

Concrete Tool for Laying Concrete Pavements: Zero Clearance

Y. CHARONNAT, M. L. GALLENNE, AND P. DELIGNE

Traditional equipment for construction of concrete pavement requires two additional lateral runs, which is caused by the position of molding between the tracks of a tractor. It is not necessary to place the molding at the rear of the tractor. The use of a floating table is the solution to this problem. This concrete tool is equipped with a rack of hydraulic vibrators, a rigid floating table, and two lateral formworks. It is pulled by two arms. Various experiments were performed at the Laboratoire Central des Ponts et Chaussées (Public Works Research Laboratory). The results showed that, (a) concrete behaves in the same manner as other compaction materials; (b) self-leveling and self-stabilization of concrete were possible with a floating table; and (c) vibration and delivery of concrete are two parameters that require regularity. These results also show that this concrete tool is useful for laying concrete pavement. The concrete tool does not require the width that is necessary when traditional equipment is used; thus it operates successfully at zero clearance.

The construction of a cement concrete roadway with traditional equipment requires two additional high-quality runs (evenness and bearing capacity) across the road to be constructed. This type of construction is expensive and can lead to rejection of the idea of laying a concrete roadway. Techniques used for spreading and stabilizing materials do not have this inconvenience. Laying is carried out by using a "floating table" drawn behind the tractor. Having analyzed this situation, the Laboratoire Central des Ponts et Chaussées (Public Works Research Laboratory) and the Viafrance Company designed a special piece of equipment for cement concrete, known as the "concrete tool."

ANALYSIS OF EQUIPMENT

To analyze equipment, it is necessary to state properties of the mix. Two types of equipment can then be compared: the traditional, (i.e., bearing table), and the innovative, (i.e., floating table).

Properties of Cement Concrete Material

Cement concrete is a viscoelastic material with Bingham characteristics (Figure 1) (1), which means that the material develops a flow effect when placed under stress. If this stress is removed, the material returns to its initial state as a solid material. When applied to laying a cement concrete roadway, this property is explained in the following manner (Figure 2) (Y. Charonnat, unpublished data, 1987):

1. Before entering the vibration zone (non-stressed) concrete is in a solid but bulked condition. In this state, it has a very low bearing capacity (self-weight).

2. In the vibration zone (the basis of the stress), concrete becomes liquid. Under the Archimedes effect, air has a tendency to rise to the free surface and the density of concrete increases. Because of its liquid state, concrete takes on the shape of the receptacle in which it is found; thus concrete is moldable.

3. As soon as it is removed from the vibration zone, concrete returns to its solid state, but with two very important modifications: it has taken on the shape of the mold in which it was contained and it has acquired a high degree of compactness (approximately 2.4), which gives it a bearing capacity of several hundredths of megapascal (1.5 psi) (Figure 3) (2).

Equipment Required for Laying Concrete

Among traditional types of equipment, we shall examine only those that use all concrete properties, i.e., those for which the mold gives the final shape to the works.

When concrete is delivered, spread, and leveled over the width of roadway to be constructed, several successive operations take place. First concrete is vibrated. This step is generally carried out by using vibrators that generate the stress that causes liquefaction. The material is then "conditioned" in a mold made up from a table and side form. Once removed from the mold, the laid concrete should have acquired its shape and service compactness.

The following requirements impose certain conditions on the equipment:

- Vibrators should be sufficiently powerful to liquefy concrete across the entire width and throughout the thickness of the roadway to be constructed (3). The vibration time should be sufficient to ensure that as much air as possible is evacuated from the concrete while it is still in a liquid form under the mold gate.

- The table should be the same shape as that required for the structure, and its position should be defined in terms of the elevation of the structure to be laid (4). The position and movements of the table will be largely responsible for the evenness of the roadway.

Bearing Table

General Description

The bearing table is fixed to the frame of the machine that takes up the pressure load of material. Normally four jacks

Y. Charonnat and M. L. Gallenne, Laboratoire Central des Ponts et Chaussées, BP 19, 44340 Bouguenais, France. P. Deligne, Society Viafrance, 92/98 Boulevard Victor Hugo, 92115 Clichy, France.

