Author Queries

JOB NUMBER: MS 179834—
JOURNAL: GPAV

Q1 Kindly check the inserted running title.
Q2 Kindly provide the history informations.
Q3 Kindly check the inserted keywords.
Q4 Kindly check the placement of figure 6 inside the text.
Q5 Figure is of low resolution, Kindly check.

GPAV 179834—25/5/2006——213630

International Journal of Pavement Engineering, Vol. 00, No. 0, 2006, 1–10

Taylor & Francis
Taylor & Francis Group

Theoretical and field evaluation of interaction between ultra-thin whitetopping and existing asphalt pavement

DEIVIDI DA S. PEREIRA†§, JOSÉ T. BALBO‡* and LEV KHAZANOVICH¶||

†ECOSUL Road Private Operator Co., Avenue Fernando Osório, 815, Pelotas RS 96065-000, Brazil
‡Escola Politécnica, Universidade de São Paulo, Brazil Avenue Professor Almeida Prado, Travessa 2, no. 83, C. Universitária, São, Paulo SP 05508-900, Brazil
§University of Minnesota, Twin cities, MN, USA

Q2

Ultra-thin concrete overlays or ultra-thin whitetopping (UTW), are an attractive alternative to traditional practices for the rehabilitation of asphalt pavements. However, it is widely accepted that the exiting pavement should have substantial stiffness to make a UTW a rehabilitation option. This paper re-examines this hypothesis using the performance results and structural evaluation of two experimental sections in Brazil. It is shown that structural contribution of the existing pavement is important for good performance of UTW. However, it appears that the ability of the existing pavement to ensure composite action of the individual slabs in the UTW is more important than its contribution to the flexural stiffness.

Q3

Keywords: Portland cement concrete; Ultra-thin whitetopping; Asphalt concrete; Fatigue cracking

1. Introduction

An ultra-thin whitetopping (UTW) is a Portland cement concrete (PCC) overlay over an existing asphalt concrete (AC) pavement that has a PCC thickness of 100 mm or less. This innovative technique of rehabilitation of AC pavements was introduced in the United States in the early 1990s. Over the last 15 years, more than 100 UTW sections were constructed in the United States, Europe, Asia and South America. Although the majority of the projects performed very well, several of them exhibited premature failure.

Recently, an extensive research has been conducted to develop rational guidelines for design and construction of UTW (American Concrete Pavement Association 1998). Theoretical, experimental and field studies resulted in a conclusion that a composite action between the UTW and the existing AC pavement is a key factor for good performance of the UTW. These lead to the following recommendations for the minimum requirements for the existing AC layer:

- The AC layer should be in a good structural condition (no extensive fatigue cracking);
- Before the overlay placement, the AC layer surface should be prepared to provide good bond between the UTW and AC layers. Milling of the top portion of the AC layer is recommended;
- The requirement for the AC layer varies between the "absolute minimum thickness of 76 mm", according to the FHWA guidelines (FHWA 2002) and as high as 150 mm, according to the European experience (Silfwerband 1997).

These requirements make UTW a non-viable alternative for rehabilitation of urban AC pavements in Brazil, because the majority of the existing Brazilian asphalt pavements are either too thin or too badly deteriorated. This motivated the Brazilian Portland Cement Association and the University of Sao Paulo to investigate a possibility to relax some of these requirements. Two experimental pavement sections were constructed and their performances were studied. The results of these experiments are presented below.

2. Brazilian conditions

Urban streets in most Brazilian cities were built following the design guidelines issued by Sao Paulo Public Roads Secretary, which recommend 100 mm of asphalt mixture surfaces for the heavy loaded streets and avenues. Later

*Corresponding author. Email: jotbalbo@usp.br
§Email: dsp@usp.br
||Email: khaza001@umn.edu

International Journal of Pavement Engineering
ISSN 1029-8436 print/ISSN 1477-268X online © 2006 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/10298430600798895

these pavements were overlaid with a typical overlay thickness approximately equal to 50 mm. Usually, the total existing asphalt thickness does not exceed 150 mm. Additional overlays are not feasible due to grade problem, so "mill and fill" is the most common rehabilitation strategy.

Another common feature of Brazilian flexible pavements is poor quality of asphalt layers due to the lack of high quality asphalt binders, as well as, poor construction quality control. Fortunately, lateritic soils provide strong, stiff and well-drained foundations and prolonged pavement life. Nevertheless, after one or two years of service these pavements exhibit substantial fatigue cracking and rutting.

