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Preventing Transverse Bumps and Cracks in New Asphalt Overlays over Crack Sealants

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16. Abstract
Crack sealants are often utilized as a preservation tool in asphalt pavements. These sealants are placed in cracks to prevent water intrusion into the pavement foundation. By reducing water intrusion, the strength of foundation layers is maintained and acceptable pavement performance is extended. However, when a hot mix asphalt overlay is placed on top a pavement containing crack sealants, a bump and additional transverse cracks sometimes occur in the new asphalt overlay. These bumps and sometimes, transverse cracks are initiated during breakdown rolling and become progressively more severe upon further compaction. This paper presents results of a five-year study designed to identify factors that relate to the appearance of these bumps and consequent cracks. Results of the study indicate that vibratory breakdown rolling, pavement gradient, sealant geometry, tack coat application rate and tack coat adhesivity are factors that contribute most to the occurrence of bumps and transverse cracks during asphalt overlay construction over crack sealants. Observations suggest that transverse bumps and consequent cracks occur in proportion to the size of the 'bow wave' of asphalt concrete present immediately in front of the breakdown roller. The increase in the 'bow wave' size is dependent on asphalt mixture properties, breakdown roller size, speed, vibration characteristics and pavement gradient. Four pavement test sections also indicate that tack coat application rate and adhesive properties also have an effect on reducing the appearance of transverse bumps.

Implementation Statement

The results of the findings are to be presented to the CDOT Study Panel and to the Materials Advisory Committee (MAC) for review and approval for implementation in the construction of asphalt overlay projects. Since the tack coat application rate is found to have the greatest impact in the formation of bumps in the asphalt overlay, CDOT construction personnel will be advised by respective Region Materials personnel to ensure that the relevant current standard special provisions which already address this issue are enforced strictly in all asphalt overlay construction projects. The MAC will communicate with the Colorado Asphalt Pavement Association (CAPA) to alert the industry about the research findings and the need to follow the required tack coat application procedure more rigorously. CDOT materials, construction and inspection personnel will be asked to coordinate with contractors more closely during asphalt paving operations to ensure that tack coats are applied diligently and accurately in accordance with the specified levels.

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EXECUTIVE SUMMARY

This research was designed to identify factors that relate to the appearance of bumps and sometimes cracks that occur in asphalt overlays placed over transverse crack sealant. Results of the study indicate that vibratory breakdown rolling, pavement gradient, sealant geometry, tack coat application rate and tack coat adhesivity are factors that contribute most to the occurrence of bumps and transverse cracks during asphalt overlay construction over crack sealants. Observations suggest that transverse bumps and consequent cracks occur in proportion to the size of the 'bow wave' of asphalt paving materials present immediately in front of the breakdown roller. The increase in the 'bow wave' size is dependent on asphalt mixture properties, breakdown roller size, speed, vibration characteristics and pavement gradient. Four pavement test sections also indicate that tack coat application rate and adhesive properties also have considerable effect on reducing the appearance of transverse bumps.

INTRODUCTION

Crack sealing is a common method of pavement preservation conducted by most highway agencies. The sealing is done to reduce moisture and debris infiltration into the pavement structure. This improves pavement performance by reducing moisture infiltration into the pavement layers. During the life of most asphalt pavements, overlays are placed to rehabilitate and further extend pavement life. During compaction of the overlay, breakdown rolling can produce transverse bumps in the new overlay at locations where crack sealant is present in the substrate pavement. It is believed that multiple reasons may cause this phenomenon, including mixture design, climatic conditions, paving and compaction equipment, timing of the overlay with respect to sealant placement, sealant type, sealant installation method and pavement grade.

Background

Although bumps and transverse cracks have appeared in new asphalt overlays on top of crack sealant for some time, little objective research has been done to determine the cause and prevention. Methods to prevent these bumps include use of asphalt overlay mixtures with high frictional properties such as open graded mixtures, stone mastic asphalt, or dense graded mixtures with highly angular and fractured aggregate (1). Breakdown rolling with the non-driven front roll moving forward tends to push the mixture instead of pulling the mixture under the drive roll. This creates a larger 'bow wave' in the mixture, often resulting in transverse bumps if conditions favor the appearance of bumps. Use of stiffer tack coats has resulted in less overlay shoving and less bump formation. Hard, stiff sealants may not melt into the overlay, while soft, low melt temperature sealants may soften enough when heated by the overlay to not restrain the mix if it displaces during compaction. However, medium stiffness sealants with elastic properties may have a tendency to soften, adhere and restrain the overlay 'bow wave' (2).

