## Technical Paper T-123

# PAVEMENT SMOOTHNESS

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## INTRODUCTION

Many changes have taken place in the asphalt industry as we have progressed into the 21st century. Among these are the general increase in the loads that asphalt roads are expected to carry, new improved science in the mix design itself with the implementation of Superpave™, and an understanding of the complicated loads (stresses and strains) that our pavements must endure. Our industry has provided new tools with which to address these issues. These tools allow us to design stronger, more durable mixes and give us the means to apply them so that our roads can perform under the traffic loads of today and of the future.

Trucks have always created severe damage to our highways. The number of trucks on our roads has increased dramatically in the last two decades and is expected to keep growing into the future. Higher tire pressures in use today also cause more damage to our roads. These factors coupled with decreased spending on maintenance and repairs in proportion to the miles traveled, means that the demands for quality, smooth road construction have become greater.

The general public has always demanded smooth roads and engineers must meet these expectations regardless of the materials selected. The need to develop techniques to build more miles of roads for fewer dollars and to build roads that last longer is evident.

In this bulletin we will look at the benefits of building roads to a higher smoothness standard in order to satisfy the public demand for smooth highways, reduce pavement maintenance costs, and insure a longer lasting highway. In addition new research has concluded that many other benefits are obtained when we increase the initial smoothness of our highways.

## SMOOTHER ROADS LAST LONGER & COST LESS

In the later part of 1988, Astec Industries contracted with Mr. Michael S. Janoff of JMJ Research in Newton, Pennsylvania, to study the effect of initial smoothness on long term pavement performance. From this early research many additional studies have been conducted on this important topic. We will look at some of these projects and their results.

Mr. Janoff presented the results of his research at the annual NAPA meeting in January of 1990 in his publication entitled "The Effect of Increased Pavement Smoothness on Long Term Pavement Performance & Annual Pavement Maintenance Cost."

| INITIAL SMOOTHNESS in./mi. (mm/km) | LONG TERM ROUGHNESS in./mi. (mm/km) | IMPROVEMENT (%) |
|---|---|---|
| 35 (553) | 41 (647) | 0 |
| 30 (474) | 35 (553) | 13 |
| 25 (395) | 30 (474) | 27 |
| 20 (316) | 24 (379) | 40 |
| 15 (237) | 19 (300) | 54 |
| 10 (158) | 13 (205) | 67 |

**INITIAL SMOOTHNESS vs. LONG TERM ROUGHNESS** F1

| INITIAL SMOOTHNESS in./mi. (mm/km) | LONG TERM CRACKING in./mi. (mm/km) | IMPROVEMENT % |
|---|---|---|
| 35 (553) | 26 (410) | 0 |
| 30 (474) | 17 (268) | 35 |
| 25 (395) | 9.5 (150) | 63 |
| 20 (316) | 4 (63) | 85 |
| 15 (237) | 1 (16) | 96 |
| 10 (158) | 0 | 100 |

**INITIAL SMOOTHNESS vs. LONG TERM CRACKING** F2

The results of Mr. Janoff's studies were as follows:

**1)** Pavements with increased initial smoothness have lower roughness levels in the 10 years following construction. (Fig. 1)

**2)** Pavements with increased initial smoothness have lower cracking levels in the 10 years following construction. (Fig. 2)

**3)** Pavements with increased initial smoothness have lower average annual maintenance costs in the 10 years following construction. (Fig. 3)

From a cost benefit standpoint, highway agencies can afford to expend considerable additional cost per lane mile (or kilometer) to build smoother roadways, being assured that these additional costs would be offset by a reduction in annual maintenance costs.

Since the conclusion of these early studies, additional research has been conducted, which yielded data supporting them.

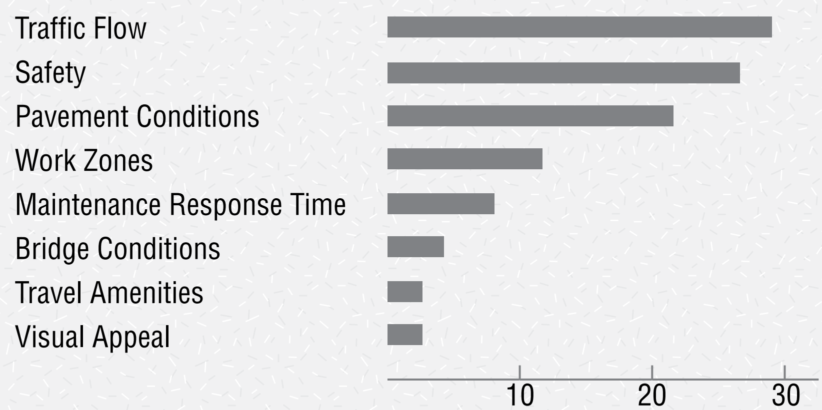
As mentioned in the introduction, pavement smoothness is something the public not only understands but requires in highway construction. In a study conducted in 1996 by the National Quality Initiative (NQI) survey, highway users ranked concerns over Pavement Smoothness as most important (31%), followed by Safety (21%), Traffic Flow (19%), and Bridge Conditions (10%). This survey was further supported by a follow-up study in 2000, which came to the conclusions shown in Figure 4.

These studies, as well as the American Association of State Highway and Transportation Officials (AASHTO) Road Test, confirm that all road users judge a road by its ride quality (smoothness). Clearly, roughness correlates directly to faults that exist in the road surface. These can vary from a bump to either longitudinal or transverse cracking or to the ultimate roughness, a “pothole."

Looking further into smooth roads and how initial smoothness in construction effects the life of the pavement, the National Center for Highway Research (NCHR) conducted their own studies under project 1-31. The results of the study clearly showed that smoothness also extended the life of a pavement. To increase a pavement's initial smoothness by 50%, (this is a minimal improvement by a single lift of HMA), the life of the road could be increased by as much as 27%.

| INITIAL SMOOTHNESS in./mi. (mm/km) | AVERAGE COST $/lane mi. ($lane/km) | COST SAVINGS $/lane mi. ($lane/km) |
|---|---|---|
| 35 (553) | 949 (590) | 0 |
| 30 (474) | 670 (416) | 280 (174) |
| 25 (395) | 440 (273) | 509 ( 316) |
| 20 (316) | 261 (162) | 689 (428) |
| 15 (237) | 131 (81) | 818 (508) |
| 10 (158) | 52 (32) | 898 (558) |