In the last decade, traffic on major streets in Brazilian cities has increased in volume and axle weights. Frequent "milling and filling" does not provide long-term rehabilitation solutions, but rather postpones major reconstruction projects. Meanwhile, frequent closings for traffic of major arteries aggravate the traffic congestion problem. This makes the search for long-term, economically viable rehabilitation alternatives very important.

ttractive alternatives to asphalt overlays could be PCC overlays or UTW. However, Brazilian city streets have very severe grade restrictions. In most cases, there is no possibility to raise the pavement grade. Therefore, traditional whitetoppings constructed on top of the existing AC pavements have few opportunities to be used in Brazil. At the same time, UTW inlanes would be an attractive rehabilitation option. An inlane strategy requires milling off 75–100 mm of an exiting AC surface and construction of a thin PCC layer with a short joint spacing. A strong and durable PCC surface may be able to provide much longer service life than the one currently exhibited by AC overlay. There is, however, a valid concern that a very small thickness of the remaining AC layer (25–75 mm) would not be able to provide an adequate structural support for the UTW inlane.

To address this concern and to develop rational design guidelines for UTW inlanes, it is important to re-evaluate a concept of the structural contribution of the existing AC pavement to the UTW. The results of theoretical and field examination of interaction between the UTW and the exiting AC layers addressing these concerns are presented below.

3. UTW test sections in Brazil

In the recent years, two experimental UTW sections were constructed in Brazil. One of them is located on a heavy trafficked highway (SP-280) approximately 150 km from Sao Paulo. Another section is a bus stop pavement in Sao Paulo City. These sections were evaluated in this study.

The first UTW test project was built in October 1997. An original highway SP-280 was built in 1969 as a semi-rigid pavement with a 100 mm-thick AC layer and 150-mm thick soil-cement stabilized base over a lateritic quartz sand (CBR = 40). The pavement was overlaid twice (in 1979 and 1988) and the AC thickness has reached 200 mm. In 1997, daily truck traffic in the design lane was equal to 4500 heavy trucks (equivalent to 6800 ESAL daily). The pavement exhibited signs of substantial structural deterioration. A 150-mm cement-treated base was badly cracked. An AC surface exhibited extensive alligator cracking and rutting. Even after milling of up to 100 mm of AC surface, a large number of fine alligator cracks were observed.

Eight experimental inlane UTW sections with the total length of 546 m were constructed on SP-280 (figure 1). Two design UTW parameters were varied: PCC thickness and joint spacing. The PCC thickness of these sections was equal to 80 and 100 mm. To keep the grade, the thickness of the milled AC layer was greater for thicker UTW sections. The remaining AC layer thickness was equal to 100 and 80 mm, respectively. For each UTW PCC thickness, four test sections with slab sizes 0.65 by 0.65, 0.80 by 0.80, 1.15 by 1.15 and 1.65 by 1.65 m were constructed (Balbo 2003).

The second UTW test project was build in 1999 on a bus stop at University of Sao Paulo campus in Sao Paulo City. The existing pavement was constructed in 1978 and consisted of 50 mm of AC layer, and 100 mm of Hydraulic Macadam base over a lateritic porous clay subgrade. The daily traffic consisted of 120 heavy loaded busses and 500 passenger cars. The existing pavement was in good structural condition exhibiting only 5 mm of rutting (Balbo *et al.* 2001). Traffic loads differ substantially from the other experiment, consisting mainly of urban buses with single rear axles not loaded by more than 100 kN, while the first UTW was loaded by trucks with tandem and tridem multiple axles and a large spectrum of loads.

The UTW overlay was built after milling off 5 mm of AC layer and to eliminate unevenness of the AC surface and improve bond between the AC layer and the overlay. The PCC overlay thickness was equal to 95 mm. Two test sections with the slab sizes 0.6 by 0.6 and 1 by 1 m were constructed (figure 2). It should be noted that design of these sections does not meet the ACPA recommendation, since the remaining thickness of the AC layer is only

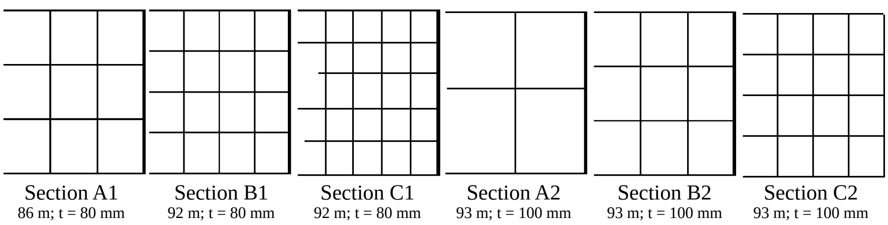

Figure 1. Sequential UTW sections in SP-280 at truck lane (section length and UTW thickness).

