KEYS TO PAVEMENT SMOOTHNESS: A PAVING SUPERINTENDENT'S VIEWPOINT

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INTRODUCTION

Ten years ago, the paving industry constructed relatively smooth riding surfaces, but today we find difficulty in producing a comparable product. Perhaps an explanation lies partially in the fact that our needs and conditions have changed with time. For instance, today's economic conditions require that we construct what we can afford rather than what we might desire.

Many factors have changed over the last ten years which influence the construction of smooth pavements. Pavement design and construction has changed. Secondary roads with low traffic volumes do not justify the implementation of high design standards demanded in the past. Spot reconstruction such as bridge gaps and patching is now required on the primary system as we try to prolong its life. Increased wheel loading has necessitated the use of doweled contraction joints, subbases and sand subgrades. Our machinery has changed to increase productivity as we attempt to realize a profit and yet keep prices from rising.

These changes in design and construction techniques create situations which account for many of today's rough pavements. However, the general public is much more vocal in its desire for smooth pavements. To meet this goal, a testing instrument for measuring pavement smoothness, the California Profilograph, has been developed which enables us to evaluate the ride quality immediately.

Today's paving industry finds itself in a new ball game that will require modification of equipment, changes in procedures and innovative thinking if we expect to win. Simplistic solutions of the past, such as workmanship, will result in singles, not home runs. Let us consider some of the factors which the industry must counter to become a winner in the game.

EQUIPMENT

There are many factors which contribute to rough pavements, and it is essential that we continue to try to identify these sources. However, because our present equipment was designed for increased productivity instead of pavement smoothness; I believe that the future major advances will occur from contractor modification of present equipment.

To successfully make these changes we must understand some basic principles and apply them correctly. The slipform paving process is essentially similar to that used to form an aluminum extrusion. In this process, material under closely controlled viscosity and pressure is forced through a rigid die. The product will be uniform only when the die, viscosity and pressure remain constant. Much of the current roughness of slipform paving can be explained by the fact that these three items of the extrusion process are, in fact, constantly changing during the paving process.

Central Paving chose to stabilize the die opening of the extrusion meter first because we felt that it was in this area that our Town and Country Paver was the most deficient.

Our initial effort was to reduce track pad penetration. Each track pad of the paver had three 1/2-inch square grouser bars which resulted in a soil bearing pressure of 9 tons per square foot at the face of the grouser. When soft trackline conditions were encountered and the grousers were submerged the full 1/2 inch, thus affecting the die opening, soil bearing pressure dropped to 0.86 tons per square foot. By eliminating the grouser bars, widening the track pad and lengthening the track, we now have a constant soil bearing pressure of 0.58 tons per square foot or 8 pounds per square inch. Although we did not detect a noticeable improvement in ride quality we felt that a firm foundation had been established for the control of other factors which were more critical in the paver's performance.

Many people consider the weight of slipform pavers as a factor in producing smooth pavement. While this is true, it is somewhat more complicated. We need to consider the two most important factors of weight which are the location of the center of gravity and the distribution of the weight.

When we lengthened the track of our paver we had the opportunity to correct these two deficiencies. The Quad City Paver was the only model which Rex produced that located the center of gravity at the trailing edge of the extrusion meter. The three later models, the SFQ, the STR and the Town and Country had the center of gravity located at the center of the extrusion meter. On these models, the opening at the rear of the meter changes as the machine rotates around the center of gravity. This angle of rotation is normally less than one degree, but even this can produce substantial roughness in the pavement.

Weight distribution is the other important factor which influences smoothness. Pavers should be nose-heavy to compensate for the rotational forces which are produced on the pan by the extrusion process. These rotational forces can become very large if their effect is not considered in the adjustment of extrusion meter lead when poor concrete workability is encountered.

The Iowa I-80 12-foot inlay job is an example of an unbalanced machine. On this project the machine was narrowed to 12 feet, thus reducing rotational forces, but the auger system was replaced with a strikeoff. This resulted in an unbalanced machine which weighed 17-1/2 tons. As the unbalanced machine paved, rotational forces lifted the toe of the track, decreasing the die opening, and increasing the rotational forces on the pan since the lead of the meter increased. The end result was that the machine began to float and fall resulting in a loss of traction and rough pavement.

The fourth item is pan deflection. Profilograph analyses indicate that the SFQ extrusion meter is superior by 4 to 5 inches/mile in performance over the Town and Country pan. I believe that the difference in performance is caused by structural instability of the Town and Country extrusion meter. At one point, we installed a deflection gauge on the SFQ meter to check its performance while paving. To our surprise, we found vertical movements as large as 1/8 inch between batches. We are inclined to believe that slump variations and structural weakness explain a large part of this deflection.

The fifth item is indirectly associated with the die opening. After we purchased four new elevation sensors for the CMI Autograde, we noticed an immediate improvement in the appearance of the grade and trackline as well as a reduction in concrete overrun. We are now firm believers that ride quality is built from the bottom up.

