

1 **Tire/Pavement Noise Levels Related To Roadway Friction Improvement**

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26  
27 **ABSTRACT**

28 In the United States, much has been learned about pavement acoustics in the past  
29 eight years with the development of the new On-Board-Sound-Intensity (OBSI)  
30 measurement method. OBSI allows researchers to quickly measure and compare  
31 pavement acoustics in great detail. A field demonstration provided a unique and  
32 controlled opportunity to examine how tire/pavement noise levels could be influenced  
33 with increases in friction on flexible and rigid pavements. The OBSI spectral  
34 measurements provided additional insight on how a shot peening process altered the  
35 noise generating mechanisms of the pavement surfaces. Spectral shifts in low and high  
36 frequencies were observed and the magnitude of the shifts varied between the two  
37 flexible and two rigid pavements. Generally, at frequencies below 1000 Hz, the texturing  
38 tended to increase the one third octave band levels. The process removed fine surface  
39 material and exposed larger aggregates which increased macrotexture depth and  
40 improved friction, but generated more low frequency noise. Frequencies from 1600 to  
41 5000 Hz decreased after shot peening. The increase in low frequency noise was counter  
42 balanced by a reduction in high frequency noise. Overall OBSI A-weighted noise levels  
43 (re SRTT at 60 mph) of the flexible and rigid pavements were not significantly changed  
44 by the shot peening (Skidabrader®) process. Rigid pavement became slightly quieter and  
45 flexible pavement did not change or became slightly louder.

## 1 BACKGROUND

2 Higher coefficients of friction on roadway surfaces equate to fewer traffic  
3 accidents, so maintaining high friction is a primary safety issue for roadway owners.  
4 Typically low friction on flexible pavements is remedied by a new overlay and low  
5 friction on rigid pavement can be addressed by grinding. Another option to increase  
6 roadway friction is to shot peen or 'sandblast' the road surface using steel pellets or shots.  
7 Shot peening can be used on both flexible and rigid pavements. A private company,  
8 Skidabrader®, developed a proprietary shot peening process and approached Caltrans to  
9 determine if their operation might have application as a strategy for creating quieter  
10 pavement as well as improving friction coefficients. This presented a very unique  
11 opportunity to determine how this process influenced pavement acoustics and also  
12 examine how changes in friction would influence acoustics. In this limited field study,  
13 acoustic engineers and pavement material engineers worked side-by-side and this report  
14 attempts to merge the data collected by the two disciplines to identify trends and draw  
15 some general conclusions. Long-term impacts of the shot peening process on pavement  
16 life cycle were not examined and are beyond the scope of this study.

17 The Skidabrader® process uses a combination of two highly specialized vehicles  
18 designed to work in tandem to retexture pavement surfaces (Figure 1). The Skidabrader®  
19 process has a number potential advantages over grinding: 1) it can be used on both  
20 flexible and rigid pavements, 2) its production rate is much faster than typical grinding,  
21 3) it is a dry, environmentally-friendlier process that recycles the steel shot, vacuums up  
22 the road dust, and dumps it offsite, and 4) it costs much less than grinding. The pavement  
23 surface texture can be varied during the process by changing the velocity and diameter of  
24 the steel shot and the overall road speed of the vehicle. This demonstration used a size  
25 460 shot which has a nominal diameter of 0.0460 inches (1.1684 mm) to blast a 6 foot  
26 wide swath of roadway. Figure 2 shows the overall appearance of retextured flexible and  
27 rigid pavements after being shot peened by the Skidabrader® system. Figure 3 presents a  
28 close-up photograph comparing the surface of original and retextured dense graded  
29 asphalt concrete (DGAC).

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**Figure 1. Skidabradar® equipment used to shot peen pavement. The rear vehicle shot peens the pavement and pushes the forward vehicle which vacuums the road dust and shot and extracts the shot for recycling.**



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**Figure 2. Retextured or ‘skidabraded’ flexible (a) and rigid (b) pavements. After treatment the retextured surface has an elevated friction coefficient and appeared lighter in color than original surface.**





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2 **Figure 3. Surface detail of dense graded asphalt (DGAC) pavement. Left side is**  
3 **original smooth texture. Right side is after retexturing - notice that more fines have**  
4 **been removed, leaving behind larger aggregate.**

#### 5 6 **MEASUREMENT DETAILS**

7 The skidabrading portion of this demonstration project was done in July 2008, in  
8 northern California in Yolo County on Interstate 505 near the intersection of State Route  
9 16. This site is a rural, four lane divided Interstate freeway on flat terrain with a relatively  
10 low traffic volume by California standards of approximately 20,000 ADT. OBSI, skid,  
11 and texture measurements were taken on the pavements before and after retexturing with  
12 the Skidabrader®. The four test pavements included longitudinally tined Portland cement  
13 concrete (LT PCC), burlap drag Portland cement concrete (PD PCC), dense graded  
14 asphalt concrete (DGAC), and an open graded asphalt concrete (OGAC). The LT PCC,  
15 OGAC, and DGAC are representative of typical pavements in California. Each pavement  
16 texture was one mile long, and the measured segments within each pavement were at the  
17 end of each quarter mile and this supplied four test sections per pavement type. All  
18 pavements were in the outside truck-carrying lane, with the exception of the DGAC  
19 which was on the shoulder next to the OGAC pavement. The climate was moderate and  
20 completely dry during the study. Pre-texturing (Before) OBSI measurements were taken  
21 in early July 2008 when air temperatures were 88° to 94° F and post texturing (After)  
22 OBSI measurements were done a month later in August and air temperatures were 82° to  
23 91° F.