**INITIAL SMOOTHNESS vs. AVERAGE ANNUAL MAINTENANCE COST** **F3**

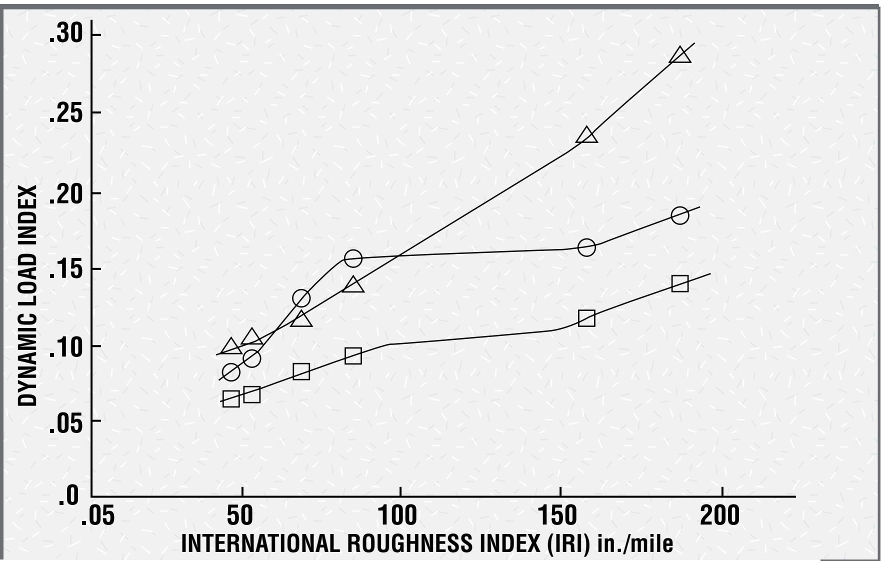



The public thinks improvements to traffic flow, safety, and pavement conditions are most important.
Source: Infrastructure Survey (2000)

**MOST IMPORTANT HIGHWAY IMPROVEMENTS (percent)** **F4**

| REDUCTION IN INITIAL ROUGHNESS % | AVERAGE % INCREASE IN SERVICE LIFE | |
|---|---|---|
| | ASPHALT | CONCRETE |
| 10 | 5 | 7 |
| 25 | 13 | 18 |
| 50 | 27 | 36 |

**REDUCTION IN ROUGHNESS vs. INCREASED SERVICE LIFE** F5



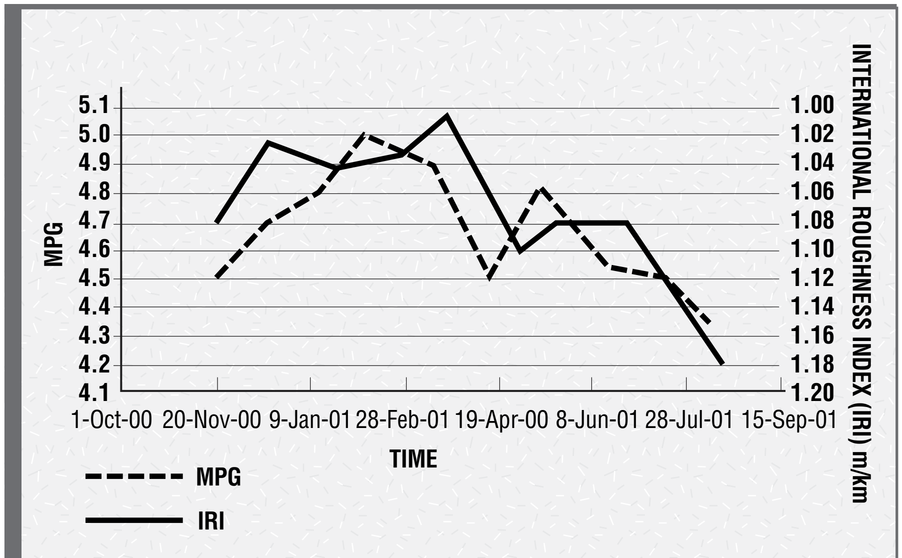

**DYNAMIC LOADING INCREASE vs. ROUGHNESS INDEX** F6

Figure 5 summarizes the NCHR findings. It shows the incremental amounts of smoothness improvement on projects and the anticipated additional life that could be expected. Any increase of the smoothness requirements results in considerable savings over time.

The opposite is also true. Any roughness in the surface will decrease the expected life of the road. It's easy to visualize that any vehicle that passes over a bump placed during initial road construction will have its normal load accelerated on the other side of that roughness. The result is a tremendous increase in loading and increased damage to the surface. We can see in the graph (Figure 6) how the dynamic loading increases as the roughness increases. As the IRI (International Roughness Index) increases all types of dynamic loading goes up, dramatically increasing the damage and decreasing the life of the pavement. Clearly, different vehicles cause different damage, but they decrease the life of the pavement and the cycle can only get worse.

The result of building pavements that are smoother is a decrease in the dynamic loading that each vehicle produces. This not only lowers maintenance cost but extends the interval between maintenance operations, resulting in tax dollar savings and fewer road work zones for the average road user.

Increased car maintenance can easily be determined by looking at the front alignment of our vehicle after running over a pothole. Front end work can cost anywhere from a little over $100 to some extraordinary front end replacement parts and repair costs. Beyond other time delays caused by excessive road work, there is an additional, immediate benefit we can derive from smoother roads and that is the increased efficiency of our own car. A car will use less fuel and be subjected to less wear and tear on smooth roads.




**FUEL ECONOMY AND ROUGHNESS vs. TIME** F7

Recent studies conducted by the National Center for Asphalt Technology (NCAT) and WESTRACK indicate that smoothness and fuel economy are directly related. The smoother the road the less fuel is consumed. Prior to a scheduled rehabilitation at WESTRACK the fuel economy on the testing vehicles was checked. They were averaging 4.2 miles/gallon as they went around the track. After rehabilitating the track the measured roughness was reduced by 10% and the fuel economy was increased by 4.5 %.

Similar data has been collected at the NCAT test facility in Auburn, Alabama as shown in Figure 7. Here we can see the seasonal effect that changing IRI can have on fuel economy as well. Additional research has been conducted by N. Mike Jackson Ph.D.,P.E., from the University of North Florida on the relationship between smoothness and fuel economy. The Asphalt Pavement Alliance requested the study to be conducted. In September 2004 the results were published, indicating that smoother surfaces could lead to as much as a 20% improvement in mileage.

The additional benefits of smooth roads are that we have increased mobility and can go about our business much more safely. Clearly, smoother roads are a benefit to everyone.