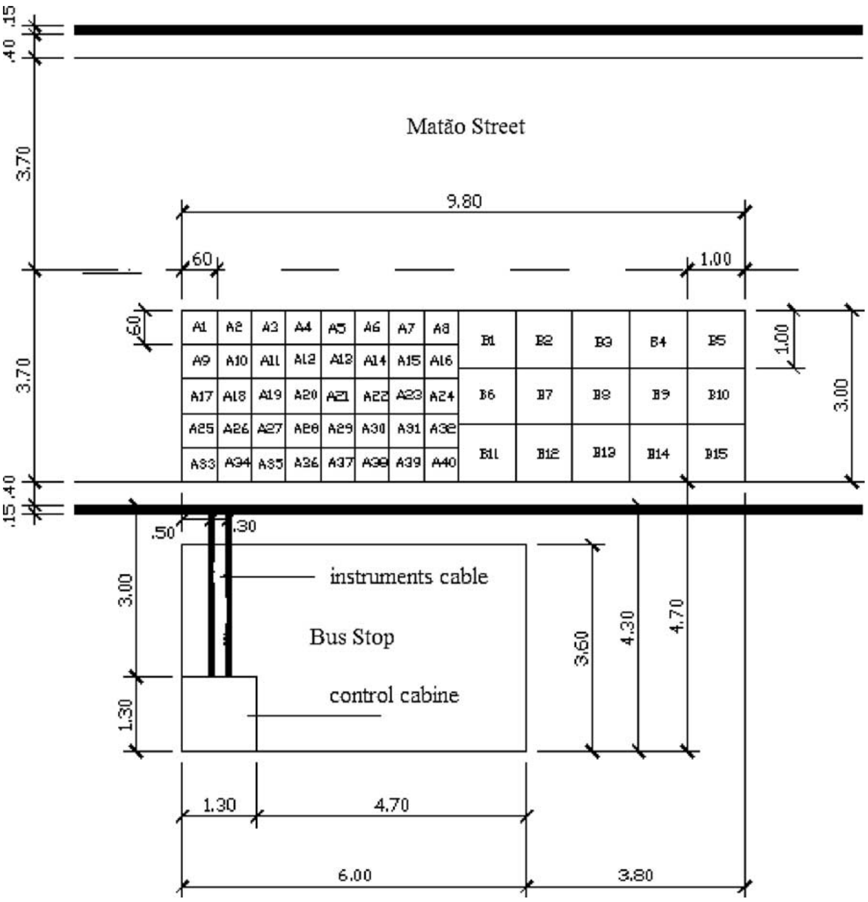

Figure 2. UTW instrumented sections at a bus stop in the USP campus.

45 mm, which is much less than the recommended minimum AC layer thickness of 75 mm.

Table 1 provides a summary of design features of these UTW projects along with the concrete strength properties and material stiffnesses backcalculated from deflections measured on the top of the existing AC layer prior to rehabilitation. The elastic multilayer program ELSYM5 was used for backcalculation.

Although the SP-280 and USP campus bus stop UTW have similar design characteristics, there is a very important difference in their support conditions. The SP-280 sections are placed over a thick, but badly deteriorated AC layer. The USP campus bus stop UTWs

Table 1. UTW experimental sections in Brazil.

Location	SP-280 (highway)	USP campus (urban street)
Date of UTW experiment (construction)	October 11, 1997	November 1st, 1999
Test length (m)	546	10
Lane type	Truck lane (3.3 m)	Bus stop (3 m)
System for laying the concrete	Inlay	Overlay
UTW slab type	Squared	Squared
UTW joint spacing (m)	0.65/0.80/1.15/1.65	0.6/1.00
UTW thickness (mm)	80/100	95
PCC flexural strength (MPa) at 7 days	6.1	7.0
Remaining old asphalt thickness (mm)	100/80	45
Existing base type	Soil cement	Hydraulic macadam
Base thickness (mm)	150	100
Subgrade type	Lateritic quartz sand	Lateritic porous clay
Year of pavement construction	1969	1978
Asphalt overlays history	1979–1988	None
Asphalt layer modulus (MPa)	1.100	3.500
Base layer modulus (MPa)	300	150
Subgrade CBR (%)	40	12
Subgrade modulus (MPa)	200	150
Subgrade modulus of reaction (MPa/m)	25	55

Table 2. Concrete mix proportions.

Material or property	SP-280 (highway)	USP campus (urban street)
Early strength Portland cement (kg/m^3)	440	476
Silica fume (kg/m^3)	44	28.5
Round quartz fine sand (kg/m^3)	493	642
Crushed granite stone ϕmax = 19 mm (kg/m^3)	1194	1029
w/c ratio	0.365	0.4
Plasticizer (l/m^3)	1.65	1.43
Superplasticizer (l/m^3)	5.424	2.38
Air entraining additive (ml/m^3)	119	–
Entrained air (%)	≤5.0	–
Slump (mm)	80 ± 10	140
28-day flexural strength (MPa)	6.0	7.2

are placed over a very thin, but structurally sound AC layer. A comparison of the behaviours of these sections provided important information on the contribution of the existing AC layer to the performance of the UTW. Table 2 presents the concrete mix design for both UTW experiments.

4. Performance of the Brazilian UTW test sections

The UTW test projects described above exhibited dramatically different performance. The SP-280 test sections designed to serve 10 years started to exhibit the signs of deterioration almost immediately after opening to traffic. Figure 3 shows development of fatigue cracking in the 80-mm thick, 0.65-m joint spacing UTW sections. One can see that after 3 months of traffic, the majority of outer slabs were cracked. Performance of the inner slabs was better, but still unacceptable. Figure 4 shows UTW at SP-280 before and after opening to traffic.