A recent study indicated the speed of the vibrating steel roller during breakdown was directly proportional to the size of the bumps that formed. Also, as the number of roller passes increased, the size of the bumps increased (3). A study conducted for Colorado DOT (4) found that bumps accompanied by transverse cracking occurred after the crack sealants had been in service for two years in one test pavement. The number of passes of the vibrating steel rollers further exacerbated the presence of the bumps and cracks. The same rollers used in static mode reduced the effect, and pneumatic rollers used for breakdown eliminated the effect. The ambient temperature and temperature of the substrate pavement during construction was reported to have little effect (4).

The Hypothesis

The mechanism of bump formation is hypothesized to be the result of the breakdown roller creating a 'bow wave' or shoving of the overlay asphalt during the first pass. Heat from the overlay is transferred down into the substrate pavement and crack sealant. The viscosity of the crack sealant decreases and rises into the hot overlay. The adhesive nature of the crack sealant produces a resistant force greater than the surrounding pavement friction.

As the 'bow wave' in front of the breakdown roller passes over the higher friction/adhesive sealant, a reduction in speed of the 'bow wave' occurs and the breakdown roller passes over the 'bow wave' creating a bump slightly offset from the crack in the direction of the paving machine. This offset location of the bump has been documented in the literature (4), however, the position and condition of the crack sealant after the overlay is placed are unknown.

APPROACH

This study was conducted in 2011, 2013, 2015 and 2016 in two phases. Phase I occurred in 2011 using information learned from the previous studies conducted in 2009 and narrowed the search for a cause of transverse bumps. Phase II occurred in 2013 through 2016. This phase built on the 2011 experiment to further focus on the cause of the bumps. The Phase I study will be reported first, then the Phase II study. Final conclusions based on the results of these studies and the previous work will be provided at the end of the paper.

Phase I - 2011

Phase I of the experiment was designed as a blocked, partial factorial with replication to evaluate the effects of five independent variables on bump appearance. These five variables were:

1. Sealant Application Method: Recessed, Flush, Overbanded, Overbanded/Release agent
2. Breakdown Roller Type: Vibrating Steel, Static Steel, Pneumatic
3. Breakdown Roller Speed: 200 fpm, 300 fpm
4. Overlay Type: Hot Mix, Warm Mix
5. Pavement Grade: 0-1%, 3-5%

This experiment resulted in a total of 144 filled cracks. Crack sealant properties are shown in Table 1.

TABLE 1. Physical Properties of Crack Sealant

Property	D6690 Specification-Type II	Test Result
Cone Penetration, 25 °C, max	90	65
Softening Point, °C, min	80	100
Bond, Non –immersed	Pass	Pass
Resilience, %, min	60	85
Asphalt Compatibility, 60 °C, 72 hrs.	Pass	Pass

Properties of the overlay mixture are shown in Table 2.

TABLE 2. Aggregate and Asphalt Mixture Properties Phase I

Aggregate Property	Result	Specification
Micro Deval, Loss %	7.6	18, max
L.A. Abrasion, Loss %	13	45, max
Fractured Faces, 2+ %	100	80, min
Fine Aggregate Angularity, %	46.4	45, min
Sand Equivalent, %	77	45, min
Flat and Elongated, 1:5, %	3	10, max
Adherent Fines, %	0.4	0.5, max
Asphalt Mixture Property	Result	Specification
Asphalt Content, %	4.9	n/a
Voids in Total Mix, %	3.8	3 – 5
VMA, %	14.7	14.0, min
VFA, %	74.1	65 – 75
Hveem Stability	46	30, min
Dust to Asphalt Ratio	1.2	0.6 – 1.2
Dry Indirect Tensile Strength, psi	103	30, min
Tensile Strength Ratio	96	80, min
Superpave Gyrations	75	75

Dependent Variable

The dependent variable in this experiment is the appearance of transverse bumps and cracks on top of the sealants in the substrate pavement. Bumps and cracks were evaluated quantitatively depending on when the bump or cracks appeared after breakdown rolling as shown in Table 3. Any appearance of a bump determines the score shown in Table 3. Severity is not considered, although if a bump appears after the first pass of the breakdown roller, the bump is likely to be more severe after subsequent passes.

