Operation and Automation of Finishers

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New measuring techniques that have made it possible to study the effect of a finisher's controls (height of tow points) and settings (frequencies of vibrators and tampers, operating speed, etc.) on its behavior (thickness, levelling, and precompaction) are described. The laws governing this behavior are stated, and two models that account for its main features are presented. Finally, possible consequences of this knowledge for the future development of the finisher are considered, particularly the automation of its operation.

Opposite to its functions (self-extended screed, high-compaction power screed, etc.), the adjusting and running methods of the finisher (Figure 1) have evolved little during last 10 years, irrespective of the economic and technical stakes (the amount of materials and the security and comfort of roadways). An important effort has therefore been made to at least correctly set the problem, that is to evaluate more precisely the effect of the finisher's controls on pavement's characteristics. The means used, results obtained, and some possible developments are discussed.

EXPERIMENTAL STUDY

Means of Measurement

The main difficulty in such a study is to collect numerous, accurate, and self-connected measurements about, on one hand, the road characteristics before and after laying (such as levelling, capacity, etc.), and on the other, the settings and the commands of the finisher.

Density Measurements

An extensive range of equipment that uses radioactive isotopes is used in France for density measurements. This equipment may be used to measure either the mean density of various thicknesses or density gradients (double probe). The following equipment is used to measure the mean density of various thicknesses: variable-depth point gamma densitometer (GPV); fixed-depth gamma densitometer (GF); small moving shoe, fixed gamma densitometer (PSM-GDF); and mobile gamma densitometer (GDM).

Topometric Measurements

Usual optical methods are unusable before compaction of the course or to reach such high-rate levelling as one or more measurement per second. Two methods are used to exceed these limits:

- For site use, the Saint-Brieuc Regional Laboratory has developed a moving target (the Laserographe) that can be used to survey one or two longitudinal profiles, with at least one point per meter; the method is precise (accurate to within approximately 2 mm). The information is received and processed by a computer.
- At the LCPC spreading test track at Nantes (*1*) (shown in Figure 2), an absolute reference is provided by 2 parallel 150-m-long concrete rails that flank a 8.5-m-wide track, on which a rigid gantry equipped with ultrasonic rangefinders travels.

These rangefinders (Figure 3), derived from those used in cameras by eliminating the device that translates the output into discrete form and by adding temperature correction microprocessors, provide a measurement (without contact) of the distance to the nearest surface (between 0.3 and 2 m), precise to within 0.3 mm. One rangefinder per meter of width is generally used. A thumbwheel switch triggers the acquisition of each range measurement every 5 or 10 cm. The measurements are displayed on a screen.

For both methods, programs able to plot the surfaces surveyed and process them for analysis (evenness, etc.) or for design assistance in pavement work (new construction, maintenance) are being developed.

Measurements on Finisher

Figure 4 shows typical finisher instrumentation. Proximity sensors are used to measure angles of rotation (and thus distances) and, with the help of a clock, speeds of rotation. The speed of the finisher and the distance traveled are measured on the solid-tired wheels supporting the hopper, which have a constant diameter and, because they are not driven, do not spin. For this purpose, one of the wheels is fitted with a disc having a number of studs, and a proximity sensor detects their passage. The precision is 1 percent or better for both distance and speed. For the frequencies of vibrators and tampers, the proximity sensor detects a metal nipple bonded or welded to the drive shaft. The precision is close to 1.5 Hz. For the distance from the tow points to the ground or the chassis, the rangefinders are used. To measure the thickness laid down, either plunger potentiometers or rangefinders mounted on the ends of the screed are used. The precision is within a few millimeters. The position of the sensors, however, is not always ideal for measuring purposes and exposes them to some damage. Consequently other approaches are being developed. Finally, to measure the temperature, a thermocouple

