Placement and Compaction of Asphalt Mixtures

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editor

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Foreword

The symposium on Placement and Compaction of Asphalt Mixtures was presented at Phoenix, Ariz., 8 Dec. 1982. The symposium was sponsored by ASTM Committee D-4 on Road and Paving Materials. F. T. Wagner, State of North Carolina Department of Transportation, presided as chairman and editor of the publication.

Contents

Introduction

A major portion of the public roads in the United States of America are paved with asphalt concrete. The ability to produce an asphalt concrete pavement that is capable of carrying the ever increasing legal (and higher illegal) wheel loads and today's high volume of traffic without deforming in the wheel paths and maintaining the ability to withstand thermal expansion and certain amounts of deflection is becoming more demanding each day. The placing of the asphalt concrete mixture within acceptable temperature ranges without segregation, and then compacting the mixture while still within an appropriate temperature range, goes a long way towards achieving a dense durable pavement.

The papers in this STP cover (1) the development of the asphalt paver over the past 50 years, (2) the changes in compaction equipment since World War II, (3) effects of low mixing and compaction temperature on engineering properties of asphalt pavement, (4) low density resulting from insufficient rolling and improper construction procedures, (5) asphalt density measurement, nuclear versus core, (6) inadequate compaction resulting from late season construction, poor compaction procedures, and excessive minus 200 material in the mixture, (7) a procedure for estimating the service life of pavement when materials do not conform to the specifications, and (8) the value of creep tests in determining an asphalt mixture's ability to resist traffic densification.

I thank my fellow committeemen and past committeemen of ASTM Committee D04.92 on Papers and Symposia for their assistance during my year as Chairman of both the subcommittee and the symposium. To these peers I am forever indebted: Grant J. Allen, Arizona DOT; J. J. Emery, Trow, Ltd.; J. E. Huffman, Sahuard Petroleum and Asphalt Co.; B. E. Ruth, University of Florida at Gainesville; and J. A. Scherocman, Barber Greene Company.

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Placement of Asphalt Concrete Mixtures

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ABSTRACT: A brief description of the history of the development of the asphalt paver is given in this paper. It discusses the principle of the floating screed and the operation of the paver tractor unit and screed unit. The forces that act on the screed and keep it in balance (level) to provide a smooth asphalt concrete mat are explained. Improvements in paver design and operation are detailed, and the most recent innovation of the self-widening screed is described. It is pointed out, however, that the basic operational functions of a modern paver are still the same as developed over 50 years ago. The paper also describes the causes of and cures for twelve different common problems that can occur in the asphalt concrete mat behind the paver. Emphasis is placed on why the various deficiencies have occurred and on what can be done to correct the problem when it does happen. Finally, for each mat problem area, the paper discusses the affect of each defect on the long-term performance of the asphalt concrete pavement structure.

KEY WORDS: asphalt paver, tractor unit, floating screed unit, screed balance point, ski angle, mat deficiencies, surface waves, ripples, mat tearing, texture, screed marks, screed responsiveness, auger shadows, precompaction, joints, checking, shoving, bleeding, fat spots, roller marks, asphalt concrete mix design, compaction

Asphalt Paver Principles

History

Before the 1930s, the placement of asphalt concrete mixtures was accomplished primarily by hand-labor methods. In 1931, the first piece of equipment that was designed particularly for laying these materials was exhibited at the St. Louis Road Show [*1*]. This first unit, which operated on steel rails or side forms, featured a bucket loader machine to pick up a windrow of aggregate, a pugmill to mix the aggregate with asphalt cement, a screw conveyor to spread the material across a 6.10 m (20 ft) width, and a screed riding on the forms to strike off the mixture.

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A second version of the paver eliminated the need for the side forms and made the spreader a self-propelled machine by mounting it on crawler tracks. The screed, which was towed by the spreader, was equipped with elongated outrigger-type leveling arms projecting fore and aft from each side of the screed. These long arms, which supported the screed, provided a "wheelbase" for averaging the variations in the road surface being paved. Another version, operated in late 1931, eliminated the long arms and used the concept of the floating screed for the first time. This principle provided a means for the screed to both strike off and compact the asphalt concrete material being laid. The screed unit was towed by "leveling" arms projecting to the rear from the main spreader chassis.