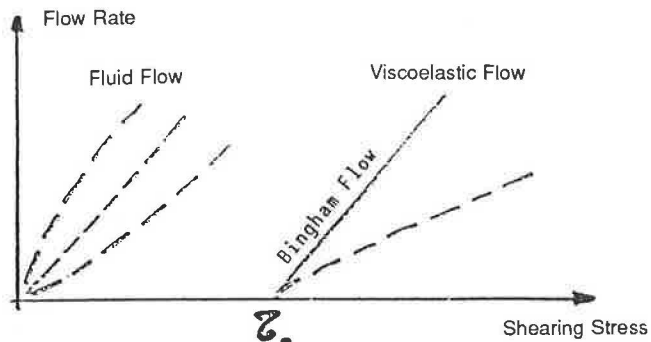


FIGURE 1 Concrete is a viscoelastic material with Bingham characteristics.

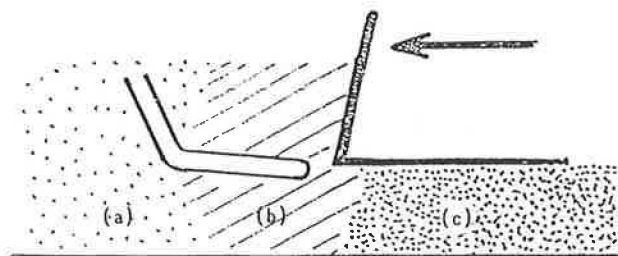


FIGURE 2 Various concrete phases: (a) solid, bulked state, (b) liquid phase, (c) return to solid state after removal from vibration zone.

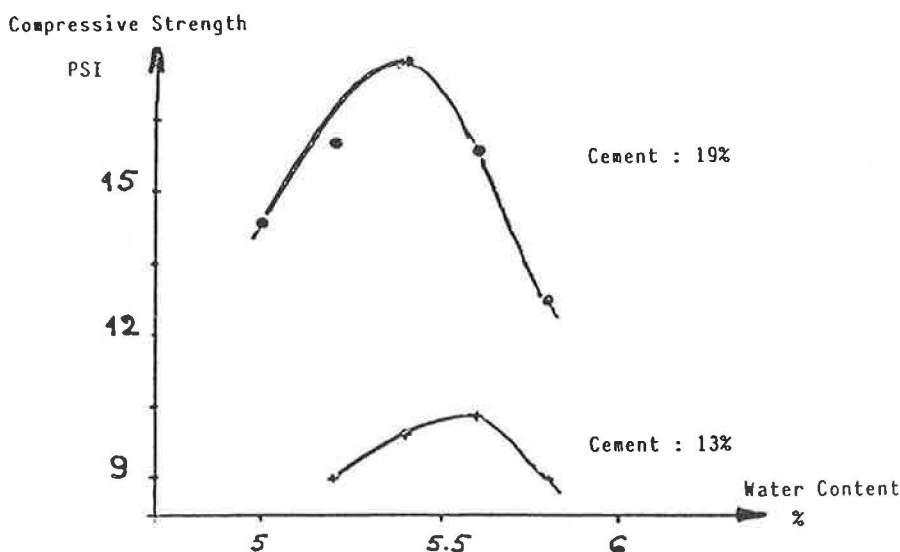


FIGURE 3 Bearing capacity of fresh concrete depends on water and fine element content.

connect the frame to the translation tracks placed laterally to the roadway under construction. Jack positions respond directly to the guide mechanism. The spacial position of the table is thus totally defined (Figure 4).

Positioning and Guiding

The machine driver carries out two successive operations for adjustment. The first involves placing the mold in a parallel position to the roadway to be laid. The second operation involves an opening to the front of approximately 0.1 degrees to improve the surface condition. This angle is adjusted when inspections are made on the laid slab.

The guide reference generally consists of two contact wires. For reduced wires (less than 6 m or 6 yd) a single wire and cross-fall corrector may be used.

Bearing Table Movements

Soil over which the tracks run requires, but often does not have, the necessary evenness required for a roadway. The table, however, must maintain a constant position in space.

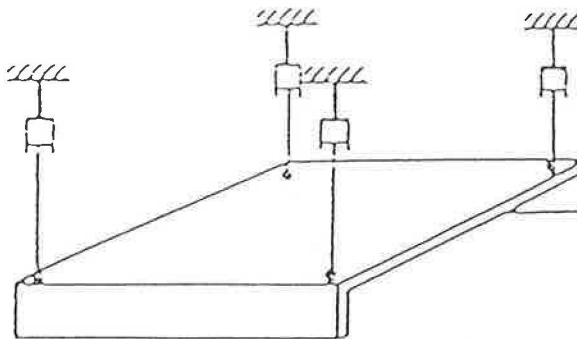


FIGURE 4 Diagram of bearing table.

