R&T UPDATE
Concrete Pavement Research & Technology

The Joint Slap Effect

Results from the Purdue Tire Pavement Test Apparatus (TPTA) and Discussion of Preliminary Field Validation Testing

Introduction

Consumers often relate their satisfaction with a roadway to what they hear inside their vehicle. This aspect of pavement noise is difficult to control, however, because it depends upon the characteristics of both the roadway and the vehicle. With the large fleet of vehicles in existence today, and their diverse designs, what may be perceived as a pleasurable ride in one vehicle may be unpleasant in another.

One issue affecting consumer satisfaction is the joint slap effect, an impulse noise similar in sound to something being slapped. This phenomenon occurs when a vehicle travels over a faulted pavement, a pavement with wide joints, or a pavement where joints have been overbanded or are missing sealant.

To better understand this phenomenon, the ACPA contracted with Purdue University to study joint slap.

Equipment

Purdue University's Herrick Laboratories uses a Tire Pavement Test Apparatus (TPTA), shown in Figure 1, to conduct pavement noise research. This device is capable of simultaneously testing six curved pavement specimens arranged on a 12 ft (3.7 m) diameter drum. This configuration makes it possible to test numerous pavement textures and compositions in conjunction with various tire designs, while also varying the environmental conditions. Two tires loaded up to 1000 lbs (450 kgs) are rolled over the test specimens at varying speeds [0 to 30 mph (0 to 48 kph)] while microphones and other sensors collect data. Figure 2 shows a close-up of the On Board Sound Intensity (OBSI) equipment used to measure noise at the tire-pavement interface.

ACPA is utilizing the TPTA for innovative research on concrete pavement surface textures. It allows textures to be produced and tested that may not currently be possible to construct or test with present day equipment. Additionally, the testing can be accomplished without requiring traffic control or endangering workers or travelers.

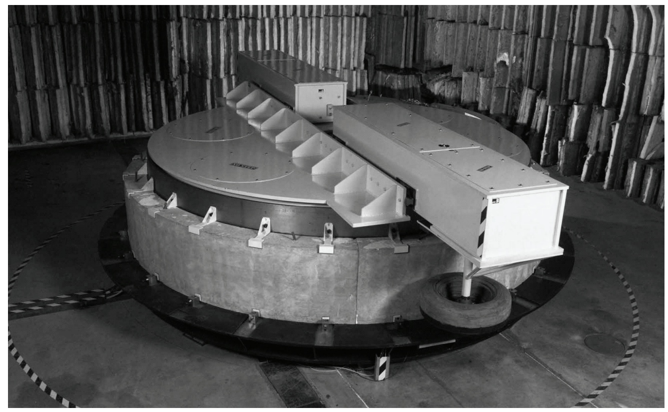

Figure 1. *The Purdue Tire Pavement Test Apparatus (TPTA).*

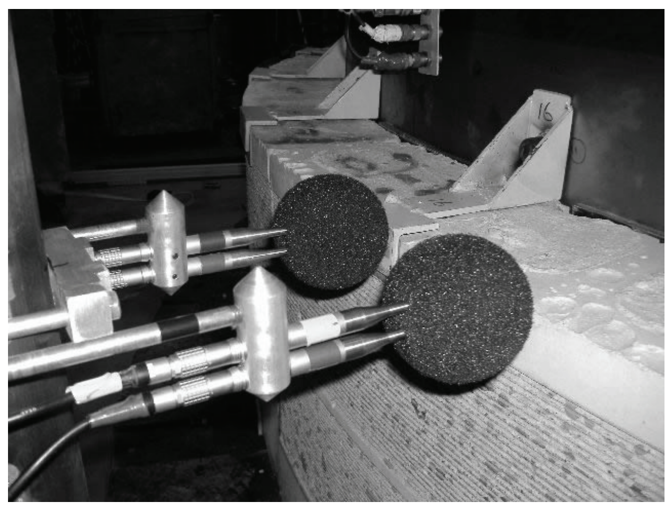

Figure 2. *Close-up of the TPTA's on board sound intensity equipment.*

Purdue Results

The Transverse Joint Slap Phenomenon

As a tire passes over a transverse joint in a pavement, a transient noise is generated. The noise generation is due to vibration in the tire tread and carcass, created by the impact with the joint. The first and largest response is the leading edge impact. The vibrations attain their maximum impulse shortly after leading edge contact and then begin "ringing out" until the trailing edge of the tire pulls away from the joint in another apparent impact event, with its own accompanying "ringing out". The total event happens over a period of approximately 0.02 seconds at 30 mph (48 kph).