#### 24 25 **OBSI Measurements**

26 The OBSI measurements were conducted using the new draft AASHTO standard (1). As

1 per this standard, each pavement was subdivided into 440 foot long test sections over  
2 which OBSI was measured three times at 60 mph for 5 seconds and these three results are  
3 arithmetically averaged for one representative A-weighted result per 440 foot test  
4 segment. All four kinds of pavements provided four separate, but similar 440 foot test  
5 segments. Three of the tested pavements were in southbound (SB) lanes and the  
6 longitudinal tined PCC was in a northbound (NB) traffic lane as labeled in Figure 4.  
7 OBSI testing was carried out by both Illingworth and Rodkin Inc. (I&R) and also the  
8 University of California at Davis Pavement Research Center (UCDPRC), with each team  
9 using their own independent OBSI systems. In addition to measuring with the Standard  
10 Reference Test Tire (SRTT), I&R also tested with the Goodyear Aquatred 3 tire used  
11 historically for the Caltrans OBSI pavement data base(2). The difference in level between  
12 the old Aquatred 3 and the newly adapted SRTT was only 0.2 dB on average and  
13 identical trends were seen with both tire designs. The OBSI measurements made by both  
14 teams used the second generation dual vertical probe configuration (3), and there were no  
15 considerable differences between the results of the two systems (4, 5). For simplicity,  
16 only the I&R acoustic data is presented in this report.

### 17 **Macrotexture Measurements**

18 The texture and skid data presented in this report are from the UCDPRC team.  
19 Pavement macrotexture was evaluated using the Circular Track Meter (6). This device  
20 uses a laser sensor at about 30mm over the pavement surface and measures the profile  
21 elevation at intervals of about 0.87mm following a circular track of 284 mm (11.2 in.) in  
22 diameter. This device reports the Mean Profile Depth, MPD, which is highly correlated  
23 with the volumetric measurement historically used for determination of texture depth.  
24 The MPD is calculated from the profile elevations using a standard procedure that  
25 considers the highest peak in segments of 100mm (7).

### 26 **Friction Measurements**

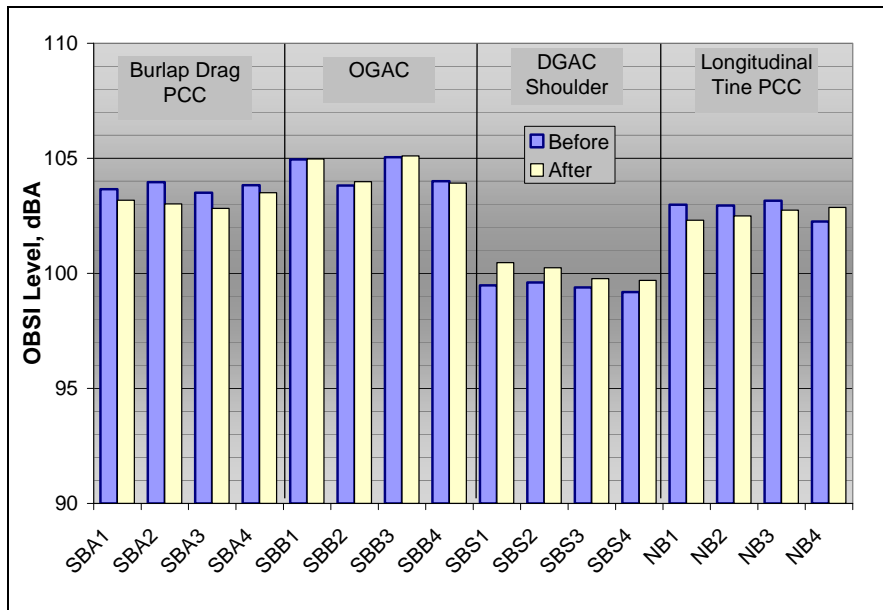
27 Friction testing was conducted using two different devices. The first one was a locked  
28 wheel friction trailer (8) regularly used by Caltrans, and the second was a Dynamic  
29 Friction Tester or DFT (9). The DFT reports surface friction as a function of sliding  
30 speed. It uses a horizontal spinning disk fitted with spring loaded rubber sliders which  
31 contact the paved surface as the disk rotational speed decreases.  
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1 **MEASUREMENT RESULTS**