The sixth item is also indirectly associated with die opening in that the paver track was changed from 15 to 21 feet. Three objectives were accomplished by this. Track pad pressure was reduced, angular rotation of the extrusion meter was controlled and most importantly the chord length of the paver track now more nearly coincides with the chord length of the profilograph.

Most of the information derived from testing has little value until it is all put together to obtain a better understanding. We found that finishers have little effect on pavement smoothness. We also found that the profilograph is sensitive enough to detect whether we are dragging one or two feet of astro-grass for texture.

We analyzed the size of bumps in relation to the frequency of their occurrence and found that 40% of the total roughness measured by the profilograph was caused by 0.05 inch bumps. If all bumps could be reduced by 0.05 inch, profilograph readings would be enhanced by 66% and ride quality would be improved.

We began to notice that profilographs of rumble strips were 33 feet long which represents the distance from the front to the rear wheel of the profilograph. Considering the sensitivity of the profilograph, we concluded that as the front wheel passes through a dip, part of the movement is transmitted to the end of the truss section and the trace records a bump. We then began to look at the profilograph in a new light; it represented a traveling chord which had a length of 33 feet.

This simple test explained why new sensors on the CMI Autograde (with a distance between sensors of 37 feet) were an effective tool in our search for smooth pavements; why a paver with a 15 foot track cannot compete with a profilograph and why even a master finisher with a ten foot straight edge cannot produce the desired pavement smoothness. Part of the reason the I-80 inlay job was rough may have been that the pad line was cut with a 10 foot ski and roughness was checked with a 33 foot profilograph. By putting together seemingly worthless pieces of information derived from profilograph testing we are beginning to learn how to solve our problems.

A well maintained profilograph is an excellent tool for evaluating the ride quality characteristics of each paving operation. I am aware of only one condition in which it fails to serve the intended purpose. This condition occurs in locations where it is necessary to warp or dip the mainline portion of the pavement to assure drainage and reduce the probability of skidding at stop signs. As the length of the warped section approaches the length of the profilograph we cease to measure the roughness and begin to measure the profile of the section. We should be aware of this so that the profilograph is not misused.

ROAD GEOMETRY

In our last few years of working with the profilograph we have learned about many factors pertaining to road geometry which influence the smoothness of the finished project. The concrete slump begins to become a factor in pavement smoothness when paving on tangent grades as the percent of grade increases. This will vary with the pavement design, percent of grade and the slump of the concrete. We have had acceptable ride quality on plain pavements with grades as high as 7%. However, I am inclined to believe that roughness will increase rapidly above 7%.

Roughness characteristics on horizontal curves are first noticed in the transition section where corrective machine adjustments must be made. As the degree of curvature increases, the potential for roughness within the curve increases. When the degree of curvature approaches 5 to 6 degrees, greater care must be used in the paving operation. Between 6 to 7 degrees, roughness may start to accumulate. Horizontal curves in excess of 7 degrees create a problem in production of smooth pavements.

In 1981 we became aware of increased roughness on crest and sag vertical curve locations. On the profilograph, this roughness produced a sine wave pattern with a 50 foot interval. We did not believe that this represented loose stringline because it is tensioned in 1500 foot lengths. Further investigation revealed that the magnitude of the sine wave varied with the rate of change of the vertical curve. From this we concluded that the sine wave configuration represented the chords of a parabolic curve.

Additional testing proved that the sine wave curve could be reduced or completely eliminated by reducing the staking interval from 50 to 25 feet. While this is helpful, it doesn't really give us a guide to go by. If we use a vertical curve with a rate of change of 1% and stake it in 100 foot intervals, then the stringline chords will have an external deflection angle of 1% grade change. If the staking interval is decreased to 50 feet the external chord angle becomes 0.5%. Experience indicates that this will produce rough pavement. When we further reduce the staking interval to 25 feet, the chord angle becomes 0.25% and we have a smooth pavement. From this analysis I conclude that the staking interval should be such that the external deflection angle of the stringline chords not exceed 0.3%. Thus for any given vertical curve, we now can establish the maximum staking interval.

Following our success in understanding vertical curve roughness, I decided to try a 25 foot staking interval on tangent grades. To our surprise we experienced an improvement in ride quality. Initially my personnel resisted because of the additional work involved in staking. Today, the same people insist that if they stake at 25 foot intervals and use one other piece of equipment, the Lewis float, they will produce a smooth job. However, we are still dealing with the bits and pieces of information rather than the principle. Perhaps we are adding stability to the stringline. Or perhaps it is because we are approximating curves and straight lines with a series of chords.

SPEAKING OF STRINGLINE

Our search for the factors which contribute to pavement roughness has brought a new awareness of the importance of stringline. We now know that the practice of correcting surveying mistakes by eyeballing is a poor substitute for accurate surveying. Accurate setting of stringline cannot be over emphasized; however, maintaining an undisturbed stringline is even more important because a disturbance can destroy the surveying and setting accuracy. Some national pavers use wire instead of string because of the importance of this factor on smoothness.