A joint slap condition creates a transient noise event which can be 4-6 dBA louder than the noise produced by the pavement texture alone. However, when the joint event is included into the time-averaged pavement noise level, its affect is often undervalued because the "slap" occurs over a very short time interval. Also, since the overall effect of joint slap is a function of the noise level of the existing pavement surface, additional problems exist in quantifying its real world contribution. Nevertheless, this type of event can be very annoying to humans, particularly within the vehicle itself.

Effect of Transverse Joint Opening Width

Figure 3 illustrates the effect of joint opening width on joint slap for a filled and an unfilled joint. There is an increase in joint noise of approximately 10 dB per inch of joint opening for an unfilled (unsealed) joint tested at 30 mph (48 kph). This result indicates that narrower joint openings produced less joint slap.

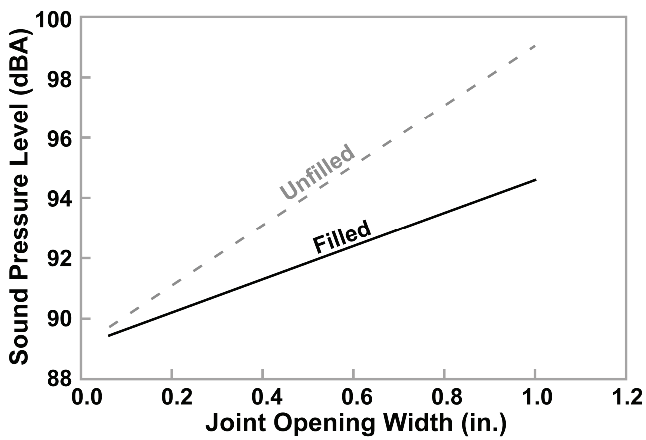

Figure 3. *Measured noise level from joint slap as a function of transverse joint opening width at 30 mph (48 kph).*

Figure 3 indicates that the contribution from the joint opening becomes insignificant at a joint width of approximately 1/8 in. (3 mm). Thus, this joint opening width can be considered as the baseline for this effect (i.e., joints less than 1/8 in. (3 mm) wide will produce no joint slap effect). Subsequent testing on a smaller opening size verified this assertion.

This baseline value, however, is a function of the existing pavement texture. For the results presented in Figure 3, the specimen had a very quiet smooth and blank concrete surface. Had the existing surface been textured, the baseline value would have been greater.

Figure 4 indicates the predicted joint opening effect in relationship to existing texture noise levels for three pavement textural conditions; quiet (100 dBA), noisy (105 dBA), and very noisy (110 dBA).

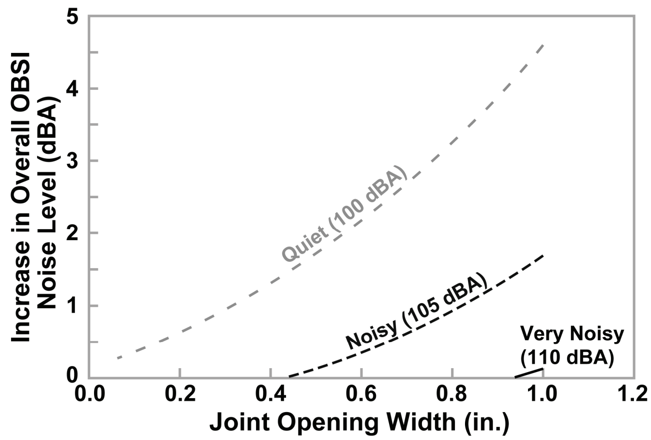

Figure 4. *Predicted transverse joint opening effect in relationship to pavement texture noise levels at 60 mph (97 kph).*

As shown in Figure 4, as the existing pavement texture noise level (e.g., background noise) increases, the contribution of the joint opening effect decreases. For the quiet pavement surface, the joint opening effect begins around a joint opening width of 1/8 in. (3 mm), and adds between 4 and 5 dBA to the overall tire-pavement noise level at a 1 in. (25 mm) joint opening width. For the very noisy pavement, however, the joint opening width must be almost 1 in. (25 mm) to contribute to the overall noise level.

Effect of Joint Faulting

The Purdue work indicates that a step-down faulting (e.g., the leave slab is lower in elevation than the approach slab) condition creates more joint slap than a step-up fault condition. This is unfortunate because step-down faulting is the most common.

Figure 5 indicates the predicted effect of the step-down fault level on joint slap for an unsealed 3/8 in. (10 mm) wide joint with three pavement noise levels.

As indicated in Figure 5, a ¼ in. (6 mm) fault can add approximately 9 dBA to a quiet pavement surface while only adding approximately 2 dBA to a very noisy surface.