A forensic study conducted for this UTW concluded that the existing pavement failed to provide substantial structural support to the UTW. Although a very good bond was achieved between the UTW and the existing pavement, the bond between the layers in the exiting AC pavement failed. Figure 5 shows a core taken from one of the sections after several months of opening of the UTW to traffic. One can observe that the PCC and AC layers are bonded with each other, but the interface between the AC layers failed.

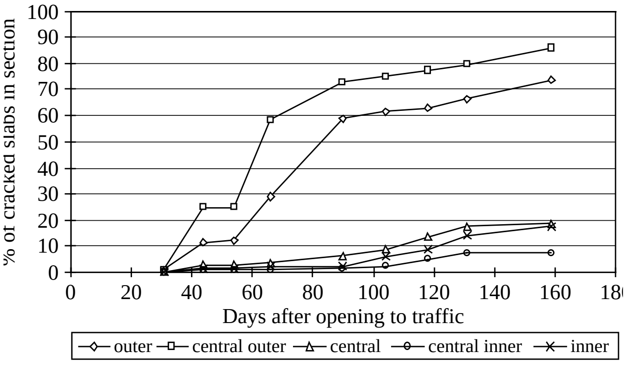

Figure 3. Development of fatigue cracking in the UTW overlay on the SP-280.

Three months after opening to traffic, 27 cores were taken from the UTW to evaluate bond conditions between concrete and existing asphalt layer. It was found that only 41% of the samples showed strong bond at interface. The remaining cores either exhibited no bond between the concrete and asphalt layers or the asphalt part of the core was badly deteriorated.

Performance of the UTW on the USP campus bus stop was remarkably different. After more than 6 years of service, the UTW and almost 350,000 heavy bus and truck loadings, the UTW did not exhibit any signs of structural deterioration or loss of serviceability. Cores have not been taken yet from the pavement that still in service but no indication of loss of bond have been noted currently.

Striking difference in performance of these sections prompted a more detailed investigation of their behavior. Analysis of structural responses (strains and deflections) measured for these sections provided valuable insight, and Q4 this analysis is presented below (figure 6).

5. Deflection basins for UTW

To investigate the effect of the UTW on the pavement flexibility, the deflections basins induced by a heavy truck loading were measured on top of the existing pavements and the overlays. A truck with a rear 80-kN single axle moved along the pavement and an electronic Benkelman beam (with a device able to continuously record the deflection at one point while the load is moving) was used Q5 for deflection measurements, as shown in figure 7. The beam was placed in the wheel path of the existing pavement and at the centerline of the UTW slab in the longitudinal direction. The accuracy of the deflection reading was equal to 0.001 mm. Note that for all deflection measurements are taken for the same point for different load positions.

Figure 8 shows comparison of AC surface and UTW deflections for the test section located on SP-280. The deflections were measured at the interior of the AC surface just before the UTW was constructed. The deflections for the UTW were measured at the slab center. The defection basin shown in figure 3 is measured for the 100-mm thick UTW with joint spacing equal to 1.15 m one month after construction.

Figure 4. UTW at SP-280 test sections as constructed (left) and after 3 months (right).

Analysis of figure 8 shows that the presence of the UTW did not significantly alter the maximum deflection under the heavy axle load, but significantly changed the shape of the deflection basin. The maximum deflection of the UTW was only 10% lower than the maximum deflection of the existing AC pavement. At the same time, while the deflection of the AC surface was gradually decreasing with increase of the distance from the axle load, the deflection of the PCC slab was virtually the same as the axle load was applied to the same slab where the deflection was measured. As soon as the axle crossed the joint with the adjacent slab, the deflection dropped to almost zero.

This behavior of the UTW suggests that a very low load transfer exists between the adjacent slabs. This suggests that excessive concrete shrinkage caused the sawcuts in the concrete layer not only to propagate throughout the PCC thickness and become wide open, but also to affect (develop throughout) the weak existing AC layer. This not only almost completely eliminated the aggregate interlock in the joint, but also reduced the load transfer through the underlying layers and made each slab work as an independent block. That in turn, increased the deflections exhibited by the slabs. Since the underlying AC layer failed shortly after UTW construction, it significantly reduced the combined stiffness of the overlay. This is why the UTW overlay failed to provide significant reduction in the maximum defections.

Figure 5. Core from UTW of SP-280.

A completely different behavior was exhibited by the UTWs on a bus stop at USP campus in Sao Paulo. Figure 9 shows comparison between the deflections measured before and after the overlay. One can see that the overlays constructed over a structurally sound AC layer not only provided a significant reduction in the maximum deflections (43% for the 0.6 m slab and 55% for the 1.0 m slab), but also exhibited more continuous and shallow defection basin indicating substantial load transfer efficiency between the adjacent slabs in the overlay. This suggests that the overlaid pavement behaves as a semi-rigid structure. Lower maximum deflection and curvature of the deflection bows indicate that presence of the overlay significantly reduces tensile stresses at the bottom of the AC layer and the compressive strength at the top of the base and subgrade layers. Therefore, the UTW of this pavement increased the structural capacity of the underlying layers.