This floating screed principle represents the heart of the asphalt paver, a concept characteristic of all asphalt pavers operating today. As shown in Fig. 1, in 1933 the paver consisted of a hopper to receive asphalt concrete mixtures from the hauling units, a spreading screw, or auger, and a 3.05-m (10-ft) wide floating screed. The tow point of the screed was supported on sledlike runners that ran on top of the existing pavement surface [*1*]. Developments in the late 1930s included use of a flight feeder to move the mix more efficiently from the hopper to the spreading screws and, most importantly, the relocation of the screed tow point from its own averaging ski-reference to the crawler tractor frame, allowing the machine itself to provide the leveling

FIG. 1—*1933 model self-propelled paver with floating screed.*

wheelbase. The pavers changed little in design throughout the years during and soon after World War II. It was not until the mid 1950s that significant changes began to occur in the mechanics of the paver operation.

Paver Operation

The asphalt paver consists of two major parts. The first is the tractor unit. The second is the screed unit. The functions and operation of each part are discussed below.

Tractor Unit—The tractor unit is the prime mover section of the paver; as such, it performs a wide variety of tasks necessary in the laydown process. Utilizing push rollers mounted at the front of the paver to contact the rear tires of the haul truck, the tractor unit is used to propel the truck along the roadway. A receiving hopper accepts mix from the haul vehicle and, using twin drag slat conveyors, the tractor unit carries the asphalt concrete materials to the rear of the machine through a set of metering gates and deposits the mixture directly in front of the paver screed. The material is then transported transversely across the width to be paved by a pair of screw conveyors, or augers. Each auger is mechanically linked to one of the drag slat conveyors. This allows for independent control of the amount of asphalt concrete supplied to each side of the paver.

The tractor unit, equipped with its own engine, contains all the necessary mechanisms to power and control the mix receiving, conveying, and distributing systems. In addition, the tractor provides the required propulsion energy to move the machine forward, either on crawler tracks or on rubber tires, to place the material.

The Screed Unit—The elements and nomenclature of the screed unit are shown in Fig. 2. This unit is towed by the tractor unit, with the towing point pivotally mounted to the tractor by a pin that eliminates any ability to transmit torque. The combination of the screed pivot point at the leveling arm and the thickness control screw provides for adjustments to be manually introduced to the system. The key to the leveling performance of the screed is its ability to establish an equilibrium attitude based on the forces applied. As

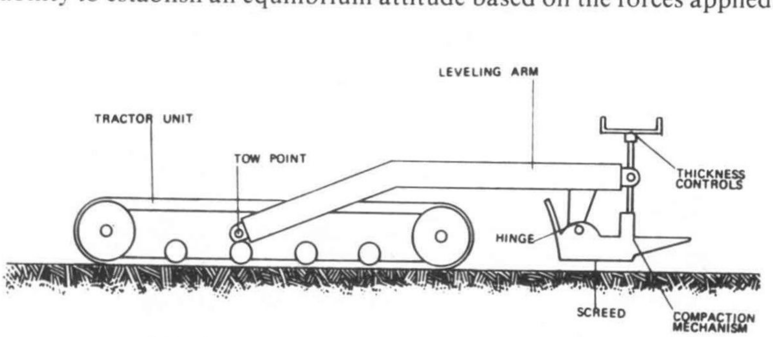

FIG. 2—*Elements of the self-leveling floating screed.*

the mix passes under the heated, flat screed plate, the screed floats on the mix, determining both mat thickness and texture and providing some degree of initial compaction to the asphalt concrete mixture.

Several different forces (Fig. 3) act on the screed. These forces are (1) the towing force F_t, (2) the material force against the screed F_m as the screed pushes the excess mix ahead of it, (3) the frictional force (generally small) F_f that is created between the screed plate and the mix passing under that unit, and (4) the weight of the screed W_t. The resultant force F_x is generated in a force polygon that is used to balance the equation. The analysis of force F_x shown in Fig. 4 is the essence of the principle of the floating paver screed.