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3 **Acoustic Findings**

4 The overall A-weighted levels (400 to 5000 Hz) are presented in Figure 4 for the  
 5 different pavement and each of the four 440 measurement segments within each  
 6 pavement. In both the Before and After set of measurements, with the exception of the  
 7 OGAC, there is less than 1 dB of variation between the 440 foot segments. This small  
 8 amount of acoustic variation indicates that these pavements are in uniform condition from  
 9 end to end. The most uniform results were produced by the rigid pavements and the  
 10 DGAC which is located in the shoulder. The OGAC in the mainline had segment to  
 11 segment variability of over 1dB in SBB2 and SBB4 and this is an indicator of uneven  
 12 surface distress. The OGAC pavement also displayed a greater amount of variability  
 13 each of the three times it was measured in addition to the variability between each 440  
 14 foot section. The Before and After measurements variation between segments in the  
 15 OGAC is consistent. In terms of the Before and After data, it is seen that differences are  
 16 small for all pavements and all segments—1.0 dB or less.  
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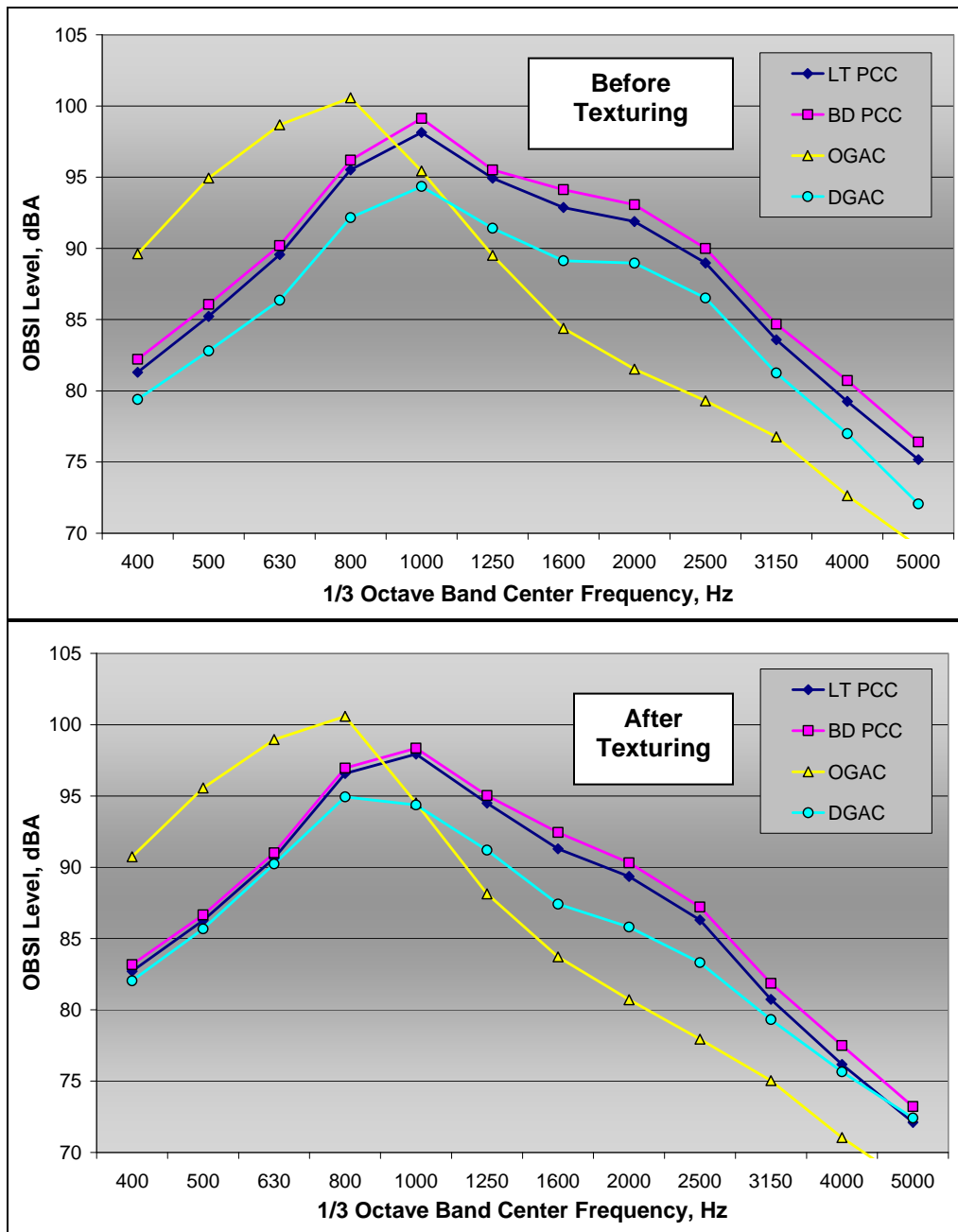


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 19 **Figure 4. Overall A-weighted OBSI levels measured before and after the**  
 20 **Skidabrader® operation for all pavements and each 440 ft segment within each**  
 21 **section; re SRTT at 60 mph. NB and SB indicate north or southbound direction**  
 22 **followed by site label information.**