## TRENDS IN SMOOTHNESS

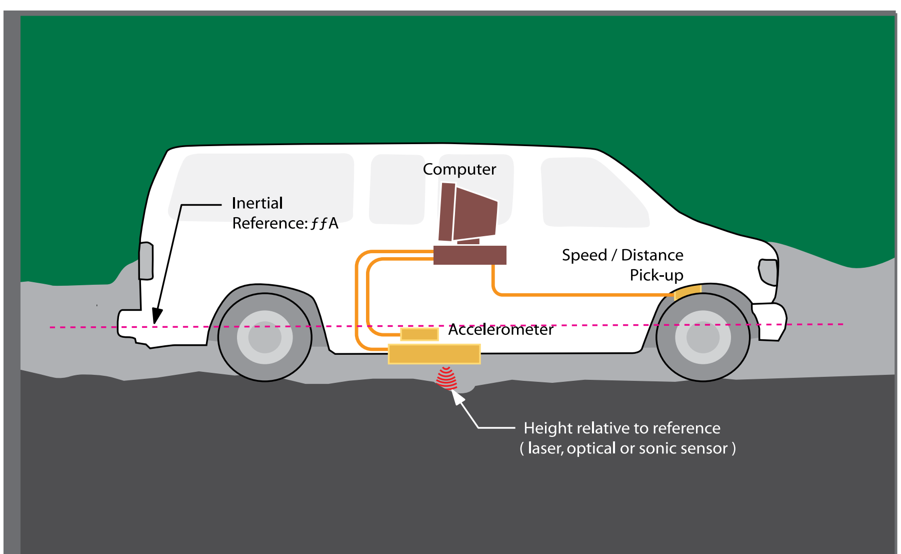
The Federal Highway Administration (FHWA) has the difficult job of judging not only the condition of our roads, but ranking of States in their performance in building the interstate system. Clearly, smoothness indicates the quality of the roadway and should be an ideal measurement. Unfortunately there are several methods used by State Departments of Transportation (DOT) to measure the smoothness of their roads. The issue is further complicated by States not only using different devices for measuring smoothness but different units of measure as well. This is the reason the FHWA has settled on a single unit of measure to be used in every state to report the condition of their roads. It is IRI, the International Roughness Index.

IRI is a universally accepted measurement of a road's smoothness which was developed by the World Bank as a result of the International Road Roughness Experiment that was conducted in the 1980's. The goal of the experiment was to standardize the measurement for smoothness to compare road conditions worldwide.

Starting in 2001, the FHWA required the state DOT's to report their road conditions in IRI. There is a simple mathematical conversion from their current unit of measure (Profile Index, or Ride Number) to the International Roughness Index. Unfortunately the data was still compromised because there could be no correlation between the existing measuring systems of the DOT and mathematically converting it ot IRI if there were blanking bands used in the specification.

The next step in developing a suitable report system would be to eliminate the blanking bands in the specifications and then consider a universally acceptable method to measure the smoothness.

The answer came in the form of improved technology and the introduction of the inertial profiler. All measuring devices in the past were flawed because they didn't really measure the profile of the road, they were systems that lacked the capacity for repeatability, and they would measure some elevations higher or lower than they actually were.




**INERTIAL PROFILOMETER®** F8

Using the inertial profiler is as close as one can get to the results a survey crew would get if they actually went out and measured elevations at six inch intervals along the road. The inertial profiler measures the actual profile of the road and, through the use of a computer program, compares the heights to a flat plane to determine smoothness. Any vehicle movement that made ride numbers unrepeatable in the past have been eliminated by mounting an accelerometer over the height measuring device, which is usually a laser. The accelerometer collects all the vehicle movement data and subtracts it from the results.

This system provides a method that is not only accurate and repeatable, but also cradle-to-grave statistics on the condition of all the roads in the country.

Currently there are several Provisional Specifications published by AASHTO for the state DOT's to use in developing their smoothness requirements. They are:

**MP 11** — Standard Equipment Specification for an Inertial Profiler

**PP 49** — Standard Practice for Certification of Inertial Profiling Systems

**PP 50** — Standard Practice for Operating Inertial Profilers and Evaluating Pavement Profiles

**PP 51** — Standard Practice for Pavement Ride Quality when Measured Using Inertial Profiling Systems

Many states using Profile Index or Ride Numbers for acceptance are converting over to the International Roughness Index. Many others have already made the transition to IRI. Among the states that are currently using IRI for construction acceptance are: Pennsylvania, Texas, New York, Maryland, Virginia, Minnesota, New Mexico, Louisiana, Arkansas, Idaho, South Dakota, Montana, Wyoming, and Washington.

Additionally, several states have revised their specifications to make the final acceptance test based on the number of opportunities a contractor has to obtain the smoothness. Obviously, if we had a single 2" overlay on a road, the most we could expect to improve the ride would be by 50%. If on the other hand we were able to put down mix in two lifts we could improve the ride by 75% (50% improvement with each opportunity). These specifications bring together not only the smoothness requirements but the practical side of the construction capabilities of the equipment.

## BUILDING FOR SMOOTHNESS

As we look closely at the opportunities to achieve better smoothness on projects, it becomes clear that when building a new road, or rebuilding and maintaining an existing structure, there are several different approaches we can use and still meet the goal of making a smoother, longer-lasting highway that will be constructed efficiently.

Looking at some of our farm-to-market roads that are in poor condition, we can see the potential for use of innovative technology while remaining conscious of the need to use existing materials in the process. Before deciding on the process we must identify the failure, and come up with a solution. A failed asphalt road, for example, could easily be caused by overloading the structure or we could be looking at an underlying base failure that took the asphalt along with it.

After a good forensic study we may even determine that it was a combination of increased loading (more trucks using the road than anticipated) and a base failure. A simple overlay will not be the solution.

As we view the innovations available in equipment, we should recognize that we could use a soil stabilizer/reclaimer to pulverize the existing asphalt, and then blend it with some of the base material to rebuild an entirely stronger subgrade.

**STABILIZING THE SUBGRADE** **F9**

If the required degree of structural support cannot be achieved with the existing in-place materials, improvements can be made with the addition of granular material, such as virgin aggregates, reclaimed granular materials or RAP (mechanical stabilization). In addition, a wide range of chemical and/or bituminous stabilizing agents can be employed to improve the physical properties and water resistance of the reclaimed material. Portland cement, lime, fly ash or blends of these materials are used in the chemical stabilization process (Fig. 9). Asphalt emulsions or foamed asphalts are typically employed for what is known as bituminous stabilization.

Once the base is reconstructed, a simple overlay would complete the process. Overall we can now have a stronger, smoother, longer-lasting road.

As we remix and blend the existing material with additives to strengthen the sub- grade we will replace the material in place with pavers or motor graders and roll the mix conventionally. This process combined with an overlay provides two (2) opportunities for smoothness and at the same time builds a stronger structure. The conservation and use of the existing materials also makes good "life cycle cost" sense.