For these two conditions to be compatible, it is necessary that a jack absorb all the vertical track movements. It is therefore imperative that these movements be detected as early as possible so that they may be absorbed by jacks, which are moved in one direction or another. Since sensors are all-or-nothing detectors, movement commands are translated into short orders, which are the probable cause of reduced length faults that often occur on concrete pavements.

Bearing Table Placed to the Rear of Tractor

It is not necessary to position the table between the tracks; instead, it is possible to place it to the rear of the tractor. The result of this is the ability to lay a roadway wider than the tractor tracks. To pick up vertical pressure loads, the table tractor connection should be rigid. This layout amplifies all tractor movement jacks with a great travel length, which limits the possibility of curves.

Floating Table

General Description

The floating table is integrally assembled on two arms (Figure 5). These arms are connected to the tractor frame by a device that permits vertical rotation of each arm on a vertical axis, slight rotation on a horizontal axis, and longitudinal movement (Figure 6).

The vertical position of the connection points to the tractor are made mobile through the use of a jack whose movement can be blocked or controlled by a guide system. In its working position, the floating table, located at the rear of the tractor,

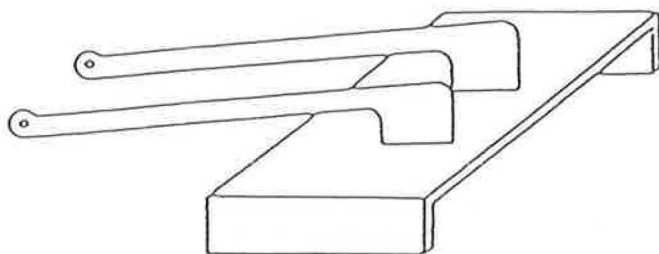


FIGURE 5 Diagram of floating table.

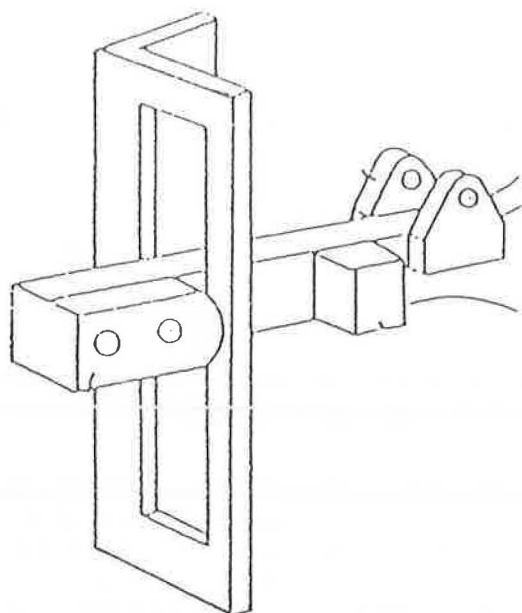


FIGURE 6 Connecting points on tractor.

sits entirely on a layer of material that it is spreading. Its self-weight picks up the vertical thrust (see section on *Influence of Thickness of Material in Front of Mold*).

Positioning and Guiding

The table position adjustment for a given thickness to be laid is carried out by adjusting connection points to the tractor. This operation allows the cutting level of material in its liquid state to be determined and to calibrate the quantity of material entering under the table.

Spreading with the floating table is often carried out without a guide. When a guide system is used, the guide reference is either two contact wires or one wire and a cross-fall corrector. The guide action occurs at the connecting point of the arms.

There are several theoretical sensor assembly possibilities. Two particular points require checking: the connecting point that is linked to tractor movement, and the table spreading edge that determines the thickness of the layer. The intermediate position is generally chosen between these two points, offering a compromise that is currently judged as acceptable.

Floating Table Movements

The reaction of the table to stress at a connecting point (Figure 7) causes the following:

- The vertical movement of the connecting point modifies only the opening angle of the table; the rear load point (table spreading line) remains unchanged.
- Because the length of the arms is much greater than the length of the table (four to six times longer), the instant vertical movement of the spreading edge of the table will be four to six times lower.