The resultant force F_x is generated as the asphalt concrete material passes under the screed. The angularity of F_x is an indication of the differential compaction that occurs under the screed plate, that is, lower density at the front and higher density at the rear. This difference, then, reflects that the screed indeed floats at an inclined ski angle. Based on constant forces, if the ski angle is disturbed, it will always return to the equilibrium position. This can be illustrated by a manual change that can be input into the system by turning the thickness control screw shown in Fig. 3 and increasing the distance D_1. This change will, in turn, cause an increase in the screed angle by rotating the screed about its pivot point. As the screed unit is towed down the roadway, the screed towing arm complex is free to rise about the towing point. This causes the ski angle to decrease from that artificially (manually) introduced.

In approximately six leveling arm lengths, sufficient rotation will occur so that the screed will have returned to over 99% of its original equilibrium angle. The result, of course, is that the thickness of the asphalt concrete material passing under the screed has been increased. The up correction, or increase in mat thickness, can easily be reversed by turning the thickness control screws in the opposite direction, thereby decreasing the distance D_1 shown in Fig. 3. This change causes a negative ski angle from the equilibrium position. As the tractor unit moves ahead six leveling arm lengths, the screed floats down to the new equilibrium point, reducing the thickness of the mat being placed. It is important to remember that the tractor unit must move forward a distance of approximately six times the length of the leveling arm

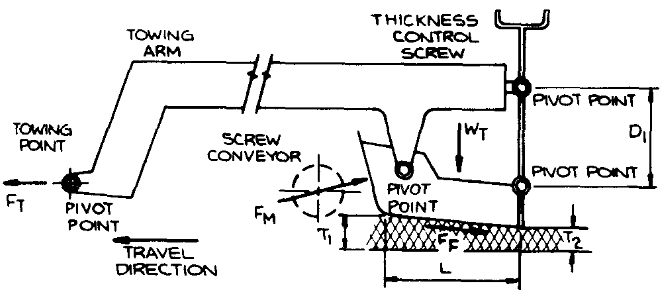

FIG. 3—*Forces acting on the screed.*

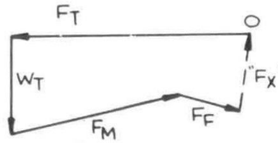

FIG. 4—*Screed forces polygon.*

on the paver before the change in thickness introduced by a manual change in the setting of the thickness control screws is 100% completed, and the forces on the screed are back in balance in an equilibrium position.

While the manual thickness control change most easily describes the concept of a change in ski angle, there is another source of angle change being input continuously into the system at the towing point. That point, which is attached to the tractor and uses it as a wheelbase, is moving up and down in response to the average grade being spanned by that wheelbase. These vertical movements of the tow point also cause the ski angle of the screed to change. This, in turn, imposes correcting actions on the screed as it constantly searches for its equilibrium angle or position. The net result is that the self-leveling, equilibrium seeking action of the screed causes the mat to be placed such that the mix fills in the low spots in the existing surface, and less mix is placed on the high spots on that surface. This phenomenon is shown in Fig. 5.

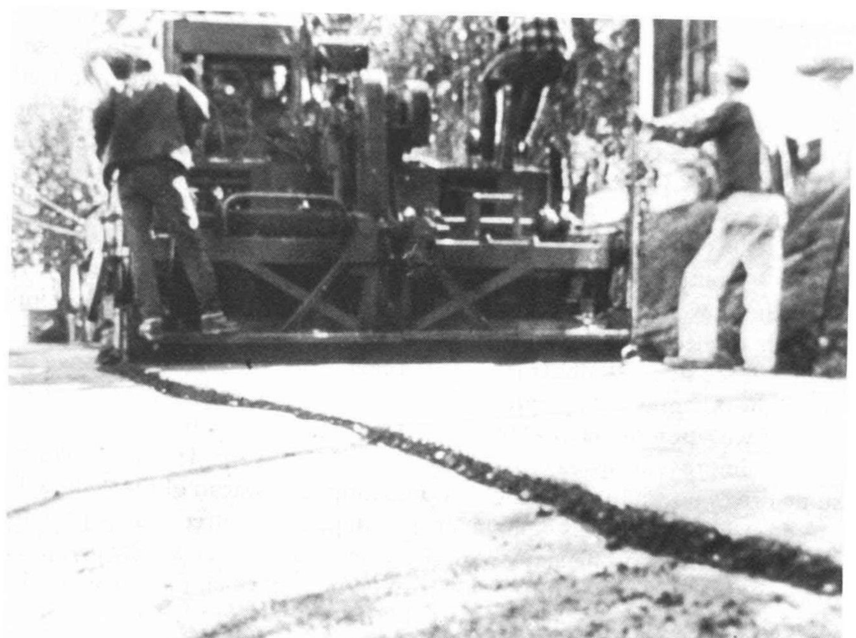

FIG. 5—*The leveling action of the floating screed.*

Paver Improvements

The fundamental principle of the floating screed has remained unchanged for over 50 years. Many significant changes have occurred, however, in paver operation over those years. Several of those basic improvements are described below, with emphasis on how this affected the smoothness of the mat being placed by the paver.