TABLE 3. Rating Scale for Bump and Crack Appearance after Breakdown

Rating	Appearance of Bump and/or Cracks
0	No Bump/Cracks
1	First Pass of Breakdown Roller
2	Second Pass
3	Third Pass
4	Fourth Pass

Construction

Two pavements in Golden, Colorado were selected for evaluation in this experiment. Location 1 on Yank Street was selected because of the 0 to 1 percent grade. Location 2 on 55th Place was selected for the 3 to 4 percent grade. Both pavements had transverse cracks of approximately the same severity of ¼-inch wide traversing the entire pavement width.

Each crack to be filled was identified prior to installation and numbered on the edge of the pavement. Installation was done by the Jefferson County Colorado Road and Bridge Division at both pavement locations on March 17, 2011. The sealant was installed in accordance with recommendations supplied by Deery American Corporation for the crack sealant.

Crack preparation method included blowing out the cracks using 100-psi compressed air. Sealant was applied to the cracks by hot pouring using a pressure wand and either filling to level with the surrounding pavement or filling to slightly over full and then spreading the excess off the surface with a V-shaped squeegee creating the 'over-band' application. Two-ply Charmin toilet paper was used as a release agent on top of specific overbanded cracks prior to overlay construction on August 31, 2011.

Table 4 is a summary of the site characteristics.

TABLE 4. Test Site Characteristics-Golden, CO

Location	Pavement Section	AASHTO Soil Class	MSL Elevation, ft.	AADT
Yank St	2 inches ½" NMAS HMA* 4 inches Class 6**	A3	5230	500
55^{th} Place	¾" ½" NMAS HMA 3 inches Class 6	A1	5520	200

* HMA refers to hot mix asphalt pavement, 12.5mm or 19mm refers to approximate maximum aggregate size
** Class 6 is a water-bound crushed aggregate base
AASHTO – American Association of State Highway and Transportation Officials
MSL – Mean Sea Level
AADT – Annual Average Daily Traffic

The weather conditions and pavement temperature during installation were clear and dry with no moisture present in the cracks. Pavement temperatures ranged from 94 ^{o}F to 102 ^{o}F during construction at both sites.

The hot mix and warm mix asphalt was produced by Asphalt Paving Company of Golden, Colorado. The materials were delivered to the jobsites in covered tandem 12-ton dump trucks operated by Jefferson County. All paving was accomplished by Jefferson County using a Caterpillar AP1055D paving machine, a Caterpillar CB534D vibratory steel wheel roller with drum amplitude set at the Number 1 position and a Caterpillar PS150C pneumatic tire roller adjusted to 95-psi tire pressure. Temperatures of the hot mix and warm mix asphalt ranged from 275 ^{o}F to 290 ^{o}F and from 220 ^{o}F to 235 ^{o}F, respectively. Paving operations occurred in the downhill direction for 55th Place.

Results

There was a significant difference whether bumps were created during breakdown rolling between the two sites. No bumps were generated at the 0-1% grade site on Yank Street. This was true regardless of crack seal preparation method, asphalt mixture type or the type or speed of breakdown roller used. However, at the 3-5% site on 55th Place bumps and transverse cracks were created. These bumps and transverse cracks were dependent on roller type, mixture type and crack seal preparation method. The most significant reduction in bump appearance occurred when the static steel wheel roller was used for breakdown rolling over the recessed and flush filled crack sealants. However, only very minor bumps and transverse cracking occurred with static rolling over the overbanded crack sealants.

Vibratory breakdown rolling produced the most significant bumps and cracks over the overbanded and overbanded with release agent crack sealant for the hot mix overlay. However, bumps and cracks also appeared over the recessed and flush filled cracks after two or three passes of the roller. Bumps and cracks also occurred in the warm mix overlay over all four types of crack preparation, but generally required one additional pass of the breakdown roller to occur. The results of these observations are determined as an average for five cracks in each test section depicted in Figure 1 so decimal values instead of whole numbers often represent the number of passes required to generate bumps.