This transfer function translates into a slowness in reaction of the table (Figure 8), resulting in a reduced number of faults (amplitude or slope: see section on *Passage of Obstacles*).

THE CONCRETE TOOL

The concrete tool has been designed as an adaptation to the tractor. It is made up only from elements that are required for carrying out this type of operation. The tool has been patented in the United States under number A 3602115.

Tractor

The only imperative requirements for traction equipment are as follows:

- A regulator controlling the supply of material;
- A transversal distributor;
- An even and adjustable speed, upwards from 1 m/min (3 yd/min).

These characteristics are common on usual equipment (e.g., finisher, motor grader, and so on).

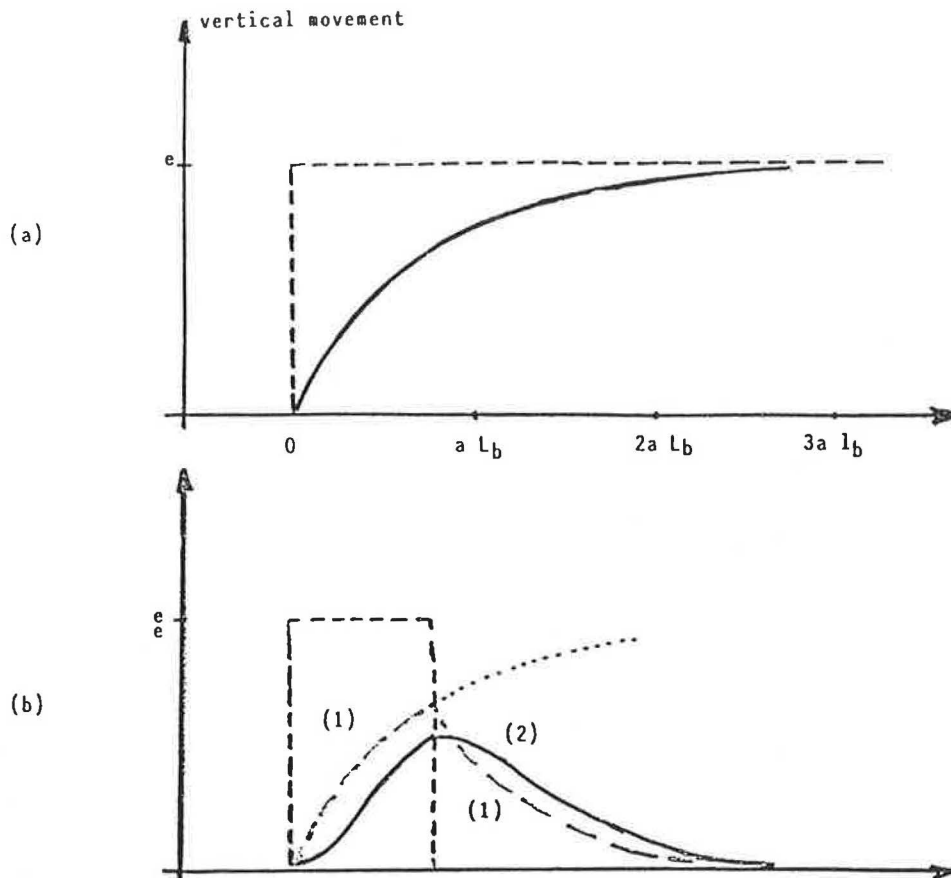


FIGURE 7 Reaction of table to stress at connecting point: (a) incremental (theoretical) response. Stability returns when mold has covered distance proportionate to length of arm, (b) Response to insufficient length fault. (1) Theoretical response, (2) observed response.