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24 To interpret the results shown in Figure 4, it is instructive to consider the one third  
 25 octave band spectra. For this purpose, since the difference in overall levels between  
 26 segments was small, the four segments for each section were averaged (arithmetically)  
 27 together to produce one representative spectrum for each pavement type both before and  
 28 after skidabrading. The spectra for the all the pavements measured Before and After  
 29 skidabrading are shown in Figure 5. These data indicate the PCC surfaces, the DGAC,  
 30 and OGAC pavements are distinctly different acoustically. The two PCC surfaces are  
 31 very close in level and spectrum shape while the DGAC is lower in level than the PCCs

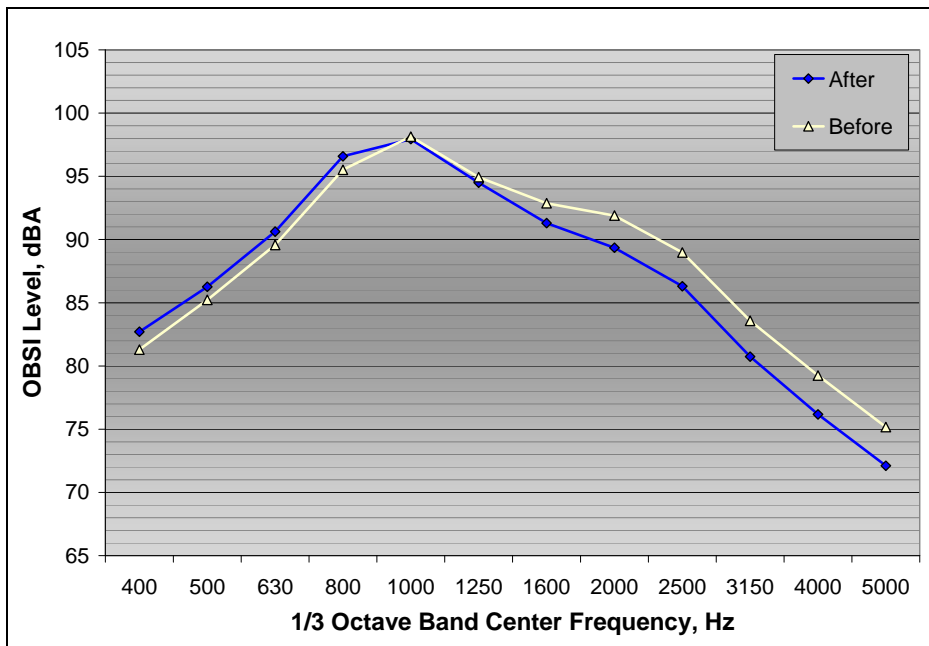
1 though generally preserving the same shape. The shape of the OGAC is appreciably  
 2 different with much more bias to the lower frequencies. The OGAC spectrum shape is  
 3 fairly typical for highly porous pavements and larger aggregate size (10).  
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7 **Figure 5. Spectra Shape and Texturing Influence on Pavement Acoustics. Before and**  
 8 **After spectra for different pavements averaged from four samples within each**  
 9 **pavement (re SRTT at 60 mph). Post texturing, the spectra move closer together at**  
 10 **both low and high frequencies.**

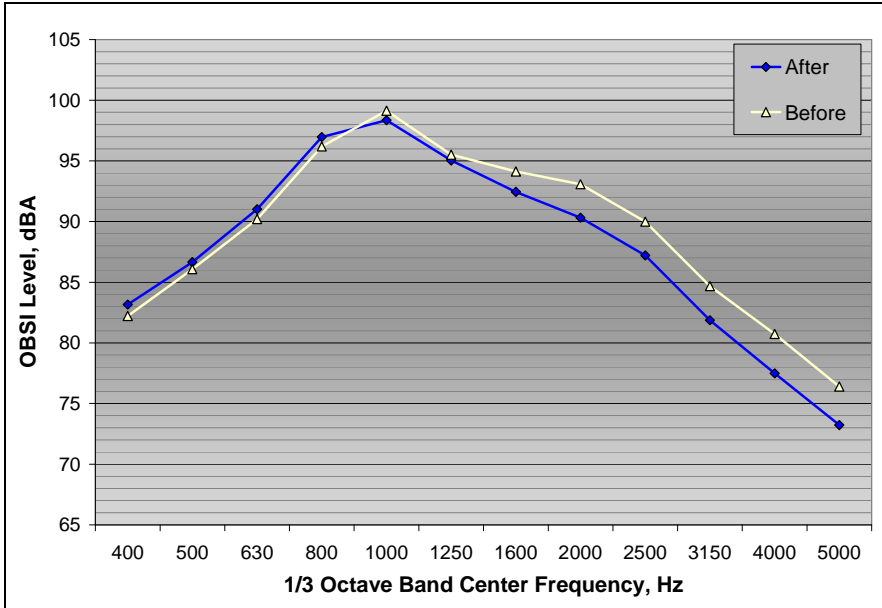
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 12 The spectral comparisons of each type of pavement before and after the skidabrader  
 13 operations are presented in Figures 6 through Figure 9. When examined in isolation, the