Effect of Joint Sealant Recess

One of the effects discovered by the Purdue work was the pronounced influence that sealant recess levels have on the overall tire-pavement noise level. This effect is illustrated in Figure 6. For this example, the filled condition represents a 1/8 in. (3 mm) recess (a sealed condition), the half-filled condition represents a ½ in. (13 mm) recess, and the unfilled condition represents a 1 in. (25 mm) recess (an unsealed condition, with no sealant used). Both the sealant recess depth and the joint opening were varied in this study so that the combined effect of these features would be observed. Due to sealant sag, the 1 in. (25 mm) joint filled condition had approximately a ¼ in. (6 mm) recess instead of the targeted 1/8 in (3 mm). Silicone sealant (with a backer rod) was used in this comparison.

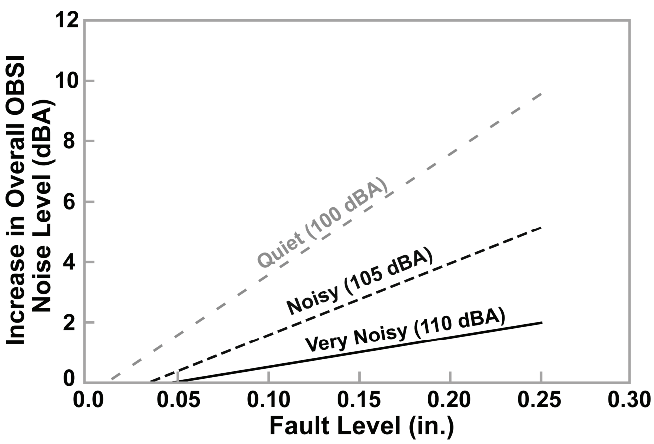

Figure 5. *Predicted effect of fault level on overall tire-pavement noise level as a function of surface noise level at 60 mph (97 kph).*

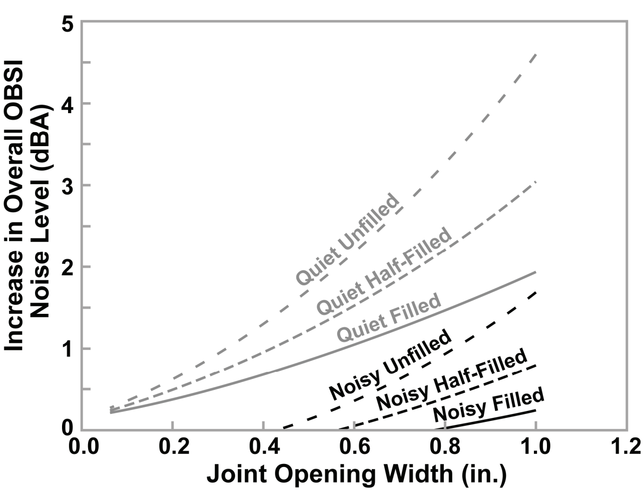

Figure 6. *Predicted effect of joint sealant recess on overall tire-pavement noise at 60 mph (97 kph).*

As indicated in Figure 6, the filled condition results in a quieter pavement than the unfilled and the half-filled conditions. For the 1 in. (25 mm) joint opening, the filled condition reduced the overall noise level approximately 2.5 dBA for the quiet pavement and 1.5 dBA for the noisy pavement. For the very noisy pavement (not shown in Figure 6), the effect was on the order of 0.1 dBA and should be considered negligible. For a typical transverse joint width of 3/8 in. (10 mm), the joint sealant recess effect results in slightly over ½ dBA difference. For a narrow joint (¼ in. (6 mm) or less) the effects of sealant recess are negligible.

Research Methods

The Purdue TPTA testing was conducted at speeds ranging from 0 to 30 mph (0 to 48 kph) using both a Goodyear Aqua Tread and Michelin Tiger Paw tire. Linear regressions were developed from this data to extrapolate to the 60 mph (97 kph) condition. The results from the Aqua Tread and Tiger Paw tires were averaged. As an example, 140 data points were used to develop the regression equations used to extrapolate to 60 mph (97 kph) for Figure 6.

Once the results had been extrapolated to 60 mph (97 kph), the joint effect was mathematically time averaged into a theoretical 15 ft (4.6 m) long slab. Three textural conditions were evaluated, representing each of the tire-pavement noise levels: quiet (100 dBA), noisy (105 dBA), and very noisy (110 dBA).