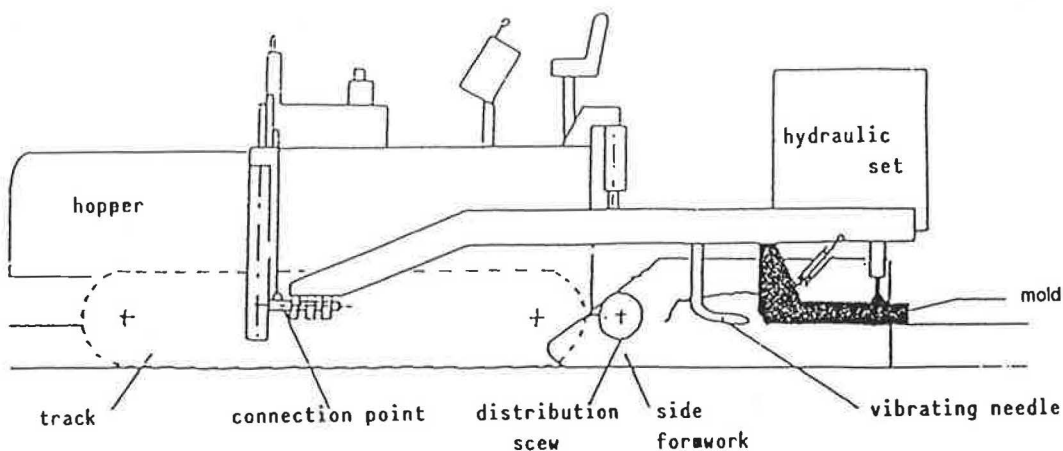


FIGURE 8 Tractor-concrete tool unit.

Concrete Tool Equipment

The concrete tool is equipped with the following:

- A rack of hydraulic vibrators. The number of vibrators depends on the width of the concrete works. Generally, one vibrator per 50 cm is used (1.5 ft).
- A hydraulic set able to supply ten vibrators. This set has a vibration power adjustment device for each of the vibrators.
- A rigid floating table approximately 1 m long (3 ft). It spans 2.5 m (7.5 ft) but can be extended to 4 m by the addition of adapted elements (12 ft).
- Two lateral formworks, capable of vertical movement, whose task is to laterally enclose the concrete.

EXPERIMENTATION

Before it was used on site, the concrete tool was tested on the spreading track of the Laboratoire Central des Ponts et Chaussées (LCPC) (Public Works Research Laboratory), Nantes, France (Figure 9) (5).

The slab is 150 m long and 8 m wide. A measuring trolley with a 5-cm pitch permits the level of the spread layer to be measured to a precision within a 0.5 mm.

Influence of Connecting Point Position

To test the influence of the connecting point position, various tests were carried out. The first series of tests consisted of determining the stabilization level of the mold at various connecting point positions. The second series consisted of checking this same stabilization level by placing the mold in various positions. Figure 10 represents all the results obtained during this first set of trials. If E is the thickness of the course and H is the level of the connecting point, then $E = 0.6 H + 4$, where E and H are expressed in inches. This form of expression is identical to that generally used for materials laid by compaction.

The precision in relation to thickness for a level connecting point is approximately 1 cm (13/32 in.); these fluctua-

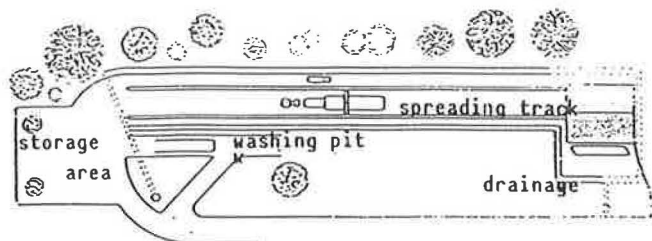


FIGURE 9 Spreading machine test site.

tions could be caused by simultaneous variations of other parameters.

Through the second series of trials, we were able to verify that the self-stabilizing property was equally true for cement concrete.

Influence of Consistency of Concrete

The range of consistency of concrete used for the trials (maneuverability from 9 to 25 sec) is much higher than that generally used on site (15 to 25 sec) (Figure 10).

Adjusting the vibration frequency in terms of consistency reduced the recorded approximation. For consistencies varying between 8 and 17 sec, the frequency chosen was 150 Hz. For consistencies between 18 and 25 sec, the frequency chosen was 100 Hz. We note that the approximation has been reduced to ± 0.5 cm (7/32 in.) (Figure 10).

Angle of Incidence of the Table

During tests establishing the various thicknesses, the angles taken by the table were measured. The results obtained from five test slabs are grouped together in Figure 11. The angle of incidence taken by the mold is proportionate to the thickness of the spread layer and depends on the quantity of air remaining in the concrete. The section equation deduced from the results is

$$\alpha = 22.5 E$$

where α is expressed in degrees and E is expressed in feet. The approximation on α is ± 0.25 degrees. The angle of the table is practically proportionate to the thickness of the laid material.