6. Strain measurements for USP test section

It is commonly believed that a structurally sound existing pavement and a good bond between the remaining partition (after milling) of the AC layer and the UTW improve performance of the UTW through the so-called "effect of composite action." It is believed that to achieve a good performance in the UTW it is important to lower the position of the neutral axis in the UTW. If the PCC layer is unbonded with the underlying AC layer, then the neutral plane of the UTW (a plane which would not experience neither compression nor tension if the UTW is subjected to pure bending) would be located at the mid-depth of the UTW. However, if the UTW is bonded to the AC layer, then the neutral plane is located in the lower portion of the UTW reducing the maximum bending stresses at the bottom of the UTW. Therefore, to achieve an appreciable change in the neutral plane position, the flexural stiffness

Figure 6. UTW at a bus stop (USP campus).

of the remaining portion of the AC layer should be substantial. This led to the ACPA recommendation of the minimum AC thickness after milling of 75 mm.

As it was stated above, the thickness of the AC layer below the UTW of the USP campus pavement is only 45 mm. Such a thin AC layer would not be expected to substantially alter the position of the neutral axis of the UTW, even if the AC layer and the UTW are fully bonded. The results of strain measurements confirmed this expectation.

Several pairs of strain gages were installed in the UTW of the USP during its construction. In each pair, one sensor was located 20 mm below the top surface and another was located 20 mm above the bottom surface of the PCC layer (Balbo *et al.* 2001). A series of moving load tests were performed using a heavily loaded dump truck. The truck had a single front axle and dual-wheel rear axle, with characteristics as described in figure 10. The actual position of loads over UTW was defined using a VHS camcorder and digital photo camera, as shown in figure 11.

Figure 12 presents a typical strain measurement recorded by an individual sensor. One can observe that the strain reading increases when the load approaches the sensor location and decreases when the load moves away from the sensor. In many cases, the reading after the complete unloading was slightly higher then the reading before loading. This can be explained by the effect of visco-elastic nature of the AC layer and damping properties of the subgrade. To eliminate these effects, the load-induced strain was calculated as a difference between the maximum measured strain in the loading cycle and the average of the strain readings before and after loading. Small oscillations of signals before and after loading were observed due to line noise.

Figure 13 presents samples of a set of data obtained from the same location for the top and bottom strain gages. The first strain peak in these figures refers to the front axle and the second peak to the pass of the rear axle. Considering that both top and bottom strain gages are placed in the same horizontal position and direction, it is evident that while the top strain gage is subjected to tension, the bottom one is under compression, or vice versa.

After the strains at the top and at the bottom sensor locations are computed, the position of the neutral plane can be computed using the following equation:

$$NA = 20 + \frac{Hpcc - 40}{\frac{|\varepsilon_{\mathrm{sgT}}|}{|\varepsilon_{\mathrm{sgB}}|} + 1} \quad (1)$$

where NA is the distance from the PCC bottom to the neutral axis [mm], $Hpcc$ is the PCC slab thickness, ϵ_{sgT} is the calculated strain for the top strain gage and ϵ_{sgB} is the calculated strain for the bottom strain gage. This equation takes into account that the strain gages are located 20 mm below and above the upper and the lower PCC surfaces, respectively.

On August 3, 2002, 26 passes of the dump truck were made and the strain gage readings were recorded. Table 3 presents the results of these measurements along with

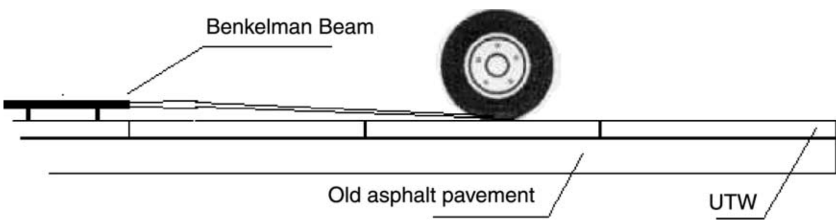

Figure 7. Deflection testing of UTWs.

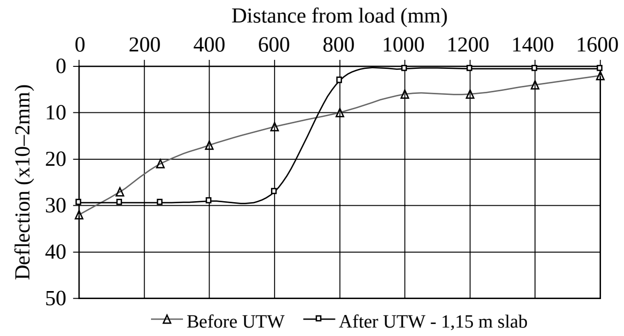

Figure 8. Deflection basins before and after overlay for the SP-280 pavement.

calculated positions of the neutral axis. In spite of significant variation in recorded strains due to different lateral position of the axle loads, the computed positions for the neutral axis are remarkably consistent. The average distance between the neutral axis and the bottom of the PCC slab computed from front axle tests is 47.33 mm from the bottom of the PCC slab (standard deviation of 2.52 mm and coefficient of variation of 5.32%); the neutral axis position computed from the rear axle test is 46.71 mm (standard deviation is 3.05 mm and coefficient of variation is 6.53%). It is worth noting that the measured stresses were as high as 6.5 MPa, i.e. near the concrete flexural strength, but no cracking has been observed yet.

