:

Compressive Strength:	[NOTE (1)] psi at 24 hours
	[NOTE (1)] psi at 28 days
Air Content:	6.5 – 9.0 % (per NMSHTD 510.12)

Water – Cement Ratio: 0.33 minimum, 0.38 maximum

[NOTE (1)]: Compressive strength and/or flexural strength to be determined by design for each project.

EQUIPMENT

Equipment shall conform to the requirements of NMSHTD Sections 414 and 451.

SURFACE PREPARATION

The existing asphalt surface shall be milled, in accordance with NMSHTD Section 414, Cold Milling, to the required depth [NOTE (2)] and all edges shall be cut vertical and square. Subsequent to the above milling operations, the milled surface shall be cleaned of all loose debris using suitable sweepers followed by air blast operations. This clean, open milled surface will provide a positive bond for the portland cement concrete overlay. The milled out area shall be replaced with a minimum 3 inch of Ultra Thin Portland Cement Concrete. No bonding agents or slurries are required.

[NOTE (2)]: To be determined by design for each project. At no time shall the remaining flexible pavement be less than 2 inches thick.

PLACING CONCRETE

The placement of portland cement concrete shall be in accordance with the applicable provisions of NMSHTD Section 451, Portland Cement Concrete Pavement.

CONCRETE FINISHING

The striking off and finishing of portland cement concrete shall be in accordance with the applicable provisions of NMSHTD Section 451.

JOINTS

Joints shall be constructed in accordance with the applicable provisions of NMSHTD Section 451, with the following. Control (contraction) joints shall be cut with a special saw that is designed to cut concrete at or near the initial set. Sawing shall begin as soon as the concrete can be walked upon. These joints shall be a minimum 3/4 inch depth and 1/8 inch width. Sawed control joints do not need to be sealed. Construction joints may be placed at the option of the contractor. Spacing of all joints shall be as specified on the plans. Where isolation joints are required, 1/4 inch minimum felt material shall be placed around all structures such as manholes, inlets, curbing, etc.

CURING

Curing compound shall be applied according to NMSHTD 451.36 and the manufacturer’s recommendations, immediately after the last finishing operation. When temperatures are expected to drop below freezing, heat retention curing, such as insulating blankets, shall be used.

APPENDIX C

EXCEL® SPREADSHEET FOR DESIGN OF UTW

The following Excel® spreadsheet was developed based on the mechanistic approach described by Wu et al (Ref. 5) for analysis of ultra-thin whitetopping (UTW). The equations were developed based on calibration of a mechanistic pavement analysis using the finite element method (FEM) with calibration against experimental field observations of actual UTW constructed pavements, including the UTW project at the Sprit of St. Louis Airport (Mowris). These equations have been previously described in the body of this report. The mechanistic model was developed based on significant bonding between the UTW and underlying asphalt pavement and the subsequent field calibration. Wu's equations are the basis for the development of the design tables presented earlier in this report. These equations are based on an 18 kip axle load with a dual tire configuration and are assumed equivalent to a 20,000 pound gross weight aircraft with a dual wheel configuration.

The spreadsheet allows for pavement and subgrade input parameters and anticipated aircraft traffic in terms of equivalent 20,000 pound gross weigh aircraft with a dual wheel gear configuration. The spreadsheet computes the pavement stresses, at the slab joint and corners, caused by both the gear loading and temperature differential across the UTW. These computed stresses are compared to allowable stresses based on fatigue criteria for both the UTW and asphalt. Computed allowable aircraft passes can then be compared with the anticipated aircraft passes. The allowable number of passes must be greater than the anticipated number of operations for an adequate UTW design.

It is cautioned that only a qualified and experienced pavement engineer use the spreadsheet that follows. Such engineer should be familiar with the principles of pavement design and with the complete contents of this report and cited references. The results obtained from use of this spreadsheet should be interpreted carefully and in the context of the tabulated results presented earlier from the ACPA Engineering Bulletin on Whitetopping.

The first spreadsheet to follow shows the data input and resultant computed values. The second spreadsheet shows the necessary formulas using the Excel® programming language. For the example shown in the first spreadsheet, and the input parameters specified, one can see that the fatigue criteria of the UTW controls. The computed stress ratio of the UTW is 0.569 and the resultant allowable aircraft passes is 75535, which is greater than the anticipated 67000 operations. In general, fatigue of the UTW will control. This may not hold true for thinner sections of underlying asphalt pavement.