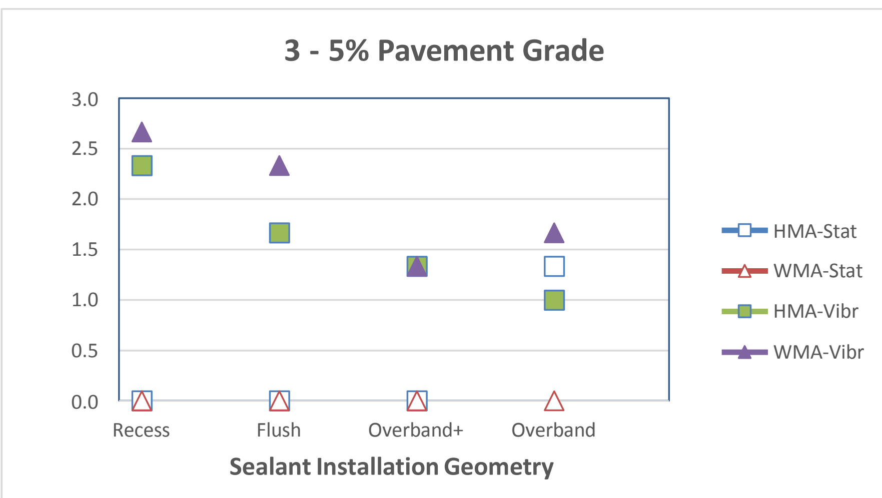

FIGURE 1. Appearance of Bumps after Breakdown Rolling at 300 feet per minute

Analysis

Transverse bumps over crack sealant on a flat gradient pavement (4) have been reported. However, a relatively large 'bow wave' was also reported during breakdown rolling during this earlier research. Observations on Yank Street (0 to 1% grade) indicate the size of the 'bow wave' in front of the breakdown roller was very small or non-existent but on 55th Place (3 to 5% grade) the 'bow wave' was larger. This could mean the 'bow wave' or pushing of the asphalt mixture is directly related to the propensity of the mixture to form a bump over crack sealant. The relatively stiff asphalt mixture used in this research, as indicated by the properties shown in Table 2, may provide evidence for the lack of bumps on Yank Street where a small ‘bow wave’ was observed and the occurrence of bumps on 55th Place where a larger ‘bow wave’ was generated due to the steeper downhill paving operation.

Results shown in Figure 1 suggest that vibratory breakdown rolling has a larger effect on bump generation than mixture temperature since bumps occurred in both the warm mix and hot mix sections when vibrating during breakdown. However, only the hot mix section with the overbanded crack sealant displayed bumps when static rolling was done.

Phase II - 2013, 2015 and 2016

The Phase II of this study was designed to determine if the frictional characteristics of the substrate pavement affected bump generation. The hypothesis in this phase was that if the friction at the overlay to substrate pavement interface was uniform, the ‘bow wave’ in front of the breakdown roller would not experience a change in friction at the overlay-substrate interface and, consequently, continue moving in front of the breakdown roller as it passed over the crack sealant. If the ‘bow wave’ does not slow at this juncture, a bump should not occur. To test this theory three test pavements were constructed using tack coat application rate as the independent variable. The dependent variable was bump generation as previously presented in the Phase I discussion.

Three full-scale test pavements were used in this phase of the study. Tack coat application rate was varied at three levels for the first test pavement: zero, 0.05 gallon per square yard and 0.10 gallon per square yard. Tack coat application rate was varied at four levels for the second test pavement: zero, 0.025 gallon per square yard, 0.05 gallon per square yard and 0.10 gallon per square yard and at three levels for the third test pavement: 0.025 gallon per square yard, 0.05 gallon per square yard and 0.10 gallon per square yard

The three pavements evaluated were S.H. 14 near Rustic, CO, S.H. 13 north of Craig, CO, and I-76 near Brush, CO. Colorado DOT Maintenance personnel constructed the Rustic project in August, 2013; Elam Construction constructed the Craig project in July, 2015; and Simon Construction built the Brush project in July, 2016.

Crack sealant utilized by CDOT on all three projects was an ASTM D6690 Type II product, however, records regarding material properties were unknown at the time of test section construction since sealant had been applied several years before the overlays were applied. However, the sealants on both projects were overbanded, with approximately four inches of width on S.H. 14 and two inches on S.H. 13 and I-76.

Mixture properties of the overlay asphalt are as shown in Table 5.

TABLE 5. Aggregate and Asphalt Mixture Properties in Phase II

Aggregate	S.H. 14	S.H. 13	I-76	Spec
Micro Deval, Loss %	9.0	9.5	11.2	18, max
L.A. Abrasion, Loss %	23	27	28	45, max
Fractured Faces, 2+ %	100	100	100	80, min
Fine Aggregate Angularity, %	47.4	45.3	46.5	45, min
Sand Equivalent, %	75	68	63	45, min
Flat and Elongated, 1:5, %	3	3	3	10, max
Adherent Fines, %	0.3	0.3	0.1	0.5, max
Asphalt Mixture				
Asphalt Content, %	4.9	5.1	5.5	n/a
Voids in Total Mix, %	3.8	3.9	4.0	3 – 5
VMA, %	15.3	15.0	15.5	15, min
VFA, %	74.3	73.8	72.7	65 – 75
Hveem Stability	46	44	45	30, min
Dust to Asphalt Ratio	1.2	1.1	1.0	0.6 – 1.2
Tensile Strength Ration, %	96	90	98	80, min
Superpave gyrations	75	75	100	n/a