These results were compared with the results of the finite element analysis performed using the finite element program ISLAB2000 (Khazanovich *et al.* 2000). The UTW and the existing AC layer were modeled as a two-layered slab. The base pavement system below the AC layer was modeled as a Winkler foundation. Using the laboratory-determined modulus of elasticity of the PCC layer equal to 38,000 MPa and backcalculated AC modulus of elasticity equal to 3540 MPa, the position of the neutral axis was found to be equal to 43.72 and 47.5 mm for the fully bonded and the fully unbonded interfaces between the PCC and the AC layers, respectively.

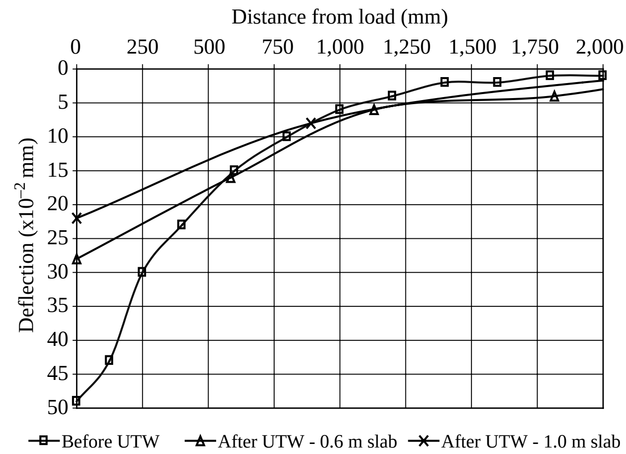

Figure 9. Deflection basins before and after overlay for the bus stop at USP campus pavement.

One can conclude that the interface conditions were somewhere between fully bonded and partially unbonded, but much more closer to the bonded condition. Therefore, the absence of a perfect bond did not jeopardize good performance of the whitetoppings. The most important finding from this experiment is that a UTW over a very thin asphalt layer (as 40–50 mm) can perform well if a good bond is ensured between the concrete and old asphalt. The first experiment on SP-280, on the other hand, showed that lack of bond between a UTW and a thick asphalt layer resulted in poor performance and advanced degradation condition of the existing asphalt.

7. Discussion of the results

Performance data from the Brazilian UTW test sections and the results of the filed deflection and strain measurements discussed above present an opportunity to re-evaluate common wisdom related to the behaviour of UTWs. Both test sections had similar UTW parameters, but had different properties of the existing pavements. Therefore, it is reasonable to attribute differences in performance to the differences in support provided to the two UTW layers by the existing pavements.

Traditionally, structural contribution of the existing pavement to the performance of the UTW was explained by its ability to reduce flexural stresses in the UTW. This definitely was not the case for both Brazilian projects. Indeed,

- The SP-280 sections had relatively thick existing AC pavement, but this pavement was in poor structural condition
- The USP bus stop sections had an existing pavement in a good structural condition, but it was too thin.

As a result, in both cases the exiting AC pavements did not show significant contribution to flexural stiffness of the UTW. Therefore, the thickness of the existing asphalt layer is not the main factor determining the behaviour of the UTW.

Comparison of figures 8 and 9 clearly shows the difference in behaviour of these two whitetoppings. The SP-280 UTW acted as individual slabs with a very low load transfer efficiency of the joints. In contrast, the UTW of the USP bus stop behaved as a “continuous” pavement with a very high load transfer efficiency of joints. Therefore, one can conclude that the most important aspect of the structural contribution of the existing pavement is to ensure the composite action of the individual UTW slabs and provide continuity in the deflection basin.

In this light, one should reconsider the importance of a good bond between the UTW and the existing pavement. As it was shown in this study, even a fully bonded interface does not necessarily provide a significant reduction in stresses and strains, as measured for the

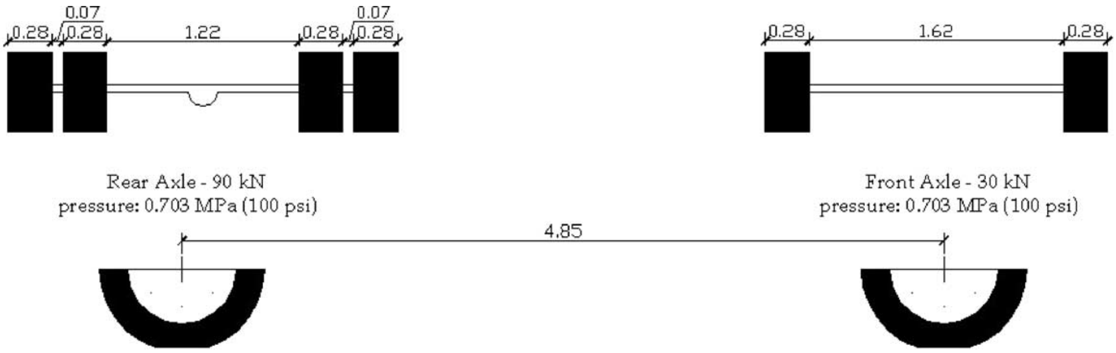

Figure 10. Dump truck characteristics for the load tests (metric units).