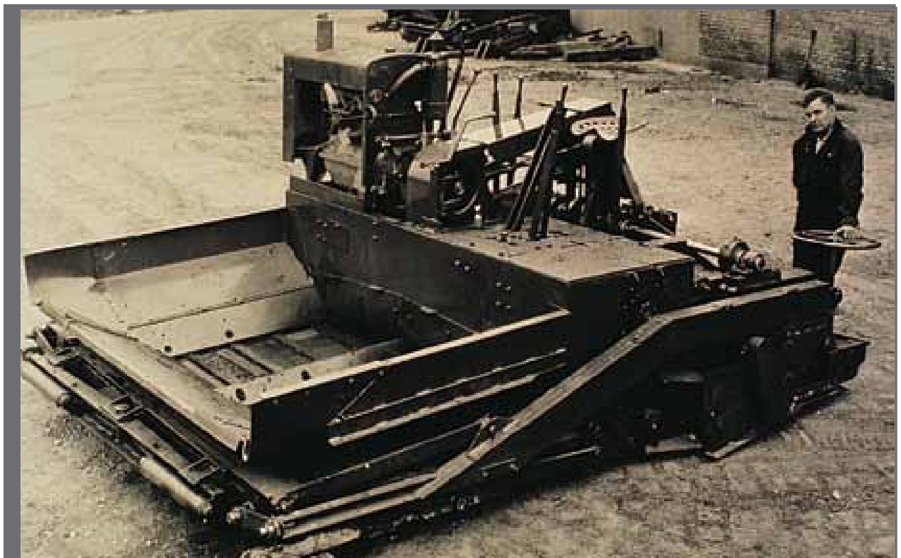
If we were to construct this road today we may want to consider other options for construction. If the usual farm-to-market road served us well, we could again put in 12” of flex-base and overlay it. This time however, we may want to consider placing the flex-base down with a paver in two lifts. Not only will this provide two smoothness opportunities but will provide thinner lifts that will make it easier to get good, uniform compaction.


**MILLING WITH SONIC SKI** **F10**

Maybe the failure we are looking at has occurred from the top down (cracking). If the surface can be milled out, we have not only conserved a valuable resource, but if no adjacent lane has to be matched this mill-and-fill may give us two opportunities for smoothness. We emphasize "may" because in many areas we mill out a single lane and fill it in with asphalt and must match the adjoining lane prior to removing it and filling it with HMA. Neither the milling nor the paving are considered opportunities for smoothness. If we can set up the milling machine with extremely accurate grade and slope controls and remove the entire width of the road surface, then we have a smoothness opportunity. Placement of the overlay is our second smoothness opportunity. Taking advantage of both will result in a smoother, longer-lasting road.

As much as this industry has changed over the years, so has the supporting equipment side of the business. New uses for soil stabilizers, milling machines, improved pavers, and the use of innovative Shuttle Buggy® material transfer vehicles provide the means to build smoother, longer-lasting, cost effective roads.

## PAVING FOR SMOOTHNESS



**BASIC PAVING PRINCIPLES REMAIN UNCHANGED** F11


**PAVING TECHNOLOGY KEEPS PACE WITH SMOOTHNESS SPECS** F12

From the earliest pavers developed in 1935 (Fig. 11) to the most modern pavers we produce today (Fig. 12), the basic principles that apply to paving smooth roads have not changed.

Today's equipment is far more productive then the original pavers, but what has had the biggest impact on smoothness are modern electronic controls and hydraulic drives. Today's pavers are much easier to operate and smoother in operation.

The basic principles of paving smooth roads have not changed over time, but we do have to pay closer attention to the details if we are to meet current specifications. Among these are:

**1.** Continuous paving is a must for smooth pavements. There will always be occasions where we must stop the paver due to material shortages caused by trucking delays, or operations that require hand work, or where we might be tying into existing pavements and/or intersections. A better term than "continuous paving" would be "constant speed paving." The number of stops as well as the length of time we remain stopped can affect potential roughness. Stops will never be completely eliminated, but they must be minimized.

Trying to pave continuously has led to some bad practices, which cause roughness. Operators can make the mistake of slowing down dramatically to allow trucks to leave or discharge into the paver's hopper. These severe speed changes can lead to smoothness problems. Focusing on constant speed paving, with rapid stops and starts, is a better approach.

**2.** Constant speed paving allows the operator to set flow gates and the sensors that control the auger speed in the proper position. After paving speed, the next most critical force that must be controlled is the head of material. Significant changes in this force lead to roughness of the pavement (Fig. 13). Set up the flow gates for the paving width, the auger height for the thickness of the mat, and the auger sensors so that the augers are turning continuously. The head of material should be held within plus or minus one inch, and just above the height of the auger shaft (Fig. 14).

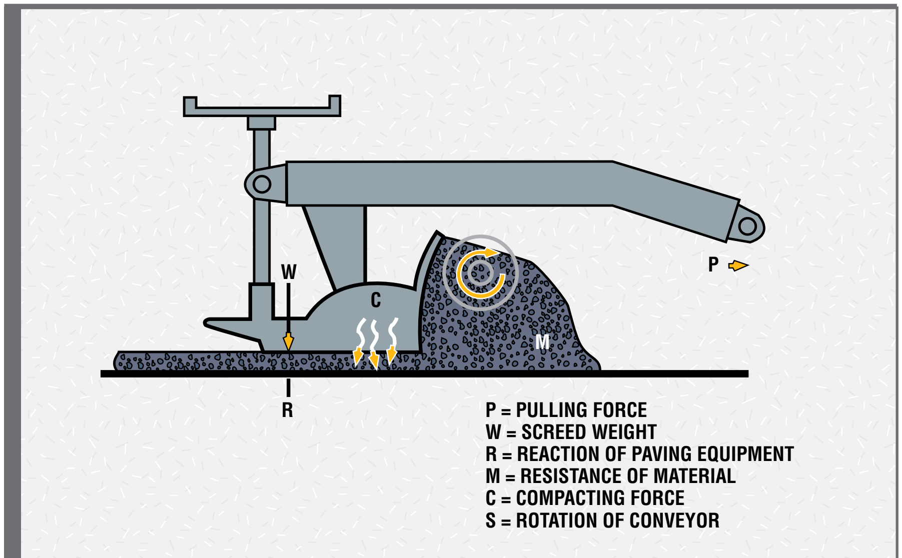
**3.** Do not let the delivery truck bump the pavers. Have the dump man always stop the truck a few feet short of the paver's hopper and drive the paver into contact with the truck.

**4.** Pay close attention to details in constructing transverse joints. Set the paver screed down on slats (shims) that are the height of asphalt roll down. Center the tow points, null out the screed on the shims, and then induce a slight angle of attack into the screed to prevent it from diving (Fig. 15).

**5.** An improperly cleaned, and therefore not free-floating, end gate can cause problems in the function of the grade and slope controls.

**6.** Last, but not least by any means, to achieve smoothness requires that we produce and deliver a uniform mix to the paver. Variation in the mix consistency, temperature or physical segregation will cause changes in the forces applied to the screed. The screed will change from its current balance point to a new one, creating roughness.

If a pavement is truly smooth it will be of high quality and uniform. Virtually all smoothness issues on asphalt pavements can be traced to changing paver's speeds or changes in the head of material in the auger chamber.