Preliminary Field Validation Testing

In an attempt to validate the Purdue joint effect models, ACPA and Purdue tested two wheel tracks at the MnROAD low volume road test site. A quiet pavement texture (99.4 dBA) and a noisy texture (104.5 dBA) were tested in both the sealed and unsealed joint condition. The joint opening width was approximately 7/16 in. (11 mm) wide for all joints.

The MnROAD validation results indicated that there was a 0.3 - 0.4 dBA and 0.9 dBA difference in overall noise level between the sealed and unsealed conditions for the quiet and noisy texture, respectively.

Using the Purdue prediction curves, there should be negligible joint slap effect for the noisy condition (a random transverse tined surface) and approximately a ¾ dBA difference for the quiet texture (a longitudinal grind/groove surface) between the sealed and unsealed conditions for a 7/16 in. (11 mm) joint opening width. Thus, the field validation results contradict the Purdue prediction curves. Despite this contradiction, the field validation work did confirm the beneficial effect of sealing the joints on overall noise level.

Perhaps the most important difference between the field and laboratory work can be seen in Figure 7, a photo of the grind/groove surface texture alongside the unground surface.

The Purdue tests were conducted on a smooth texture, similar to a trowel finish, so as to produce the minimum amount of surface texture noise (e.g., analogous to the unground surface in Figure 7). The grind/groove texture is quite different. This difference could affect the noise generation mechanisms by providing additional, and different, air passageways and by producing different tire vibrations from the different impact area surrounding the joint. Further work is necessary to draw more specific conclusions from the field validation testing.

Figure 7. *Unground and grind/groove surface textures.*

Conclusions from the Purdue TPTA Testing

The Purdue TPTA research has indicated that three variables need to be controlled to minimize joint slap noise generation: faulting, transverse joint opening width, and joint sealant recess.

Increasing the level of a step-down fault (the common fault mechanism on roadways) produces increasing joint slap levels. This phenomenon was only tested to a ¼ in. (6 mm) fault level during this study in order to prevent equipment damage, but this effect should increase with increasing slab faulting. This effect can range between approximately 2 and 10 dBA for noisy and quiet pavements, respectively, for a ¼ in. (6 mm) fault.

For pavements with a transverse joint opening width of 3/8 in. (3 mm) or less, the effects joint sealant recess are essentially negligible with respect to noise. However, for joint widths of 1 in. (25 mm), the effect of joint sealant recess could be on the order of 2.5 dBA for a quiet pavement.

The wider the transverse joint opening, the greater the effect on joint slap noise generation. For a typical joint opening width of 3/8 in. (3 mm), this contributes 1 dBA to the overall noise level for a quiet pavement.

The impact of transverse joint slap on the overall pavement noise level is a function of the pavement surface texture noise level. For very noisy pavements, the joint opening width and sealant recess condition have almost negligible effects. For quiet pavements, however, their influence can be quite significant.

The results reported herein pertain to noise levels at the tire-pavement interface. As this noise propagates to the wayside, these effects become less discernible and measurable. The joint slap effect, which presumably is most important to interior noise conditions, relates more to consumer satisfaction than noise mitigation measures.

Similarly, the TPTA testing is based on the noise levels produced from just two tire types (Aqua tread and Tire Paw) and may or may not properly represent the fleet at any given location.

In 2004, ACPA reported several causes of wheel-slap (joint slap) in R&T Update Volume 5.05, "Minimize Wheel-Slap: Keep Your Joints Narrow". Although this early investigation used only the human ear and examined just 10 concrete pavement sections, several conclusions were very similar to what was found using the Purdue TPTA, including:

- Wider joint reservoirs produce louder wheel-slap.
- Joints that are 1/2 in. (13 mm) wide or less produce no noticeable wheel-slap. – We would now say that they produce less noticeable wheel-slap.
- Wheel-slap becomes noticeable when crossing joints 5/8 in. (16 mm) wide; wheel-slap is clearly noticeable when the joint width exceeds 3/4 inch (19 mm).
- The presence/absence of joint sealant has little effect on noise generation when joint are less than 1/2 in. (13 mm) wide. – We would now say that this depends on the degree to which the joint reservoir is filled.
- Joints completely filled with sealant (no recess) may prevent the generation of wheel-slap, even for wider reservoirs [observed at 3/4 in. (19 mm)].

Thus, ACPA continues to recommend optimizing the quantity of sealant and/or joint width (with consideration of any anticipated future saw-and-seal restoration activities) to minimize joint slap.

Acknowledgment

The ACPA would like to acknowledge the contribution of Purdue University, whose work this R&T Update is based upon. In particular, Dr. Robert Bernhard, Mr. Will Thornton, Mr. Ron Evans, and Mr. Tyler Dare.