Figure 11. Dump truck video records to access the exact tires' position over UTW slabs.

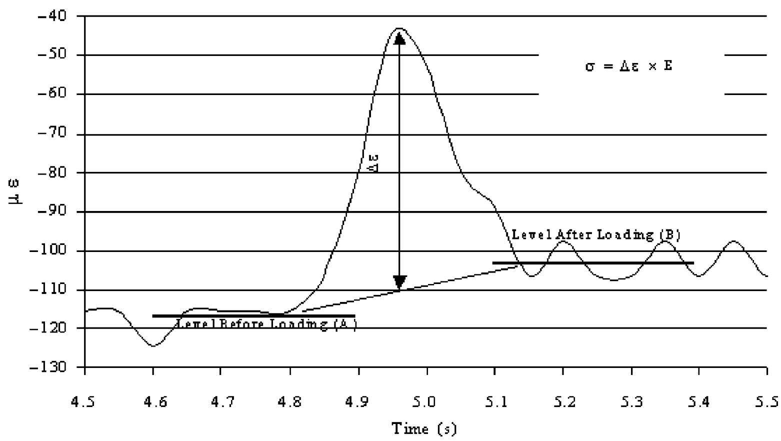

Figure 12. Typical strain reading before, during and after loading.

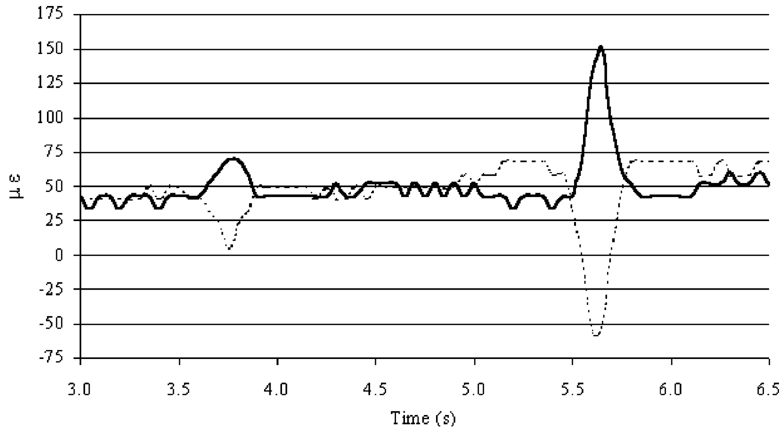

Figure 13. Example of strain measurements for top and bottom sensors.

USP experiment. On the other hand, a bonded, structurally sound existing pavement prevented separation of the individual slabs of the UTW from the AC layer due to curling and warping and, therefore, significantly contributed to the composite action of the UTW slabs.

8. Conclusions

The ACPA guidelines for design of UTW require at least 75 mm of a structurally sound existing AC pavement to be intact after milling to permit construction of the UTW. These requirements are too strict to make the UTW a viable rehabilitation alternative in Brazil. This motivated researchers to investigate a possibility to relax some of these requirements.

Two experimental pavement sections were constructed and their performance was studied. Both experiments violated ACPA recommendations for design of UTW. One UTW was built over a badly cracked AC pavement but with enough thickness in the existing asphalt layer. Another UTW was built over a very thin, but structurally sound existing AC pavement. While the first overlay failed just several weeks after the construction, the second UTW has shown remarkably good performance after 6 years in service.

The results of non-destructive testing revealed very important differences in the structural behavior of these

Table 3. Calculation of stresses and position of neutral axis (NA) during load tests (slab A26).