**MAJOR FORCES ACTING ON FLOATING SCREED** F13

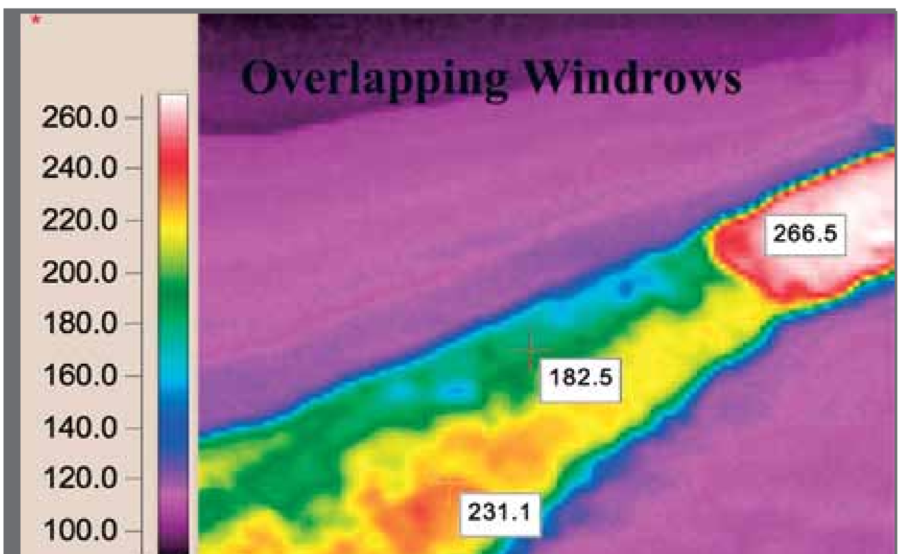

**CONTROL THE HEAD OF MATERIAL TO ± ONE INCH** F14

**SETTING UP THE SCREED TO ACHIEVE GOOD TRANSVERSE JOINT** F15

## NEW TECHNOLOGY

Over the years most people have understood the basic paving principles listed on the previous pages. A number of approaches are being taken to insure that the paver operates continuously (at a constant speed) so the material to the screed can be better controlled. One widely accepted practice is to windrow the material down in front of the paver. Using belly dump trailers, the mix is discharged on the ground and then loaded into the paver using windrow pick-up machines (Fig. 16). This practice is popular in the western parts of Canada and the United States. There is no question that this simple solution does separate the trucking operation from the paving operation, making continuous paving possible.

**WINDROW** **F16**




**INFRARED IMAGE - OVERLAPPING WINDROWS** **F17**

However, we do have to consider additional facts that could lead to non-uniform mix. First of all, we are handling the material more often and this could lead to physical segregation of the mix. The natural flow of material from a belly dump trailer leads to the larger aggregate segregating and being dumped at the end of load. This, of course, causes end-of-load segregation in the mat.

Piling the mix on the road surface and exposing it to wind and the ambient air can cause severe temperature segregation issues as well (Fig. 17). Not only does this lead to texture and smoothness problems, but it's also a major cause of premature asphalt failures due to non-uniform compaction. (See Technical Paper T-134 for more details).

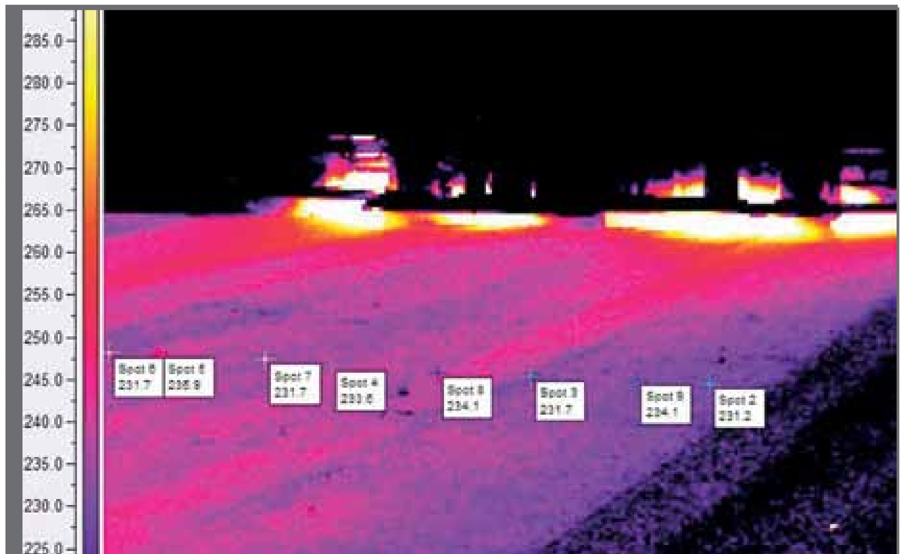
We must always do everything we can to deliver a uniform mix to the pavers. If placed at the proper grade and slope, the compaction rollers then have every opportunity to achieve the required density in the mix. Ultimately, the density achieved in the mix is the determining factor in its performance and strength.

To prevent the delivery of both physically and thermally segregated mix to the paver, the Shuttle Buggy® Material Transfer Device was developed by Astec Industries (Fig. 18). These units not only provide re-mixing of the asphalt before delivery to the paver, but also act as a mobile surge silo. The device totally separates the truck operation from the paver and can insure a smooth, uniform mix. Today, over 40 state DOT's and provinces in Canada require and/or specify the use of this machine. Moreover, the Shuttle Buggy material transfer device is rapidly gaining acceptance worldwide because of its ability to remix and to deliver uniform mix to the paver.

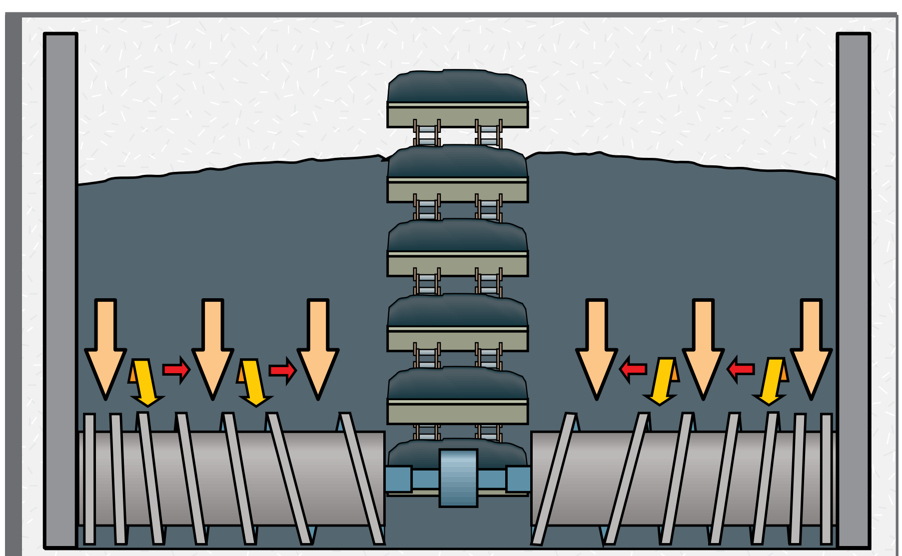
The Shuttle Buggy allows a truck to unload on the job site at a rate of 1000 tph and routes the mix to its on-board storage hopper. This high unloading speed successfully reduces truck delays at the job site and can lead to up to 25% improvement in trucking efficiency, thus reducing trucking costs by a like amount.