This conclusion shows that concrete is compressed under the table by air compression. If it is assumed that the length of the unvibrated concrete under the table is approximately

THICKNESS ADJUSTMENT

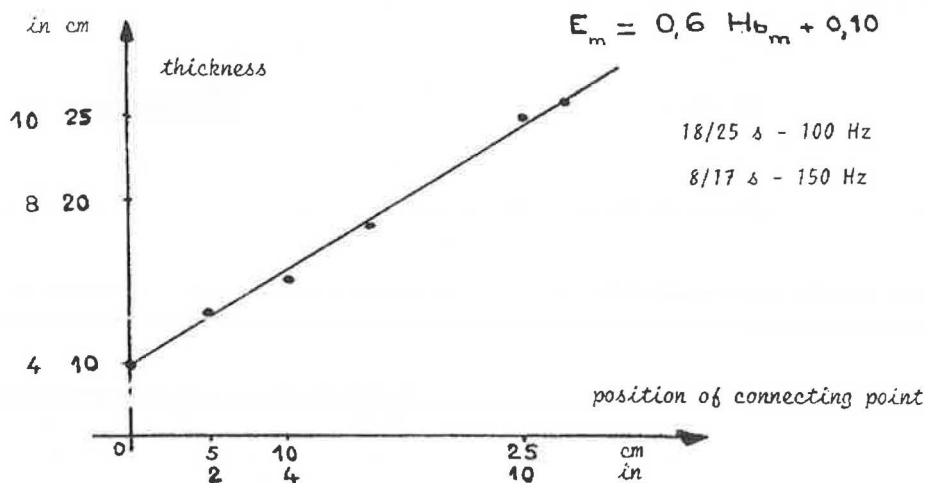


FIGURE 10 Thickness of the layer and connecting point position. (a) Dispersion around section is influenced by variations in water content, (b) adjustment in vibration frequency to consistency of concrete allows a reduction in dispersion.



FIGURE 11 Floating mold compacting effect.

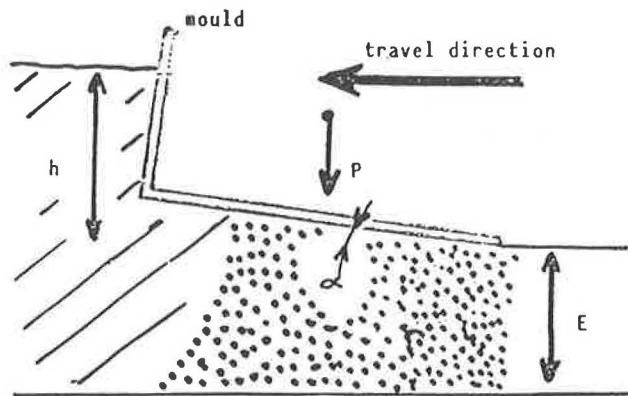


FIGURE 12 Mold balance.

1 m (1 yd), this corresponds to 13 percent of air content at the gate under the mold (8 percent for the bearing table). By reducing the air content at the gate under the mold (vibration efficiency), the variability of α is reduced and the evenness of layer thickness is increased.

Influence of Thickness of Material in Front of the Mold

The influence of thickness of the material was tested during a second trial (6). Examination of the various forces leading to the balance of the mold (Figure 12) shows that the angle of incidence taken by the table is a function of the weight of the mold and the height of the material in front of the mold (hydrostatic pressure).

$$\alpha = K (P - kh)$$

where

- α = angle of incidence,
- P = mass of the table,
- h = height of the material from the surface of the constructed slab, and

K and k = constants for work conditions.

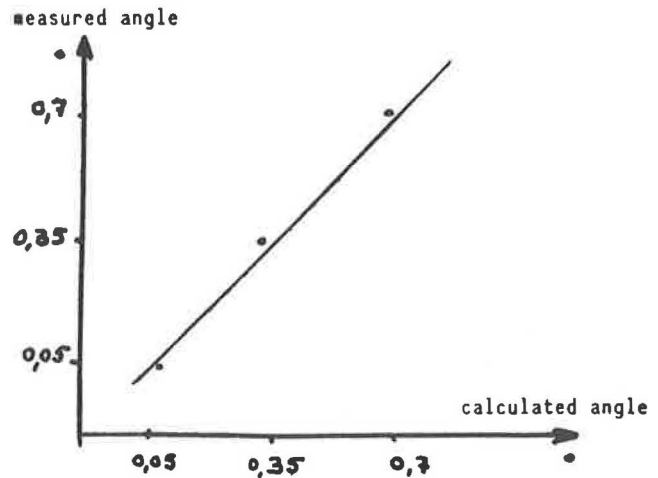


FIGURE 13 Modeling the angle taken by mold.