	Front axle			Rear axle		
	Stress (MPa)			Stress (MPa)		
Test #	Top	Bottom	Position of NA (mm)	Top	Bottom	Position of NA (mm)
01	− 1.72	1.36	44.30	− 4.47	3.75	45.07
02	− 1.72	1.36	44.26	− 3.78	3.05	44.57
03	− 1.36	1.02	43.48	− 3.41	2.37	42.55
04	− 1.37	1.02	43.49	− 4.45	4.43	47.42
05	− 0.69	1.02	52.79	− 2.76	1.69	40.94
06	− 1.37	1.18	45.51	− 3.93	3.38	45.42
07	− 1.03	1.02	47.28	− 3.10	2.71	45.66
08	− 1.71	1.35	44.28	− 4.79	4.39	46.32
09	− 0.85	0.84	47.40	− 2.55	2.36	46.46
10	− 1.38	1.52	48.88	− 3.96	3.72	46.65
11	Nr	Nr	–	Nr	Nr	–
12	Nr	Nr	–	− 2.07	1.69	44.69
13	− 0.69	0.68	47.24	Nr	Nr	–
14	Nr	Nr	–	− 3.10	2.03	41.77
15	− 3.10	2.71	45.67	− 6.88	6.43	46.58
16	− 3.45	3.41	47.32	− 6.56	6.14	46.58
17	− 1.72	1.70	47.32	− 4.48	3.74	45.03
18	Nr	Nr	–	− 4.15	3.91	46.70
19	− 1.38	1.02	43.39	− 3.79	3.06	44.57
20	− 1.02	1.02	47.42	− 3.75	3.05	44.66
21	− 1.89	1.35	42.92	− 3.78	3.04	44.51
22	− 1.54	1.18	43.83	− 5.13	4.20	44.76
23	Nr	Nr	–	− 4.11	4.08	47.38
24	− 2.23	1.70	43.76	− 5.49	5.09	46.45
25	− 1.38	1.19	45.48	− 2.99	3.39	49.24
26	− 1.03	1.02	47.31	− 3.78	3.39	45.99

sections. This information, along with the analysis of the strain gage measurements for the second overlay, led to the conclusion that performance of the UTW is improved dramatically if the existing thin AC pavement is able to provide a good load transfer between the UTW slabs. To achieve that it is not necessarily important to have a thick existing pavement, but it is important to have the existing pavement in a good structural condition and to ensure a good bond between the existing pavement and the overlay during construction. At the same time, good performance in the UTW may be achieved even if the existing pavement does not provide a substantial contribution to flexural stiffness of the UTW.

Based on these observations, a recommendation to relax the ACPA requirement for the minimum thickness of the existing AC pavement to 40 mm was made. However, if a UTW is to be placed over a very thin AC layers, it is important to ensure that asphalt is structurally sound and make the outmost efforts to achieve a good bond between the UTW and the existing AC layer. This recommendation opens an opportunity for a wider use of UTW in Brazil. It should be noted, however, that the minimum AC thickness requirement should be re-evaluated for local conditions. Both test sections considered in this study were located in a tropical climate, i.e. they did not experience freezing and thawing. Also, both sections had a very strong, drainable subgrade. Less favorable site conditions may force stricter requirements to the existing pavement to make an UTW a viable rehabilitation option.

Acknowledgement

The authors appreciate the scholarship and the research funds granted by São Paulo State Foundation for Fostering Research that allowed the construction of the experimental site and the Ph.D. program of the first author.

References

American Concrete Pavement Association, Whitetopping: state of the practice. *Engineering Bulletin*, Skokie, 1998.

Balbo, JoséTadeu, Pereira, DeivididaSilva and Severi, Andréa Arantes, Behavior and performance of utw on thin asphalt pavement. *Proceedings, 7th International Conference on Concrete Pavements*, **2**, pp. 825–838, Orlando, USA, 2001.

Balbo, JoséTadeu, Performance in fatigue crack of high strength concrete as utw. *Paper CD Proceedings, 82nd Annual Meeting of the Transportation Research Board*, 2003 (Washington, DC).

Federal Highway Administration, Portland cement concrete overlays—state of the technology—synthesis. United States Department of Transportation, Publication No. FHWA-IF-02-045, 2002 (Washington, D.C).

Illinois Department of Transportation, *Whitetopping construction and early performance in Illinois*, 2002 Springfield), Report No. FHWA/IL/PRR 144.

Khazanovich, Lev and Ioannides Anastasios, M., Finite element analysis of slabs-on-grade using improved subgrade soil models. *Proceedings of the ASCE Specialty Conference Airport Pavement Innovations—Theory to Practice*, pp. 16–30, 1993 (Waterways Experiment Station: Vicksburg).

Mack, James W., Cole, Lawrence W. and Mohsen, J.P., Analytical considerations for thin concrete overlays on asphalt. *Transportation Research Record No. 1388*, pp. 167–173, 1993 (TRB, National Research Council: Washington, D.C).

Mack, James, Hawbaker, Lon and Cole, Lawrence, Ultra-thin whitetopping: the state-of-the-practice for thin concrete overlays of asphalt. *Paper presented at the 79th Transportation Research Board Annual Meeting*, 1998 (Washington, DC).

Risser, R.J., La Hue, S.P, Voigt, G.F. and Mack, JamesW., Ultra-thin concrete overlays on existing asphalt pavements. *Proceedings of the Fifth International Conference on Concrete Pavement Design and Rehabilitation*, 1993 (Purdue University: West Lafayete).

Silfwerbrand, J., Whitetopping—Swedish field tests and recommendations. *Proceedings, Sixth International Purdue Conference on Concrete Pavement Design and Materials for High Performance*, 1997 (Indianapolis).