After the mix is delivered into the Buggy's hopper, two variable pitch augers remix the asphalt to insure that there is no physical or thermal segregation (Fig. 19). The variable auger causes additional material to be drawn down from the bin at various points, leading to complete remixing (Fig. 20). Having 25 tons of storage the hopper also provides enough dwell time for any temperature variations to be eliminated. The augers pull the material to the center discharge conveyor and out to the delivery conveyor. The material is fed to the paver at a rate of 600 TPH and the paver uses a hopper insert to store an additional

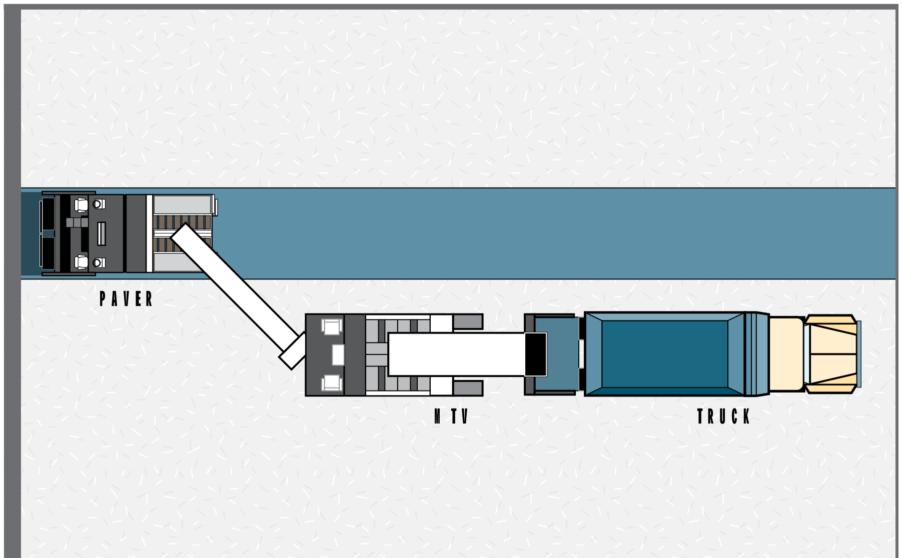

SHUTTLE BUGGY® MATERIAL TRANSFER DEVICE F18




INFRARED IMAGE - PAVER WITH SHUTTLE BUGGY® (WINDROW) F19

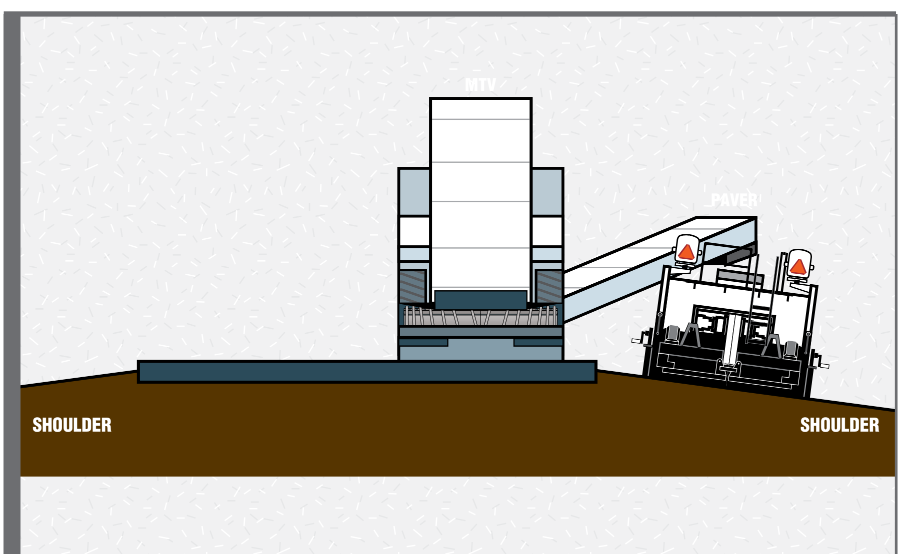


VARIABLE PITCH AUGER F20




**SHUTTLE BUGGY® FEEDS PAVER OVER STRING LINES** F21


**ROADTEC SPRAY PAVER** F22




**SHUTTLE BUGGY® ALLOWS PAVERS ON SHOULDER AREA** F23

15-20 tons of HMA.

The 20-ton hopper insert adds even more storage and insures that we can have every opportunity to manage our material delivery for a smooth paving operation. Together the hopper insert and Shuttle Buggy provide as much as 50 tons of storage on the job site.

In addition to allowing trucks to unload without moving and shuttling the material to the paver, the Shuttle Buggy® material transfer device also allows us to select optimal locations for unloading the delivery trucks that are free from overhead wires or bridges that can hinder mix delivery.

Capable of more than providing a uniform, continuous delivery of material to the paver on highway projects, the Shuttle Buggy also has proven itself invaluable in delivering mix at airport projects where string lines are erected. The dump trucks can now move freely to the Buggy which discharges the asphalt into the pavers from outside the string line (Fig. 21). In addition, this prevents the haul trucks from backing down over the tacked surface and picking up the material on the tires. (The Shuttle Buggy working in conjunction with a Roadtec spray paver (Fig. 22) completely eliminates the problem of tracking tack because the spray paver combines tack application and paving. The spray paver can also do traditional paving without spraying tack.)

Consider a normal shoulder project, where we have to build ramps into and out of the shoulder area so haul trucks can deliver material to the paver. If we have the luxury of closing two lanes, this expensive process is no longer necessary when using a Shuttle Buggy (Fig. 23).