Power Transmissions—Improvements in pavers have paralleled the development of power transmission equipment, from somewhat crude manually operated clutches that run mechanical gear and drive chains to electrical control of clutches, to hydraulic and hydrostatic drives, and finally to electronically controlled hydrostatic closed-loop systems. This evolution in paver transmission equipment has improved paver operation in three basic ways: (1) improved productivity—the capability of handling larger trucks and placing greater tonnages of material in a set amount of time using the increased horsepower and weight of the paving machine; (2) improved mat quality and smoothness—the operating variables are controlled more consistently; and (3) improved operator efficiency—the operator needs only to monitor the machine's distribution and placing functions, and can concentrate on truck exchange and steering functions.

An example of the benefits of these improvements concerns the material force F_m applied to the face of the paver screed (Fig. 3). With the original manually operated clutches, the paver operator was responsible for regulating the amount of material in the screw conveyor chamber (Fig. 3). If he was inattentive, he might let the asphalt concrete material level decline to the bottom of the augers. Noting his error, the operator might overreact and feed too much material in, overloading the chamber. The net result is that the force F_m changes both in magnitude and effective point of application caused by the variation in the level of the mix. The resultant effect is an unbalance in the force polygon, which causes a variation in the equilibrium screed ski angle. The smoothness of the mat being placed then changes as the mat thickness continually increases and decreases.

As the power transmission equipment available to the designer has improved, an electric clutch was used and a "tell-tale" on-off switch was installed in the screw chamber to control the level of the mix. This change reduced the potential for operator error but when misadjusted still allowed for enough variation in material level to affect force F_m and the mat thickness. Further improvements to electronically controlled, variable volume hydrostatic drives now allows the use of a potentiometer instead of the "tell-tale" on-off switch. Using this equipment, a voltage is produced that is proportional to the level of the material in the screw chamber. This voltage is used to vary the displacement of the hydrostatic pump, which then changes the drag slat conveyor and auger speeds to keep a constant head of material (force F_m) in front of the paver screed.

An increase in paver speed, for example, increases the demand for mix. The potentiometer sensor measures a decline in the level of material in the screw chamber. It provides an increase in voltage input to the pump to automatically increase its output, and thus speeds up the drag slat conveyors, carrying more material to the rear of the machine. This fully proportional system allows for more constant control of the force F_m (Fig. 3) and eliminates screed reactions that would reduce the quality of the final pavement. This is, however, only one example of how the refinements in power transmission equipment have improved the basic paver functions.

Automatic Grade and Slope Controls—Another area where important improvements have occurred is in the evolution of automatic grade and slope control equipment. Left alone, the self-leveling characteristics of the paver screed can provide very smooth roadway surfaces, particularly where multiple lifts are used; each course provides a smoother input to produce an even smoother output. The possibility was recognized, however, that a very long "wheelbase" could be established by erecting a surveyed stringline or, more practically, a long towed mobile reference. Use of the mobile reference would cause the tow point of the leveling arm to follow the average of the reference line rather than the shorter line of the paver crawler or rubber tire wheelbase.

By fitting the tow point with a hydraulic ram, an electronic sensing system was developed to input signals to the ram control valve that would allow the tow point to follow the average movements of the longer remote reference [*2*]. By equipping tow points on both sides of the machine and selecting either grade (line following) or slope (gravity reference) sensors, the movements of the paver tractor unit were isolated from the screed operation (Fig. 6). This development, now accepted as standard practice, has improved the ride characteristics of the new mat by extending the frame of reference.

Self-Widening Screed—A more recent development has been that of a screed unit with its own hydraulically powered extensions (Fig. 7). Previously, the mat width placed by the paver was increased by bolting rigid extensions to the ends of the basic paver screed. This chore, in addition to being a hot and dirty job, was time consuming; at times it required the whole paving operation to stop while the rigid extensions were installed or removed. The new self-widening screed can change width hydraulically from minimum to maximum in seconds, greatly improving paver operating efficiency and productivity as well as saving labor costs and downtime [*3*].