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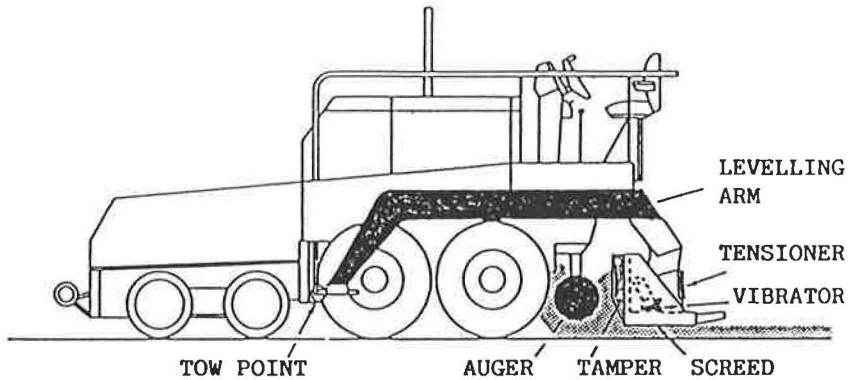

FIGURE 1 A finisher and its spreading implements (tow point, screed) and vibration adjustment units (tamper, vibrator).

FIGURE 2 Spreading of rolled asphalt on the LCPC test track at Nantes and recording of the level of the course by the measuring carriage.

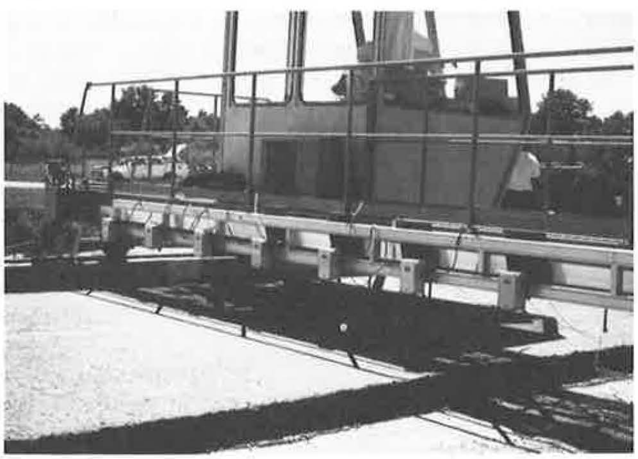

FIGURE 3 Detail of measuring carriage and ultrasonic rangefinders used to survey the course (possibility of 20 measurements per meter of longitudinal profile on each of 10 longitudinal profiles).

protected by a sheath and immersed in the material at the front of the screed is used.

The signals are displayed in real time and stored on a computer. A number of procedures have been tested. The signals may be digitized when they reach the computer or when they leave the sensors. The latter approach limits interference and

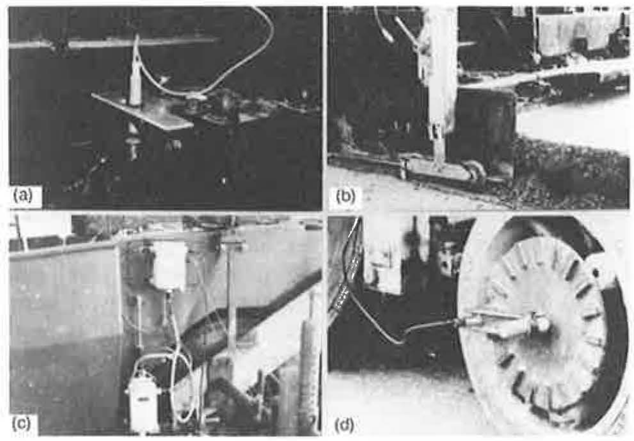

FIGURE 4 Typical finisher instrumentation: (*a*) frequency of vibration of screed—one proximity sensor directed at a metal nipple on the vibrator drive shaft; (*b*) thickness—a potentiometer on a bogie measures the displacement of the trailing edge with respect to the ground; (*c*) level of tow points—an ultrasonic rangefinder measures the displacement of the tow point—with respect to the ground (bottom housing); a potentiometer and its processing and display unit; and (*d*) operating speed—a wheel with studs detected by a proximity sensor.

makes it possible, using a suitable data bus and software, to connect the sensors in a series on a single cable. The computer may be either a special device or a standard microcomputer with a screen; the latter has the advantages of being relatively inexpensive and of being able to process and display the information.

On the spreading test track, the microcomputer—used for measurements both on the pavement and on the equipment—is in the gantry control cab. The system has now proven itself, for both the control and the analysis of the tests.