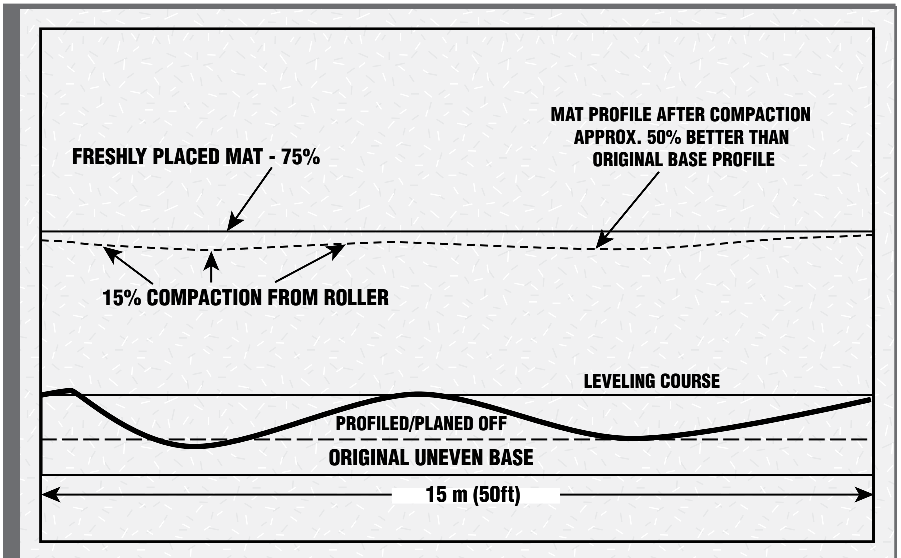
Other successful applications have found the Shuttle Buggy being used on automobile test tracks and race tracks around the country. Both require a high degree of smoothness but the banked curves can cause some severe delivery, paving and compaction problems. The Buggy can overcome them. See Figure 24.

The Shuttle Buggy is equally successful on city streets and residential cul-de-sac construction (Fig. 25). Often these projects require delivery of small batches to areas that require hand work, to areas with tight turns (cul-de-sac) or areas with overhead obstruction that won't permit a dump truck to unload.

When we control our paving operation and use proven equipment to improve

**SHUTTLE BUGGY® FEEDING OVER TRACK WALL** F24


**SHUTTLE BUGGY® WORKING IN CUL-DE-SAC** F25




**DIFFERENTIAL COMPACTION** F26

smoothness we also build roads that are quieter, safer, and a true benefit to the industry and the traveling public.

## COMPACTION

The final task on our projects is to achieve the desired (specified) density. It is this specified density that determines the ultimate performance of the mix we have placed.

Mix production and placement must be done in such a way so an opportunity is provided to the compaction roller operators to achieve the specified density. Compaction can only put on the finishing touches. It cannot fix problems created in the mix production or paving process.

In most cases a single lift of uncompacted asphalt will actually improve the smoothness of the surface by 75%, keeping in mind that the action of the free-floating, self-leveling screed is going to smooth over the irregular surface. This of course leads to irregular lift thickness and will therefore result in varying roll down thickness of the material by the rollers.

We generally consider the roll down of asphalt to be about 25% depending on the mix that it is selected. Stone Matrix Asphalt and Permeable Friction Course have much less roll down. The rollers will compact the irregular lift thickness and the resultant ride will only improve by 50%. See Figure 26.

Other complications in compaction occur if we are using scratch courses to provide some leveling or we are dealing with a surface that is considerably rutted.

There are several basic rules in rolling that must be adhered to so that the smoothness obtained by the pavers is not decreased:

**1.** Never stop the roller parallel to the direction of paving.

**2.** Always turn the roller toward the center of the mat at a 45° angle.

**3.** Never stop the roller on the hot material.

**4.** Establish and maintain the proper rolling pattern as determined in the test strip.

Keep in mind that physical segregation, temperature differential, or irregular surface thickness may prevent the rollers from obtaining uniform density, no matter how skilled the operator.

If we have taken advantage of every opportunity to have a smoother surface in the mix production and paving operations and if compaction is done by the book, then we will achieve our smoothness goal.

## APPENDIX A

American Association of State Highway and Transportation Officials (AASHTO)
Standard Practices for Inertial Profiling Systems.
These documents are available from AASHTO for a fee.
www.transportaton.org

Certification of Inertial Profiling Systems
– AASHTO Designation PP 49-03
Practice describing minimum performanace requirements for inertial profilers to be used for QC/QA of surface smoothness on owner/agency paving projects. The certification procedure for test equipment is included.

Operating Inertial Profilers and Evaluating Pavement Profiles
– AASHTO Designation PP50-03
Test Method descibing the procedure for operating and verifying the calibration of an inertial profiler, evaluation procedures for the profiles that are generated, and a methodology for resolution of disputes arising from suspect profiler output.

Pavement Ride Quality When Measured Using Inertial Profiling Systems
– AASHTO Designation PP51-03
Procedure intended to be used as an example specification for owner-agencies to use in the development of specific language when requiring the measurement and evaluation of ride quality and compliance using inertial profiling systems.

## APPENDIX B

3-6-00
ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT SPECIAL PROVISION

MATERIALS TRANSFER DEVICE / VEHICLE
Division 400 of the Standard Specifications for Highway Construction, Edition of 1996 is hereby amended as follows:
The following is hereby added to Subsection 409.04, Mechanical Spreading and Finishing Equipment:
Materials Transfer Device (MTD) / Materials Transfer Vehicle (MTV), A Materials Transfer Device or Materials Transfer Vehicle (MTD/MTV) shall be used on all State, US, and Interstate highways for the placement of all ACHM courses. ACHM quantities exempt from this requirement are projects or phases of work with less than 1,000 tons of hot mix, temporary pavements (such as detours, crossovers, driveways and turnouts), and ACHM placement in trench widening areas less than 3.3 m (11') in width. The ACHM mixture shall be transferred mechanically to the paver by means of a MTD/MTV. The material shall be continuously remixed or reblended either internally in the transfer vehicle, in a paver hopper insert, or in the paver's hopper. Remixing/reblending shall be accomplished by the use of remixing augers, paddles or screens capable of continuously blending the hot mix asphalt.
The MTD/MTV, haul units, and paver shall work together to provide a continuous uniform, segregation free flow of material. The number of haul units, speed of the paver, plant production rate, and speed of the MTD/MTV shall be coordinated to avoid stop and go operations. The wings of the paver receiving hopper shall not be raised (dumped) at any time during the paving operation.
If a MTD/MTV or remixing/reblending unit malfunctions during lay-down operations, the Contractor may continue hot mix lay-down operations until any hot mix asphalt in transit or stored in a silo has been laid and until such time as there is sufficient hot mix placed to maintain traffic in a safe manner. Lay-down operations shall cease thereafter, until such time as equipment is operational.
The Engineer will evaluate the performance of the MTD/MTV and remixing/reblending equipment by measuring the temperature profile of the mat immediately behind the screed of the paver during the placement of the rolling pattern test strip. The ACHM to be placed for temperature profile test shall be held in the haul truck(s) for at least 45 minutes, measured from the time of loading to the time of discharging into the MTD/MTV. If the bed of the haul truck is covered, the cover will be removed once arriving at the test strip location. The temperature profile measurements shall be taken of the surface of the mat at six 13 m (50 ft.) intervals during test strip construction using a non-contact thermometer. Each temperature profile shall consist of three surface temperature measurements taken transversely across the mat in a straight line at a distance of 0.3m to 1 m (1 foot to 3 feet) from the screed while the paver is operating. The three temperature measurements in each profile shall be taken approximately 0.3 m (one foot) from each edge and one in the middle of the mat. The difference between the maximum and minimum temperature of each individual profile shall not be more than 6° C (10°F).
If any two temperature measurement profiles within the test strip do not comply with the 6° C (10°F) temperature differential requirement, the paving operation shall be halted and adjustments made to the MTD/MTV or remixing/reblending equipment to ensure that the hot mix placed by the paver is within the above temperature requirements. Once adjustments are made, the Engineer will repeat this procedure to verify that the mix placed by the paver is within specifications.
Additional surface temperature profile measurements may be taken transversely across the mat at any time during the project to determine if the MTD/MTV and remixing/reblending equipment are working properly. During this verification testing, if two consecutive temperature measurement profiles do not comply with the 6° C (l0°F) temperature differential requirement, the paving operation shall be halted and adjustments made to the MTD/MTV or remixing/reblending equipment to ensure that the hot-mix placed by the paver is within the above temperature requirements.