1 Before and After changes of each pavement are modest and show slight shifts in  
 2 frequency. The plots do indicate that the texturing did alter the pavement noise generating  
 3 mechanisms. When Figures 6 through 9 are examined together, a trend is evident. In  
 4 general, relative to the pavement’s original peak frequency, all lower frequencies  
 5 increased and all higher frequencies decreased (with the exception of the Figure 8.  
 6 DGAC at 5000 Hz). For the two PCC surfaces in Figures 6 and 7, the trends are almost  
 7 identical. In the lower frequencies, a very small, but consistent increase on the order of 1  
 8 dB is seen below 1000 Hz. In the higher frequencies, 1600 Hz and greater, skidabrading  
 9 consistently lowered the one third octave band level by 2 to 3 dB. A visual inspection of  
 10 the pavements determined that the skidabrading removed some of the cement binder and  
 11 slightly exposed more of the aggregate. The newly exposed aggregate is creating a  
 12 positive texture which is increasing the lower frequency levels while simultaneously the  
 13 newly abraded surface texture is lowering the higher frequencies. Identical behavior was  
 14 encountered on PCC pavements evaluated on the Caltrans Mojave Bypass study site  
 15 before and after grinding of a burlap drag surface. In the Mojave study, however, the  
 16 grinding produced higher roughness and hence even more of a low frequency level  
 17 increase(11). The reason for the reduction of the higher frequency levels could be  
 18 attributed to one or all of several mechanisms including reduced air pumping from the  
 19 tread due to texture generated “escape paths”; reduction of the higher harmonics of the  
 20 tread passage frequency due to randomizations created by the increased texture; and less  
 21 “scrubbing” noise as the tread rubber “locks-in” to the pavement more readily with the  
 22 increased texture and friction.  
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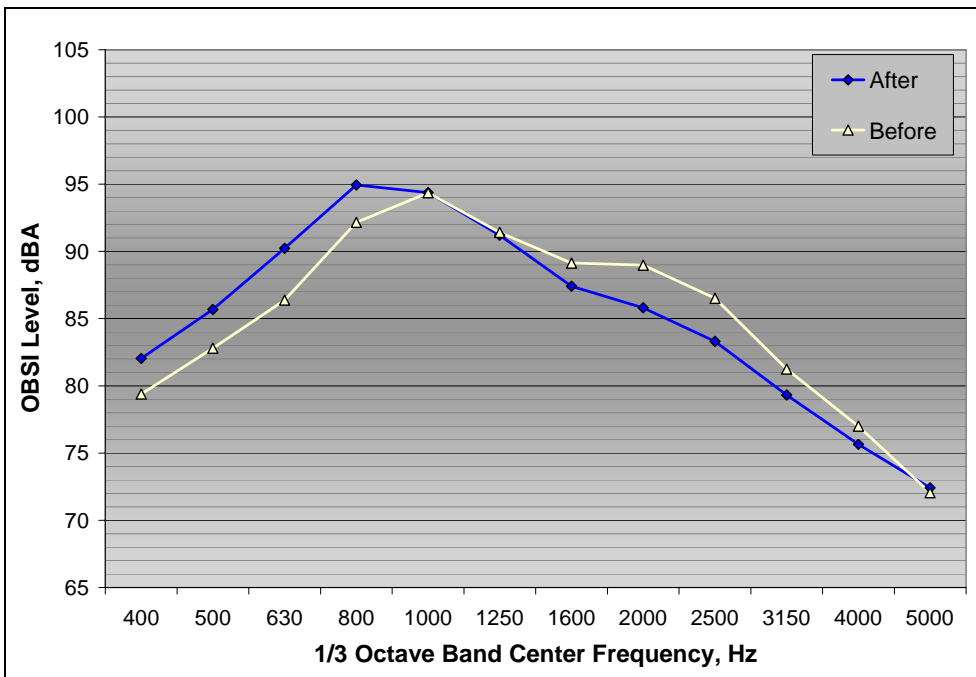
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 25 **Figure 6. Longitudinally tined PCC. Comparison of OBSI spectra Before and After**  
 26 **retexturing (re SRTT at 60 mph). Skidabrading® produced an overall reduction of**  
 27 **0.2 dBA.**  
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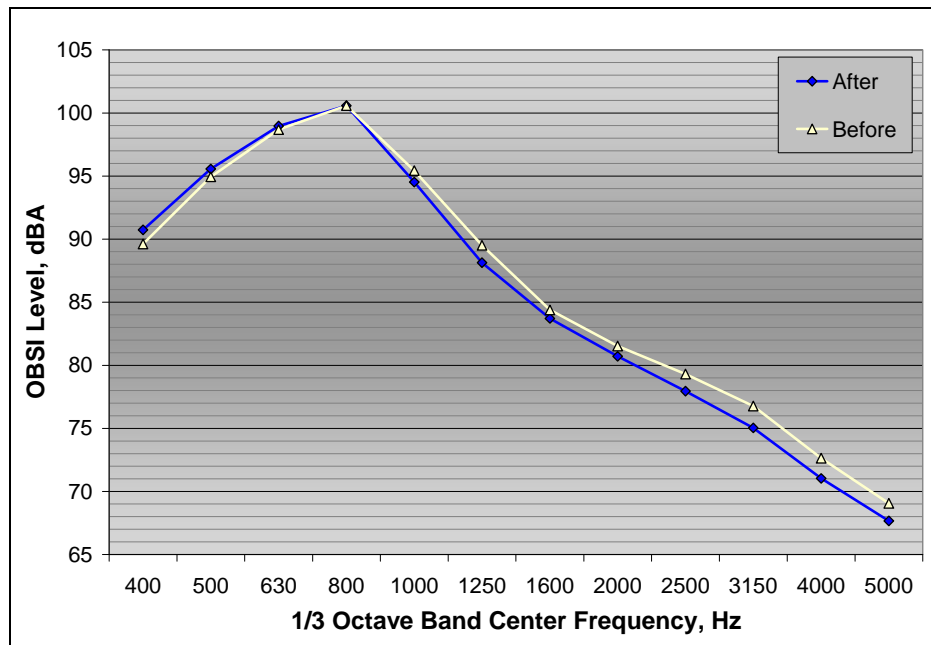
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**Figure 7. Burlap drag PCC pavement. Comparison of OBSI spectra Before and After retexturing (re SRTT at 60 mph). Skidabrading® produced an overall reduction of 0.6 dBA.**