On site, these systems have been tested by the Laboratoire Régional de l'Est Parisien at Melun. Because all of the wiring is on the outside, there is no protected location for the computer, and the system was considered to be a little too vulnerable. It is believed that, as in the case of mixing plants, only when the finisher includes the necessary openings and protected locations, making the systems sufficiently reliable from the start, will it be possible to test their true value.

Yet in 1990, about 70 km of highway construction sites including slip-form paving as finisher paving were successfully surveyed by applications teams using these methods.

Experimental Results

The finishers may operate "à vis calées" (left alone self-leveling screed), that is, with the position of each tow point fixed with respect to the tractor, or guided in one of several ways. Two examples follow:

- Imposed transverse slope: one tow point is fixed and the other slaved to a transverse pendulum; and
- Double guidance: the trajectory of each tow point is controlled (nearby structure, wire or beam of light, smoothing beam), or that of only one, with the other slaved to an imposed cant.

The behavior of the "guided" finisher can be understood only with reference to that of the finisher "à vis calées," and so the studies whose conclusions are presented below were begun on the latter. These investigations were carried out between 1983 and 1985 at the LCPC, Nantes, and at the Rouen CER, on two finishers, one after the other. The first, of an older type, had a mechanical transmission and tampers, whereas the second, of a more recent type, had a hydrostatic transmission and a Blaw-Knox combined screed. Two materials were used: a reusable artificial mix (6 to 10 cm thick) and a slag-stabilized continuously graded aggregate (18 to 22 cm thick).

Settings Studied

The heights of the tow points can be adjusted separately while in operation, within a range imposed by the travel of the actuating cylinders. The travel of the tampers and the unbalance of the vibrators can be adjusted while stopped; their frequency can be adjusted while in operation. The operating speed can be adjusted while in operation. The screed adjustment angle, which is not represented in any physical form, combined with the height of the tow points, determines the range of variation of the thickness laid down. It is adjusted when stopped.

Definition, Factors, Variations of the Steady State

The steady state is characterized by the thickness and precompactness obtained when the settings and the characteristics of the material laid down are invariant. The precompaction factors are the tampers, the vibrators, the operating speed, and the weight of the screed. The factors governing thickness E, for a given material and given settings of the precompaction factors, are the height HB of the tow points and setting angle ß (Figure 5).

Effect of *HB* and ß It can be seen that the variation in thickness is a fraction R of the variation in tow point height. The value of R depends on the characteristics of the finisher, on the material, and on the precompaction factors. Under the experimental conditions, R ranged from 0.5 to 0.7. The current interpretation of this is as follows: to a given setting of the precompaction factors there corresponds a constant increase of the density of the material between "infeed" and "outfeed." This entails a linear dependency between thickness and angle of incidence, and thus between thickness HB and ß. Further knowledge of the value of R for a variety of machines and materials should in the future facilitate the initial adjustment of the finisher.

Influence of Tampers In the course of the tests, their travel was 4 mm. Their frequency ranged from 0 to 25 Hz. It was found that a variation in tamper frequency caused a variation in the same direction in thickness and, to a lesser extent, in precompaction. A possible explanation is that the tampers act primarily on the compactness at the screed infeed. If this

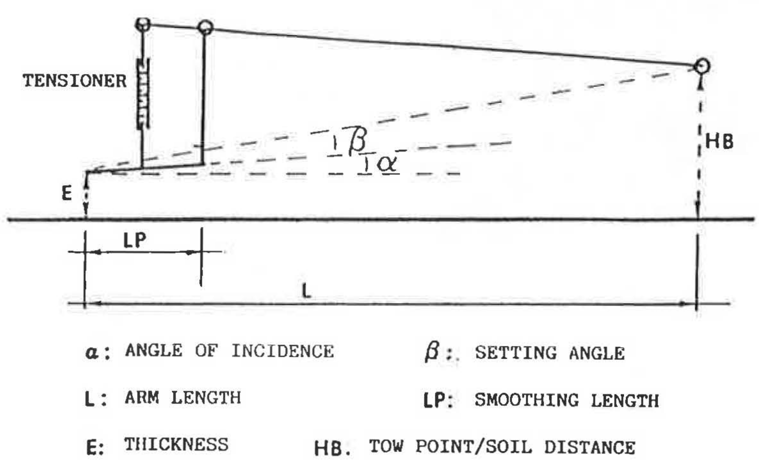

FIGURE 5 Diagram of levelling screed-arm assembly. The setting angle (ß) is fixed in operation and can be adjusted using the rear tensioners when the finisher is stopped. The angle of incidence (α) can be varied in operation by changing the tow point height (*HB*) or the thickness.