## APPENDIX C

Texas Department of Transportation 1 TxDOT 11/2004
Tex-244-F, Thermal Profile of Hot Mix Asphalt

**Section 1**

Overview

Effective Date: November 2004

Use this test method to obtain a thermal profile which identifies the presence of thermal segregation on an uncompacted mat of hot mix asphalt. The thermal profile is determined using a handheld non-contact infrared thermometer immediately behind the paver during continuous paving operations. An area will be deemed as having thermal segregation when the temperature differential within the profile is greater than 25°F.

Units of Measurement

The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in non-conformance with the standard.

**Section 2**

Apparatus

Use the following apparatus:

Handheld non-contact infrared thermometer

- capable of measuring from 40°F to 500°F with an accuracy of ± 2°F
- with a LCD display capable of displaying the maximum temperature (and minimum temperature if available)
- adjustable emissivity in increments of 0.01 or a fixed emissivity equal to or greater than 0.95 and a minimum 6:1 distance to spot ratio
- must have a distance range of at least 20 ft. (6.1 m).

**Section 3**

Report Forms

Use the following Microsoft Excel program for reporting purposes.

'Thermal Profile for Hot Mix Asphalt' (Tx244)

**Section 4**

Procedure

Follow these steps to obtain a thermal profile on an uncompacted mat of hot mix asphalt.

Temperature Profile Scan of Uncompacted Mat Surface

Step 1

Refer to the manufacturer's recommendations for operating the handheld non-contact infrared thermometer.

Step 2

Observe the following general rules while obtaining all temperature measurements.

- Use spray paint or a permanent marker to mark the pavement edge at the beginning and ending location of each thermal profile.
- Record the beginning and ending station number to identify the location of all thermal profiles. GPS coordinates or other acceptable means may be used in lieu of station numbers.
- Obtain all temperature measurements in units of degrees Fahrenheit.
- Obtain all temperature measurements while the paver is moving.
- Walk close to the edge of the uncompacted mat and at a distance of approximately 5 ft. (1.5 m) behind the paver.
- Hold the non-contact infrared thermometer approximately waist high while obtaining all temperature measurements.
- Avoid taking temperature measurements within 2 ft. (0.6 m) of the edge of the uncompacted mat.
- Measure the temperature of the uncompacted mat by pointing the non-contact infrared thermometer, squeezing (and holding) the trigger and scanning back and forth across the mat, transverse to the direction of paving. While obtaining temperature measurements, walk at approximately the same speed of the paver in order to maintain a distance of approximately 5 ft. (1.5 m) behind the paver.
- Do not attempt to obtain temperature measurements in areas of the mat that are more than 20 ft. (6.1 m) away from the infrared thermometer.
- Obtain a new maximum baseline temperature and minimum profile temperature for every thermal profile measured. Each thermal profile will be approximately 150 ft. (45.7 m) or the distance paved by 2 truckloads of hot mix. This distance does not include the 20 ft. (6.1 m) used to establish the maximum baseline temperature.

(cont. next page)

## APPENDIX C (cont. )

Step 3

- Use the procedures listed in steps 2 and 4 to measure the maximum baseline temperature.
- Use the procedures in Steps 5 and 6 to measure the minimum profile temperature.
- Determine the temperature differential for each thermal profile as listed in step 8.

Step 4

Follow the guidelines in step 2 and determine the maximum baseline temperature over a paving distance of approximately 20 ft. (6.1 m). Avoid measuring high temperature areas caused by heating from the screed while the paver is stopped (Establishing Maximum Baseline Temperature).

The infrared thermometer will display the maximum temperature of the uncompacted mat surface when the trigger is released.

Step 5

Determine the lowest allowable profile temperature by subtracting 25°F from the maximum baseline temperature measured in step 4.

Step 6

- Follow the guidelines in Step 2 and determine the minimum profile temperature over a paving distance of approximately 150 ft. (45.7 m) or 2 truck loads of hot mix.
- The minimum profile temperature is defined as the lowest temperature value measured throughout the thermal profile (Establishing Minimum Profile Temperature).

Step 7

- If the temperature of any area of the mat in the profile is less than the lowest allowable profile temperature established in Step 5, record the low temperature value obtained at the edge of the paving lane using spray paint or a permanent marker.
- Record the station number to identify the location of the mat where the minimum temperature was measured. GPS coordinates or other acceptable means of identifying the location may be used in lieu of station numbers.

Step 8

Calculate and record the temperature differential of the thermal profile by subtracting the minimum profile temperature established in Step 6 from the maximum baseline temperature established in Step 4 as shown in “Calculations.”

**Section 5**

Calculations

Calculate the Temperature Differential of the uncompacted mat surface using the following formula:

TemperatureDifferential=MaximumBaselineTemperature-MinimumProfileTemperature

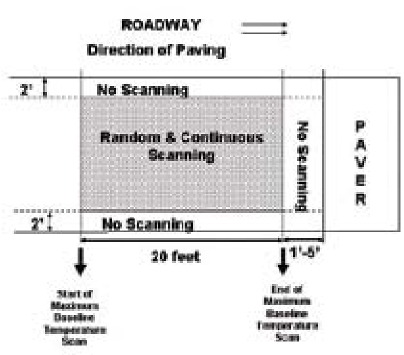



Figure 1. Establishing Maximum Baseline Temperature.

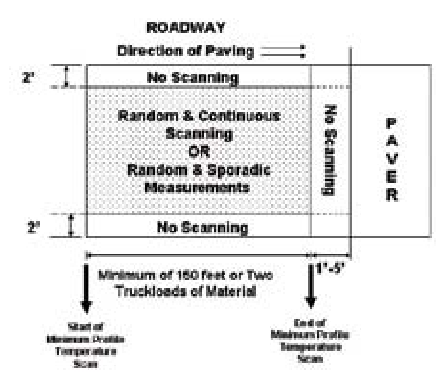



Figure 2. Establishing Minimum Profile Temperature.

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