	A	B	C	D	E	F	G	H	I
1	**Ref: Wu, C.L., et al, Development of Ultra-Thin Whitetopping Design Procedure, PCA R&D Report Ser. No. 2124, 1999.**								
2	L	48	in	(slab length & width, contraction joint spacing)					
3	a	5	in	(asphalt (AC) thickness after milling)					
4	c	3	in	(UTW (PCC) thickness)					
5	h	8	in	(total pavement thickness, PCC + AC)					
6	E_c	4000000	psi	(PCC elastic modulus)					
7	E_a	600000	psi	(AC elastic modulus)					
8	n	6.67		(modular ratio, E_c/E_a)					
9	ν_c	0.15		(Poisson's ratio of PCC)					
10	ν_a	0.35		(Poisson's ratio of AC)					
11	k	100	pci	(modulus of subgrade reaction)					
12	MOR	700	psi	(flexural strength of concrete, modulus of rupture)					
13	α_c	5.50E-06	F^{-1}	(PCC coefficient of thermal expansion)					
14	ΔT	-8	F	(temperature differential across concrete UTW, bottom to top)					
15									
16	I_t	15.000	in^3	(moment of inertia of UTW per unit width)					
17	I_b	10.417	in^3	(moment of inertia of asphalt per unit width)					
18	I_u	25.417	in^3	(moment of inertia of unbonded section width)					
19	I_{bound}	89.417	in^3	(moment of inertia of bonded section per unit width)					
20	y_{bar}	2.300	in	(neutral axis from top of UTW)					
21	ℓ_e	27.738	in	(effective radius of relative stiffness)					
22									
23	N	67000		(estimated number of channelized passes of aircraft, 20000 lb dual wheel gear)					
24									
25	$\sigma_{\text{AC allow}}$	301	psi	(allowable asphalt stress based on fatigue criteria)					
26									
27	ε_{AC}	287	$\mu\varepsilon$	(tensile strain in AC at contraction joint, microstrain)					
28	σ_{AC}	172	psi	(tensile stress in AC at contraction joint)					
29		1.188	MPa						
30	σ_{PCC}	249	psi	(tensile stress in PCC at slabe corner)					
31		1.714	MPa						
32	$\varepsilon_{\text{AC Temp}}$	-92	$\mu\varepsilon$	(tensile strain in AC at contraction joint due to temperature)					
33	$\sigma_{\text{AC Temp}}$	-55	psi	(tensile stress in AC at contraction joint due to temperature)					
34		-0.380	MPa						
35	$\sigma_{\text{PCC Temp}}$	150	psi	(tensile stress in PCC at slabe corner due to temperature)					
36		1.035	MPa						
37	$\sigma_{\text{AC Total}}$	117	psi	0.389	(stress ratio of AC stress to allowable)				
38		0.808	MPa						
39	N_{allow}	1492895		(allowable number of channelized passes of aircraft based on AC stress, 20000 lb dual wheel gear; N_{allow} must be greater than N)					
40	$\sigma_{\text{PCC Total}}$	399	psi	0.569	= SR (stress ratio of UTW stress to MOR)				
41		2.749	MPa						
42	N_{allow}			(allowable number of channelized passes of aircraft based on PCC stress, 20000 lb dual wheel gear; N_{allow} must be greater than N)					
43		72564		If SR > 0.55					
44		75535		If 0.45 <= SR <= 0.55					
45		Unlimited (Infinite)		If SR < 0.45					
46									

	A	B	C
1	**Ref: Wu, C.L., et al, Development of Ultra-Thin Whitetopping Design Procedure, PCA R&D Report Ser. No. 2124, 1999.**		
2	L	48	in
3	a	5	in
4	c	3	in
5	h	=B3+B4	in
6	E_c	4000000	psi
7	E_a	600000	psi
8	n	=B6/B7	
9	ν_c	0.15	
10	ν_a	0.35	
11	k	100	pci
12	MOR	700	psi
13	α_c	0.0000055	F^{-1}
14	ΔT	-8	F
15			
16	I_t	=B8*B4^3/12	in^3
17	I_b	=B3^3/12	in^3
18	I_u	=B16+B17	in^3
19	I_{bound}	=(B8*B4*B3*(B3+B4)^2)/(4*(B8*B4+B3))+B18	in^3
20	y_{bar}	=(B6*B4^2/2+B7*B3*(B4+B3/2))/(B6*B4+B7*B3)	in
21	ℓ_e	=((B6*(B4^3/12+B4*(B20-B4/2)^2))/(B11*(1-B9^2))+(B7*(B3^3/12+B3*(B4-B20+B3/2)^2)/(B11*(1-B10^2))))^0.25	in
22			
23	N	67000	
24			
25	$\sigma_{AC\ allow}$	=(0.0795*B7^2.437/B23)^(1/3.291)	psi
26			
27	ε_{AC}	=(10^(5.267-0.927*LOG(B11)+0.299*LOG(12*(8-24/(B2/12+2))/B21)-0.037*B21))	με
28	σ_{AC}	=B27*B7/1000000	psi
29		=B28/145	MPa
30	σ_{PCC}	=(10^(5.025-0.465*LOG(B11)+0.686*LOG(12*(8-24/(B2/12+2))/B21)-1.291*LOG(B21)))	psi
31		=B30/145	MPa
32	$\varepsilon_{AC\ Temp}$	=(-28.698+2.131*1000000*B13*(B14)+17.692*(12*(8-24/(B2/12+2))/B21))	με
33	$\sigma_{AC\ Temp}$	=B32*B7/1000000	psi
34		=B33/145	MPa
35	$\sigma_{PCC\ Temp}$	=28.037-3.496*1000000*B13*(B14)-18.382*(12*(8-24/(B2/12+2))/B21)	psi
36		=B35/145	MPa
37	$\sigma_{AC\ Total}$	=B28+B33	psi
38		=B37/145	MPa
39	N_{allow}	=0.0795*B7^2.437/B37^3.291	
40	$\sigma_{PCC\ Total}$	=B30+B35	psi
41		=B40/145	MPa
42	N_{allow}		
43		=10^((0.97187-D40)/0.0828)	
44		=(4.2577/(D40-0.43248))^3.268	
45		Unlimited (Infinite)	
46			

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