On almost all extendable screed designs, the extending portions of the screed are trailed behind the main screed. Since the screed skis at some equilibrium angle, as previously discussed, a height adjustment mechanism is used to raise or lower the extension so that its trailing edge is on the same plane as the basic screed. Misalignment of the extensions that are equipped with heaters and vibrators similar to the main screed causes the two screed sections to place the asphalt concrete mat at different thicknesses (Fig. 8). If

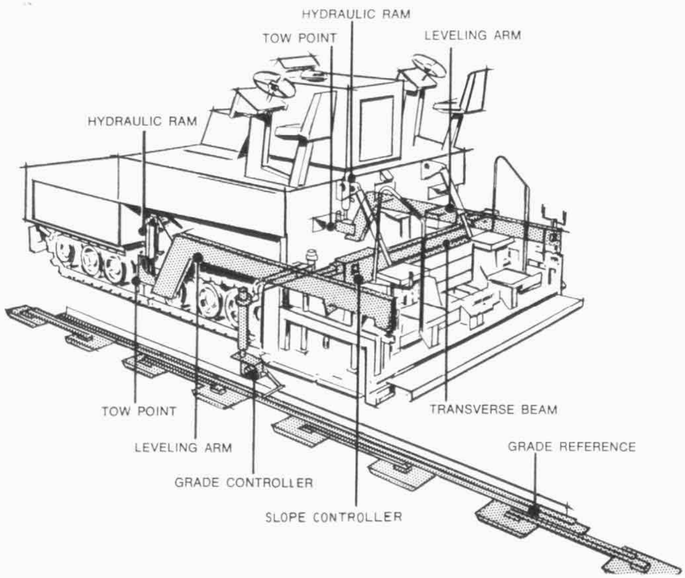

FIG. 6—*Automatic grade and slope controls.*

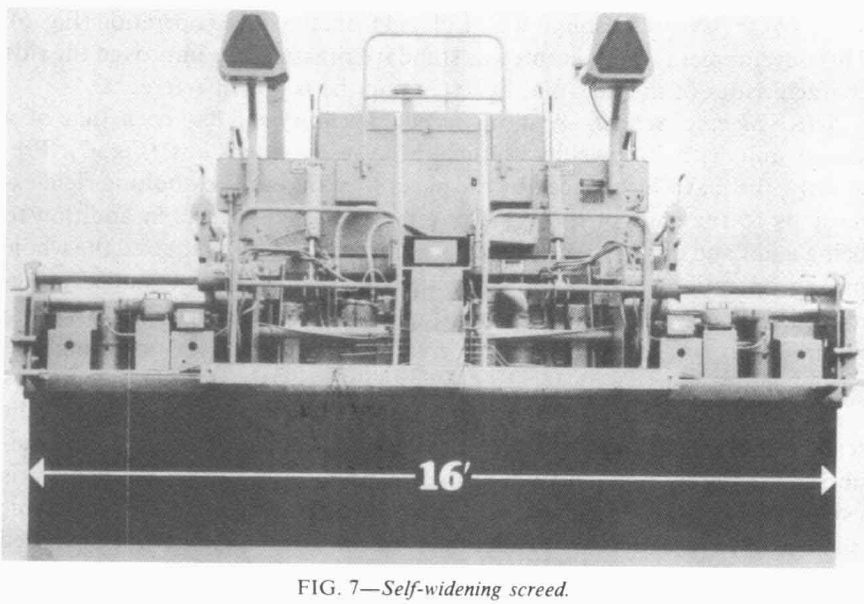

FIG. 7—*Self-widening screed.*

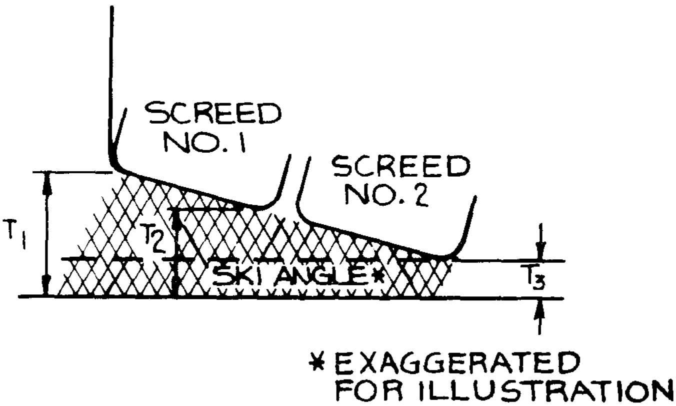

FIG. 8—*Misaligned self-widening screed.*

the extendable screeds are properly set, the heels (trailing edge) of both screeds will be at the same elevation (Fig. 9). This will result in a "markless" mat and in uniform density across the mat width, both under the main screed and the self-widening extensions [*4*].

Summary

The innovations briefly described are some examples of the many changes that have taken place in the operation of an asphalt paver during the last 50 years. These changes have increased the productivity of the machine. The improvements have increased the efficiency of the placing operation and produced a smoother mat by automatically controlling the feed of the asphalt concrete material back to the screed. The basic principle of the floating screed, however, with the ability to shave off the high spots and fill in the low spots in the existing pavement surface, has remained unchanged since 1931.

Mat Problems

Mat problems can be defined as defects that occur in the asphalt concrete mixture during or soon after the laydown and compaction operations.

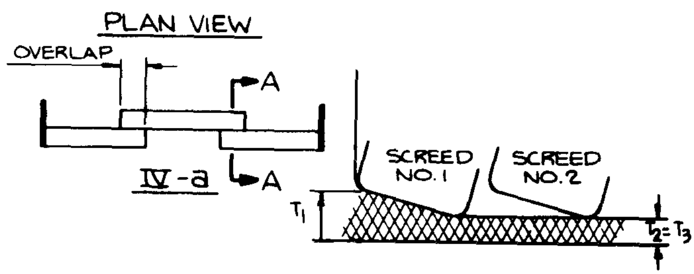

FIG. 9—*Properly set self-widening screed.*

These problems can be divided into two primary categories: (1) equipment related problems and (2) mixture related problems. Several different types of mat deficiencies will be discussed, with emphasis on the description of the problem, the cause of the problem (equipment or mix related), its cure, and its effect on pavement performance.