Inherent subgrade conditions such as frostboils, poor drainage and unstable sand or mud are an obvious source of pavement roughness. Frostboil locations are well known locally and I fail to understand why we consistently wait until the paving train approaches to commence corrective action. Utilization of sensor systems is advocated in some soft subgrade conditions. This initially appears to be a simple answer to the problem. However, my investigations indicate that although sensors can reduce some roughness, most of the stringline sensor systems currently in use lack the potential for achieving smooth pavements on unstable trackline. I feel we should address the cause of the problem rather than the effect.

Probably 95% of all pavers prefer to lock to grade rather than use sensors to achieve smooth pavements. Experience indicates that this is a very effective method on a stable trackline. Locking to grade is based on the principle of chord length distances. The profilograph relates very well with the seat of the pants ride because its chord length is twice the wheel base of a car.

If the paver locks to grade the CMI Autograde is the key to pavement smoothness since the chord distance between sensors is greater than the length of the profilograph. The sensor distance of 37 feet on the CMI is further enhanced by the use of a paver with a 21 foot track (which approximates the length of the testing instrument). To further improve pavement smoothness the staking interval length should be equal to or less than the length of the profilograph.

Many people are inclined to view the use of stringline sensors as the answer to a maiden's prayer. Contractors, as a group, have not had good results with sensors and are reluctant to use them. Understanding the principle of sensors will probably result in a position somewhere between these two viewpoints. Sensors, like any device, are subject to malfunction; and when this occurs it is not detectable except by the use of the profilograph. I paved a two mile project with expectations of an excellent ride only to find that it was rough because the CMI sensors were binding and sluggish.

For stringline sensors to operate properly it is important that the sensor be located at the point it is desired to control. The exception to this rule is that when two sensors are used on each side of the machine, the front sensor can lead the point of control by a maximum of three feet. On most slipform pavers this results in a sensor spacing of approximately ten feet. The CMI paver is an exception because the leg elevation cylinders are 37 feet apart.

To illustrate this principle, I would like to review three concrete overlay projects. The I-80 thin-bonded overlay was paved with a CMI paver and had a final roughness of three inches per mile. The Madison County secondary paving overlay was paved with a ten foot sensor base and had a roughness of approximately nine inches per mile. The Adair County overlay did not use sensors; the pad line was cut with a motor patrol, and had ride qualities in the penalty band.

The accuracy of sensors using the stringline varies widely with the type and quality of adjustment. Many of the mainline pavers use sensors of the on/off type which have a constant response rate of correction to deviations from the reference line. This type has a tendency to overrun the reference and require a reverse correction. To prevent this, the rate of response must be reduced or the non-response area either side of the reference must be opened up. These adjustments result in an accuracy of plus or minus 1/8 inch. The proportional type sensor varies the rate of correction in proportion to the amount of deviation from the reference line. As the machine returns to the reference point, the rate of response slows and the machine does not overrun. This type of sensor has an accuracy of approximately 1/32 inch.

I currently believe that by using proportional sensors and increasing the sensor base we can produce ride quality similar to the I-80 thin-bonded overlay without resorting to grinding of the pad line and then locking to grade.

Machine adjustments are also a source of rough pavements. These adjustments are required on horizontal curves or any time we are matching existing pavements or structures. These adjustments cause small bumps which are disastrous on short projects because their effect cannot be averaged out over a long distance; a bridge gap is a typical example. Sensors do not appear to help this problem.

DOWELS

I have not had actual experience with dowel contraction joints and their effect on roughness. However, my information leads me to believe that there are four major causes of roughness associated with the use of dowels. Reinforcement ripple is one source and is dependent upon the amount of concrete cover above the bar and the degree of pressure used in the extrusion process. One superintendent reports significant improvement in ride quality by lowering the dowels one inch, which may or may not be permissible. The second source is lack of concrete consolidation within the basket area and later surface settlement. The third cause is the manner in which the basket assembly springs back after the extrusion process, rising to produce a bump. The fourth source of roughness is caused by the basket assembly acting as a dam on tangent grades resulting in a bump on the high side and a dip on the down-stream side.

Three of the four sources of roughness involve the presence of the wire basket assembly used to hold the dowel bars. If present efforts are successful in developing a new type of dowel insertion machine, I feel that we may make substantial improvements in ride over the doweled contraction joint.

SUMMARY

The cost of smooth pavement is considerable at this point in time and must be included in the bid price. As the industry learns more about the problems, it is conceivable that such cost will be minimized. The success of cost reduction will lie in the cooperation of all parties involved as they attempt to reduce the number of variables affecting ride quality.

In conclusion, I would confirm the need for smooth pavement. My objective was to acquaint you with some of the problems that our industry must overcome to achieve our goal of building a smooth pavement. The ballgame is a great challenge. There are times when the challenge seems insurmountable, but we must realize that we are only in the second inning. I am confident that through a team effort of the industry including the contractors, the contracting authorities and the equipment manufacturers we can rally in the remaining innings and emerge as winners.