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**Figure 8. DGAC pavement. Comparison of OBSI spectra before and after retexturing (re SRTT at 60 mph). Skidabrading® produced an overall increase of 0.6 dBA.**



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2 **Figure 9. OGAC pavement. Comparison of OBSI spectra before and after retexturing**  
3 **(re SRTT at 60 mph). Skidabrading® produced no overall A-weighted change in**  
4 **noise levels.**

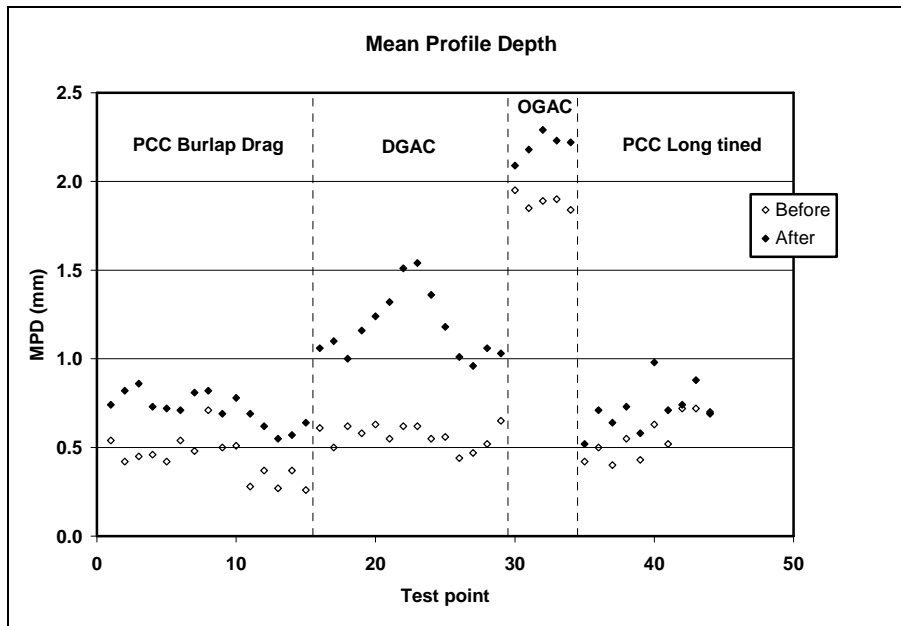
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6 Whatever the mechanisms for the high frequency behavior observed for the PCC  
7 pavements, a similar behavior was found for the DGAC (see Figure 8). For DGAC, the  
8 higher frequency reduction did not carry as high in frequency (5000 Hz) as it did for the  
9 PCC, however reductions of 2 to 3 dB were measured between 2000 and 3150 Hz. In the  
10 lower frequencies, the increases were more pronounced in the DGAC than for the PCC  
11 surfaces. For the DGAC, increases in level of 3 to 4 dB occurred at 800 Hz and below.  
12 Examination of the DGAC pavement before and after skidabrading revealed that the  
13 process appears to have removed more of the binder exposing the aggregate more than it  
14 did for the PCC pavements. As a result, the texture is visibly rougher than the before  
15 skidabrading surface condition (see Figure 3). Some of the tendencies observed for the  
16 PCC and DGAC surfaces also appear for the OGAC surface, however, at a much reduced  
17 magnitude (see Figure 9). In the higher frequency, reductions grow from 1 dB above  
18 1000 Hz to about 1½ dB. In the lower frequencies, the levels after skidabrading are  
19 slightly higher (½ to 1 dB) growing with decreasing frequency. Given the small range of  
20 these changes, they would be difficult to assign as real without the similar results seen in  
21 the other three pavements. The implication for the OGAC pavement is that with already  
22 rough and presumed porous structure with little or no fines, the skidabrading operation  
23 had little effect on the noise generation or the appearance of the surface.