Figure 10 summarizes the various kinds of problems that can occur in an asphalt concrete layer during construction [5]. Listed in the first column is a description of various mat defects. Marked in the remaining columns are several possible causes for each particular mat problem. The check marks indicate equipment related causes while the X marks indicate mix related causes.

Surface Waves

A wavy asphalt concrete surface can be of two types: short waves, or ripples, and long waves. Short waves are generally 0.30 to 0.91 m (1 to 3 ft) apart, with 0.46 to 0.61 m (1½ to 2 ft) being the most common distance. Long waves are considerably farther apart and may correspond to the distance between truckloads of mix.

The primary cause of ripples, or short waves, is a fluctuating head of material in front of the paver screed. This variation in the amount of mix being spread causes the screed to rise and fall as the pressure against it changes. Too much and then too little asphalt concrete mix being carried by the paver augers in front of the screed causes the wavy surface as the screed reacts to the variable forces on it. A secondary cause of ripples can be a screed that is in poor mechanical condition; one which has loose screed plates or has excessive play in the screed control connections. Ripples can also be formed in the mat by improper mounting or setting of the automatic grade controls on the paver or by use of an inadequate grade reference device.

Short waves can also be a function of the mix design, particularly in regard to a tender mix or one that varies in stiffness caused by changes in mix temperature or mix composition. As the stiffness of the mix varies, the forces of the mix pushing on the screed also vary, causing the screed to rise and fall and place a wavy mat. Finally, ripples can be formed in the asphalt concrete mat by the compaction equipment, especially with a tender mix. If the mix design is improper—either in aggregate gradation, asphalt content, moisture content, or mix temperature—the rollers may shove and displace the mix during the compaction process. Normally, however, ripples are placed in the mat by the paver either because of its operation or because of changes in mix stiffness rather than by the compaction equipment.

Long waves are caused by many of the same variables that cause short waves. A fluctuation in the amount of material in front of the screed and mix stiffness variation causes the screed to react to the change in pressure on it. If the distance between the wave peaks, however, corresponds to the length of