compactness increases, the compaction of the material by the pressure of the screed decreases and the thickness laid down increases. With the finisher without vibrators, stopping the tampers caused the thickness to decrease 35 percent (3.5 cm over 10 cm).

Influence of Vibrators The moments of eccentric were varied from their nominal value (0.08 mkg/m of screed) to twice this value, and their frequency was varied from 0 to 75 Hz. Variations in these two parameters caused a variation, in the same direction, of the precompaction and a smaller variation, in the opposite direction, of the thickness. One possible interpretation is that the vibrators act on the difference in compactness of the material between the screed infeed and outfeed without significantly altering its compactness at the screed infeed.

Influence of Operating Rate The speed ranged from 1 to 3 m/min during the spreading of the slag-stabilized continuously graded aggregate and from 3 to 6 m/min with the artificial mix. It was found that a variation in speed causes a variation in the opposite direction of the precompaction and, to a lesser extent, of the thickness. Current attempts at interpretation are based on the energy of compaction transmitted to the material and variations of this energy as a function of speed.

Total Effects To conclude, the ranges of variation of the thickness and precompaction for all of the settings mentioned above combined are as follows:

- Slag-stabilized continuously-graded aggregate: 1.72 < density < 2.12 (modified Proctor density: 2.16).
- Artificial mix: 1.68 < density < 1.95 (gyratory compaction test density 2.18); 9.20 < thickness < 14.2 cm (with constant tow-point height).

It can be seen that these variations are not minor.

Evolution of Equilibrium

When any one of the parameters mentioned above is changed in operation, the new equilibrium thickness is reached gradually. It is highly probable that, when it exists, the change in precompaction is also gradual. Figure 6 shows how the thickness changes when the tamper frequency changes. Figure 7 shows how the thickness changes when the tow-point height is suddenly increased.

Modeling

Dynamic Model

Work on modeling the behavior of the finisher was conducted concurrently with the experimental investigation. The point of departure was an article by Tom Shelley published in 1980

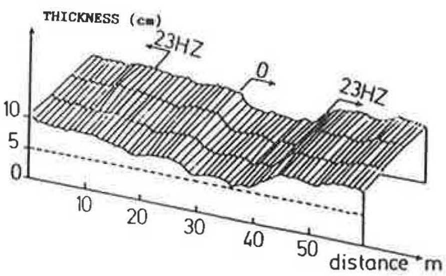

FIGURE 6 Thickness versus tamper frequency for a PF 90 DC finisher with no vibration of the smoothing screed.

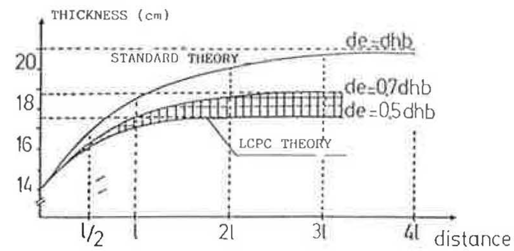

FIGURE 7 Thickness with a 70-mm change in tow-point height in the course of spreading; thickness is stable 2 LB after the command and changes by 50 to 70 percent of the change in tow-point height.

(*2*) that proposed a steady-state equilibrium model based on the following assumptions:

- No horizontal flow of the material under the screed (conservation of mass in vertical sections);
- One-to-one relation between the compactness c of the material and the pressure p to which it is subjected, in the form $c = A/(B - \log p)$;
- The resultant of the pressure of the material on the screed is equal to the weight of the screed.