24 The overall one third octave band spectra for all the pavements after skidabrading  
25 are compared in the lower portion of Figure 5. At first glance the Before and After  
26 spectra of each pavement appear to be quite similar which is expected from the small  
27 changes in overall A-weighted level produced by the treatment. However, the spectra do  
28 move closer together in both the higher and lower frequencies. In the higher frequency,  
29 the extreme difference between the pavements closes from 11.6 dB to 9.6 dB, while in  
30 the lower frequency, the difference is reduced from 12.3 dB to 9.8 dB. When the one

1 third octave band frequencies are combined into an overall A-weighted noise level, the  
 2 Skidabrading operation produced very little overall acoustic change in each pavement  
 3 type. On average, the two rigid pavement surfaces were lower in level, 0.6 dB and 0.2 dB for  
 4 the burlap drag and longitudinal tined pavements, respectively. For the two rigid pavements,  
 5 the smoother burlap drag benefitted the most from the texture changes introduced by the  
 6 abrading process. For the DGAC pavement, the A-weighted levels actually increase after  
 7 skidabrading with an average change of 0.6 dB. For the OGAC, there was no change.  
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9 **Roadway Friction Findings**

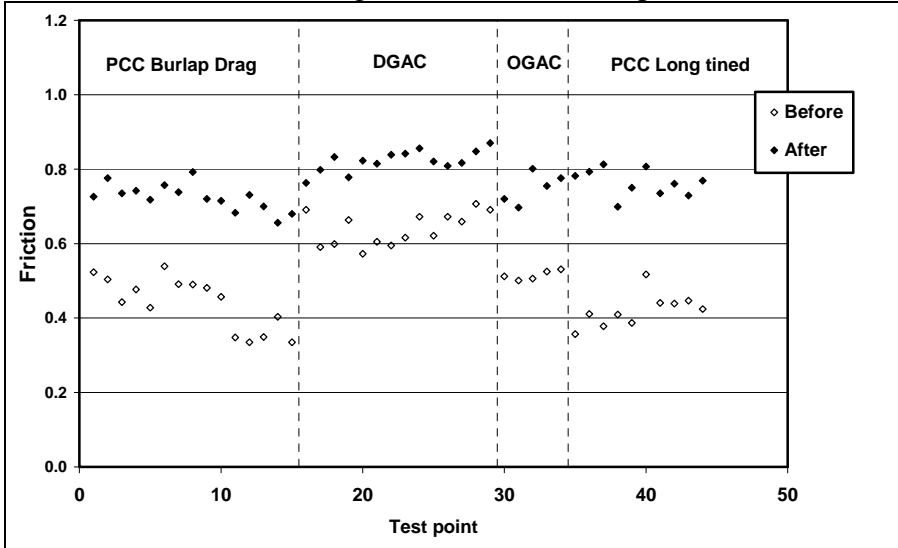
10 With respect to macrotexture, Figure 10 shows a noticeable increase in texture  
 11 depth for three of the four pavements. The largest increase in MPD occurred at the  
 12 DGAC pavement, which doubled the texture from about 0.6mm to 1.2mm (0.0236 to  
 13 0.0472 inches) The OGAC pavement started with the greatest MPD, of about 1.8mm  
 14 (0.0708 inches), and changed to 2.2mm (0.0866 inches) with treatment. The high MPD  
 15 of the OGAC correlates to the low frequency bias shown in Figure 5. The Burlap Drag  
 16 PCC pavement was similar in terms of MPD to the DGAC pavement before retexturing  
 17 (0.5mm/0.1968in), but the effect of the treatment was less so it ended up with 0.8mm  
 18 (0.03149 in.) of MPD. The least-changed pavement was the LT PCC, because the tines or  
 19 “channels” controlled the MPD results. For both the PCC pavements, the MPD was not  
 20 greatly improved upon and the changes in lower frequencies were smaller. The largest  
 21 change in MDP occurred in the DGAC and this pavement had the largest spectral shifts.  
 22 The MDP changed the least in the PCC pavements and the OGAC and these pavements  
 23 also changed the least in the low frequencies.  
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25 **Figure 10. Mean Profile Depth (MPD) for all four pavements before and after**  
 26 **retexturing.**  
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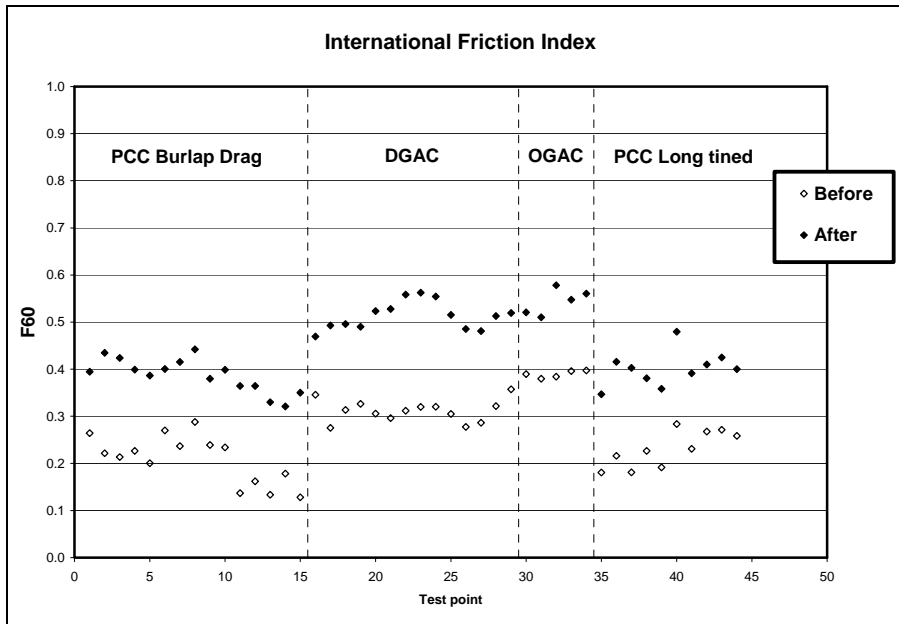
29 Regarding friction, the Skidabrader process improved the conditions for all four  
 30 pavement types. The DFT at 20mph measurements in Figure 11 shows, prior to  
 31 retexturing, a great deal of variability between all the pavements with friction ranging