Construction of S.H. 14 - 2013

Construction of the S.H. 14 site occurred on August 5, 2013 at approximately mile marker 88 in the westbound lane. Test section locations were selected based on the presence of transverse cracks containing crack sealant with sufficient overbanding. Three test sections were identified and markings applied to the pavement so the tack coat distributor driver could easily see where to stop and start each application rate. Four transverse cracks were identified in each test section for a total of twelve cracks. Test sections were arranged according to the following levels of application rate: the first section was 0.10 gallon per square yard, the second 0 gallon per square yard, then 0.05 gallon per square yard and finally, 0.025 gallon per square yard. The emulsion was a CSS-1h diluted 50:50.

The tack coat was applied with a 1979 model Roscoe distributor with no computer controls. Shot rates were varied by reducing or increasing distributor speeds after measuring the shot rate versus distributor speed for the 0.05 gallon per square yard rate.

The weather conditions and pavement temperature during installation were clear and dry with no moisture present in the cracks. Pavement temperature was 80 ^{o}F. Mixture temperature at the screed was 240 ^{o}F. Mixture temperature at breakdown was 210 ^{o}F.

The 1-1/2 inch overlay was placed with a Caterpillar 1055 paving machine. Breakdown, intermediate and finish rolling was accomplished with one Caterpillar CB34 vibratory roller ballasted to four tons. Breakdown was accomplished by vibrating up and back two times, then by static rolling two times. The amplitude of the roller was not adjustable.

Results on S.H. 14:
Bumps were observed over three of the four cracks in the test section where no tack coat was applied after three passes of the small breakdown roller. These bumps were exacerbated with continuing passes. No bumps were observed over the 0.05 or 0.10 gallon per square yard sections.

Construction of SH13-2015

Construction of the S.H. 13 site occurred on July 21, 2015 at approximately mile marker 106 in the northbound lane. Test section locations were selected based on the presence of transverse cracks containing crack sealant with sufficient overbanding as at S.H. 14. In this case, four test sections were identified to include one more tack coat rate at 0.025 gallon per square yard. Four transverse cracks were identified in each test section for a total of sixteen cracks. Test sections were arranged so the first section had 0 gallon per square yard, the second with 0.025 gallon per square yard, then with 0.10 gallon per square yard and finally, with 0.05 gallon per square yard. The emulsion was a CSS- 1h diluted 50:50.

The tack coat was applied with a two-year old Etynre distributor with computer controls. Shot rates were varied by adjusting the computer inputs.

The weather conditions during installation were rain threatening but with no moisture present in the cracks. Pavement temperature was 68 ^{o}F. Mixture temperature at the screed was 305 ^{o}F. Mixture temperature at breakdown was 260 ^{o}F.

The 1-1/2 inch overlay was placed with a Caterpillar 1055 paving machine. Breakdown rolling was accomplished with a Caterpillar CB64 vibratory roller ballasted to fourteen tons. Breakdown was accomplished by vibrating up and back two times, then by static rolling three times. The amplitude of the roller was set at the lowest value of 0.016 inch.

Results on S.H. 13

Bumps were observed over all of the cracks in the test section where no tack coat was applied and in the section where 0.025 gallon per square yard was applied after two passes of the breakdown roller. These bumps were exacerbated with continuing passes. No bumps were observed over the 0.05 or 0.10-gallon per square yard sections.

Construction of I-76 2016
Construction of the I-76 site occurred on July 8, 2016 at approximately mile marker 94 in the westbound passing lane. Test section locations were selected based on the presence of transverse cracks containing crack sealant with sufficient overbanding as at the two previous sites. Two types of tack coat were installed at this site. These materials were CSS-1h and CSS-1h with an additive to promote rapid setting and bonding called Nanotac. The Nanotac was added at the rate of 10 gallons to 1800 gallons of 50:50 diluted CSS-1h. Five transverse cracks were identified for each tack coat rate of 0.025, 0.05 and 0.10 gallon per square yard of diluted emulsion.

The tack coat was applied with an Etynre Blacktopper Centennial distributor with computer controls. Shot rates were varied by adjusting the computer inputs.