To adapt this model to the case of any tow point trajectory and any underlying course, its assumptions were completed and extended to produce the current FORTRAN program, which includes two factors that are constant in the course of execution (arm length Lb and screed smoothing length Lp) and six that can vary in the course of execution (values A and B characterizing the law of compaction of the material, the compactness Ce of the material fed to the screed, the effective weight Pt of the screed—including the action of the vibrators—and the heights Zs of the underlying course and Zb of the tow points).

This model is limited because it is rather slow (30 to 50 m/min), and it is difficult to translate the actual parameters (speed, tamper frequency, etc.) into the parameters of the model. Laboratory tests will be used in part to overcome this difficulty. However, the model does accurately account for the following main experimental results:

- $d(E)/d(HB)$ between 0.5 and 0.7 with the current equipment and materials,
- Sensitivity of the profile of the course laid down to irregularities of the underlying course, and

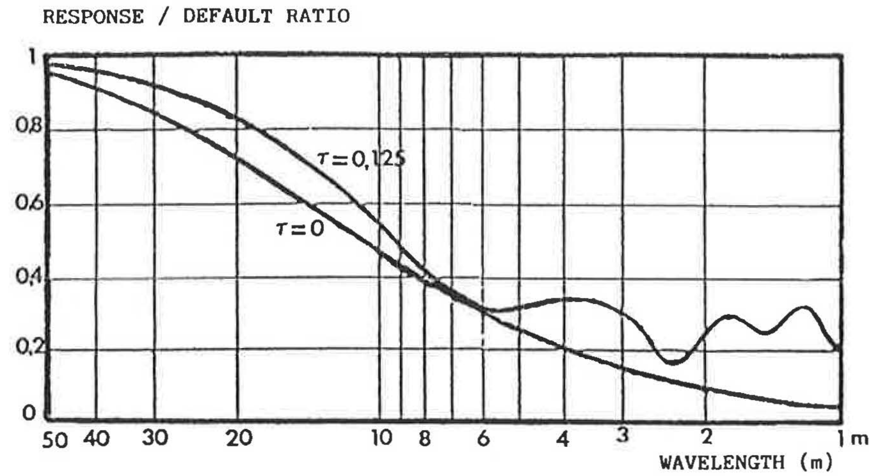

FIGURE 8 Finisher transfer function versus reciprocal of defect lengths according to the standard theory (τ = 0) and the research results (τ = 0.125).

- Gradual change of thickness following sudden changes to settings.

It therefore provides a general, but, of course, still perfectible, framework for interpreting the experimental results.

Geometric Model

The main result yielded by the foregoing model is a roughly constant relative reduction τ of thickness between the screed infeed and outfeed for a given material, finisher, and settings. This result may be used as the starting point for a simplified model in which the physical phenomena appear only indirectly, as factors modifying τ. When τ is constant, it is possible in this way to calculate the transfer function of the finisher operating with fixed settings, which has the following form (Figure 8) for common values of Lb and Lp.

The standard description of finisher behavior (*3,4*) can be recreated by setting τ equal to 0 and Lp equal to 0. The standard theory would therefore seem to be an optimum that overestimates actual finisher performance, and the model points the way to approaching this optimum: feeding a material that is already compacted ($\tau = 0$) to a finisher having a narrow screed ($Lp = 0$).

Such a model can also be used for many other applications, such as estimating the final evenness of a surfacing from that of the underlying course and the characteristics and operating mode of the finisher; comparing, for a given construction case, various ways of using a finisher; and forecasting the probable benefits of new ways of using a finisher before trying them out.

PROSPECTS

Operators' Information

A lot of the measurement techniques that have been developed during this study, although perfectible, are already usable and used on site. Integrating the measurement devices into the finisher during its manufacture would supply excellent reliability and would help operators better master their work.

Automation

The next step on this way would consist in linking together the different settings. On this point, the studies are just starting up. Yet it appears that a control system using as feedback a real-time measurement of the average thickness of the mat and which design would have taken into account the "geometric" model would be of great interest.

Laying Results Forecasting

The mathematical models, after more complete evaluation, would find other and numerous uses, such as estimating the evenness of a pavement, knowing the profile of the underlying course on one hand, the characteristics and the operating mode of the finisher on the other; comparing, for a given site or given type of site, various ways of using a finisher; and estimating the possible benefits of new ways of using a finisher before trying them out.

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