1 from 0.34 to 0.71. After retexturing the friction increased with almost all results points  
 2 (90 percent) between 0.69 and 0.85 and less variability between all the pavements. In  
 3 both the PCC pavements, the DFT coefficient increased significantly and the higher  
 4 frequencies were lowered significantly. For all pavements, after the treatment, the DFT  
 5 coefficient moved closer together, similar to the spectral data.



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 7 **Figure 11. DFT friction coefficient at 20mph (DFT20) for all four pavements before**  
 8 **and after retexturing.**  
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10 The 20mph values shown in Figure 12 are the direct results from DFT testing, based on  
 11 torque measured while the device’s rubber pads were in contact with the wetted  
 12 pavement surface. Since the DFT test is not an exact replica of what a vehicle would  
 13 experience when trying to stop on a pavement, the DFT results were used in combination  
 14 with the macrotexture to determine the International Friction Index, IFI (12). The IFI  
 15 was developed to compare and harmonize texture and skid resistance measurements, and  
 16 consists of two parameters that report the calibrated wet friction at 60 km/h (37mph)  
 17 (F60) and the speed constant of wet pavement friction ( $S_p$ ). Figure shows the IFI F60  
 18 results, again before and after retexturing. The F60 results in general increased overall by  
 19 0.20 with the treatment.  
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1  
2 **Figure 12. International Friction Index (F60) for all four pavements before and**  
3 **after retexturing.**

#### 4 5 **CONCLUSIONS**

6 This study examined the acoustic changes shot peening pavements has on pavements  
7 and it found a correlation between improving friction and it influence on acoustics. Shot  
8 peening the pavement tended to remove the fines from the surface, leaving behind larger  
9 aggregate with a positive texture which improved friction but elevated lower frequency noise  
10 levels. Noise levels in the higher frequencies of 1600 Hz and above decreased with higher  
11 friction. The Skidabrader® or shot peening process did alter the pavement noise generating  
12 mechanisms and created offsetting changes between the lower and higher frequencies of each  
13 of the pavements; however, it did not provide any significant changes to the overall A-  
14 weighted levels because of these offsetting or counter-balancing changes. All of the low  
15 frequency changes occurred below the original peak frequency of the pavement and the only  
16 shift in peak frequency occurred in the DGAC which also had the largest change in MPD.  
17 The OGAC with the least amount of 'Before' fine aggregate had the least amount of lower  
18 frequency change and the shot peening had little acoustic affect on this type of pavement.  
19 Both the spectra and DFT coefficient data moved closer across all pavements after the  
20 skidabrading treatment. The DFT coefficient improved the most on the PCC pavements  
21 and these had significant changes in the higher frequencies. The MPD changed the least  
22 for the rigid pavements and the OGAC and the low frequency noise for these pavements  
23 also changed the least.

#### 24 25 **ACKNOWLEDGEMENTS**

26 Thanks to Gary Billiard and the Skidabrader® crew for supplying the personnel and  
27 equipment for this demonstration project. Thanks also to Dr John Harvey, Mark Hannum,  
28 Bruce Steven, and the staff of UC Davis Pavement Research Center for their work.  
29 Executive support at Caltrans was provided by Bill Farnbach and field support and  
30 coordination was provided by Al Vasquez.

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