Weather conditions during construction were dry. Pavement temperature was 75 ^{o}F. Mixture temperature at the screed was 290 ^{o}F. Mixture temperature at breakdown was 265 ^{o}F to 275 ^{o}F.

The 1-inch leveling course was placed with a Terex CR562 paving machine. Breakdown rolling was accomplished with a Sakai sw800 vibratory roller ballasted to twelve tons. Breakdown was accomplished by vibrating up and back two times, then static rolling two times. Amplitude was set at 0.013 inch.

Breakdown rolling of the CSS-1h sections occurred immediately after the emulsion had broken. Breakdown of the CSS-1h + Nanotac sections also occurred immediately after the emulsion had broken but the appearance of these sections was significantly darker than the CSS-1h sections, suggesting a more complete break.

Results on I-76

Bumps were observed over all of the cracks in the test section where the CSS-1h was applied at all rates. These bumps were exacerbated with continuing passes of the breakdown roller. Bumps were observed over the 0.025-gallon per square yard section where the Nanotac modified CSS-1h was applied, but not the sections with 0.05 and 0.10 gallon per square yard.

Summary of Phase II - 2013, 2015 and 2016
Table 6 is a summary of the results of the Phase II study showing the number of passes of the breakdown roller required to cause bumps in the respective overlays.

Notice that the I-76 site with conventional tack coat produced bumps in the overlay regardless of tack coat rate. This is inconsistent with the S.H. 13 and S.H. 14 sites. However, the conventional tack coat on I-76 had not completely broken prior to overlay placement. This was the only site where the tack coat had not completely set prior to overlay placement. This may be an indication that tack coat adhesive qualities are related to the appearance of bumps in overlays placed over transverse crack sealant.

TABLE 6. Roller Passes to Cause Bumps

		Roller Passes to Cause Bumps*			
		*S.H. 14-2011***	*S.H. 13-2015****	*I-76-2016*****	*I-76 Nano-2016*****
Application Rate, gallons/sq. yd.	*0*	3	2	NA	NA
	0.025	NA	2	2	3
	0.05	No bumps	No bumps	3	No bumps
	0.10	No bumps	No bumps	4	No Bumps

*Vibrating first four passes, then static rolling
** 4 ton CB34
*** 14 ton CB64
**** 12 ton Sakai

CONCLUSIONS

This study does not prove the hypothesis stated earlier and, consequently, more work should be done to determine the actual mechanism at work. However, it does provide additional information regarding factors that increase the appearance of bumps in overlays over crack sealant and, hopefully, provides supplementary practical information for owners and builders with which to avoid creating bumps in new asphalt overlays placed over crack sealants. Factors from the Phase I study found to have a statistically significant effect on the appearance of transverse bumps in new hot and warm mix asphalt placed over crack sealant are:

- Vibrating breakdown roller (more vibration, more bumps)
- Pavement gradient (rolling downhill caused bumps)
- Crack seal overbanding (wider overbanding increased bumps)

Additional factors from the Phase II study found to have an effect on the appearance of transverse bumps in new hot and warm mix asphalt placed over crack sealant are:

- Tack coat application rate (lower rates, more bumps)
- Tack coat adhesive ability (slower setting emulsions, or unbroken emulsions, more bumps)

Possible explanations for these observations:
Vibration on breakdown may pull some of the crack sealant into the overlay and may also increase the size of the 'bow wave' in front of the breakdown roller. However, bumps have not been reported or observed in the longitudinal direction, only transverse. This suggests that movement of the crack sealant up into the new overlay is not the mechanism at work, but, instead is due to frictional differences between the substrate and new overlay. Coring the new overlay after the appearance of transverse bumps could help verify this.

An increase in pavement gradient increases the opportunity for a larger 'bow wave' to form in front of the breakdown roller since a braking force must be applied to resist undue forward movement.

Wider crack seal overbanding provides an increase in the frictional resistance between the overlay and substrate. Less tack coat provides an opportunity for a bigger difference in friction between the overlay and the substrate.

If tack coats are not completely set when the overlay is applied the adhesive bond between the overlay and the substrate may be affected. This may lead to a difference in friction from the surface of the substrate to the crack sealant. This friction differential may lead to a higher probability for bumps to occur because the 'bow wave' can 'sense' the difference in friction and slows down when moving over the crack sealant. Since the roller is moving at a constant rate, the roller jumps over the 'bow wave' causing a bump.

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