(Variations in the consistency of concrete noted during the trials did not have any particular influence.)

The mold is subjected to a number of loads: the mass or the bed (P), the hydrostatic thrust (kh), and the compression of the air. For P , varying from 1.4 to 2.9 long tons and h from 0.33 to 0.44 m (1 to 1.1 ft), α varied from 0.15 to 0.7 degrees. The equation thus becomes

$$\alpha = 0.35 (P - h)$$

where

- α is expressed in degrees,
- P is expressed in long tons, and
- h is expressed in feet.

Figure 13 gives the correspondence between calculated α and measured α . The α angle, calculated according to the $\alpha = K (P - kh)$ formula, is very close to the measured angle.

Tests were carried out to attempt to control the level of material in front of the table (7). Variations in depth of 28 cm (~1 ft) were produced for a distance varying between 2 and 4 m (2 and 4 yd). The thickness values of the slab had a 3.6-cm (1.5 in.) fluctuation.

A level sensor was installed on the table to check the height of material. This sensor automatically controls the start-up of conveyors and transversal distribution screw. The height of the material within a range of 7 cm (3 in.) with a distance of 20 to 40 cm (8 to 16 in.) could then be controlled. Fluctuations on the installed layer are not perceptible.

Passage of Obstacles

During tests carried out at LCPC, calibrated obstacles were placed below the tractor tread travel path. Runs were then made, both with and without guides. The contours of the faults were then noted.

For a first approximation, to describe the table movement without guides, the following equations can be used:

1. For the amplitude of a movement toward the top:

$$h = aHo (1 - e^{-1/aLb})$$

2. For the amplitude of a movement toward the bottom:

$$h = aHo e^{-1/2aLb}$$

3. For a length (isolated bump-type fault):

$$L = Lo + Lc + 3 aLb$$

where

Ho = height of the obstacle,

Lb = length of the arm,

Lc = length of the track,

Lo = length of the obstacle,

a = coefficient dependent on the angle of incidence
(= 0.7),

l = distance covered by the table, and

h = vertical movement of the table.

The limits to the resulting fault are hard to establish as the vertical movement is very slow at the beginning and end of the fault.

A 3-m (3-yd) long and 4-cm (1.5-in.) thick obstacle is translated into a 2-cm ($13/16$ -in.) height fault for this system. Under actual working conditions, we have noted a height of 2.2 cm (approximately 14 to 16 in.) and a length of over 10 m (10 yd). We thus find the self-leveling function, well known in the compacting technique of laying materials.

Behavior of Concrete Under the Table

Test results show that concrete behaves in the same manner as other compaction materials and that all laws applicable to these materials apply as well to concrete.

The table has two functions: the first is to give the shape and the second is to give the final density. The second function is very important as it completes the work of the vibrators.

Nevertheless, it is necessary to try and limit this regulator function (which permits an increase of a few density points) because vibrators normally should provide maximum densification levels.

WORKS CARRIED OUT

Several projects have been undertaken with this concrete equipment, two of which have given interesting results.

Works on Minor Roads

The width of the works was 2.50m (2.5 yd), and slab thickness was 12 or 15 cm (4.5 or 6 in.), depending on the zones treated. The surface area of 6,000 m² was concreted (2.5 mi²).

The equipment was adjusted based on the test results.

Because the unit had good maneuverability, these works were carried out without any difficulties. The works (Figure 14) had the following characteristics:

- 10 percent longitudinal fall,
- 7 percent support cross-fall,
- Curve radius: 30 m (30 yd), and
- Work carried out in strips or between strips.

The result was completely satisfactory.

STRENGTHENING WORKS

The width of works was 4.00 m (4 yd), and slab thickness was 25 cm (10 in.). Each part of the roadway was made up from two adjacent strips. There was a 5 percent longitudinal fall and a 2.4 percent cross-fall. The maximum laying speed was 1.6 mm/min ($1/16$ in./min) without any supply-delivery problems. Core samples were taken from the roadway. An average

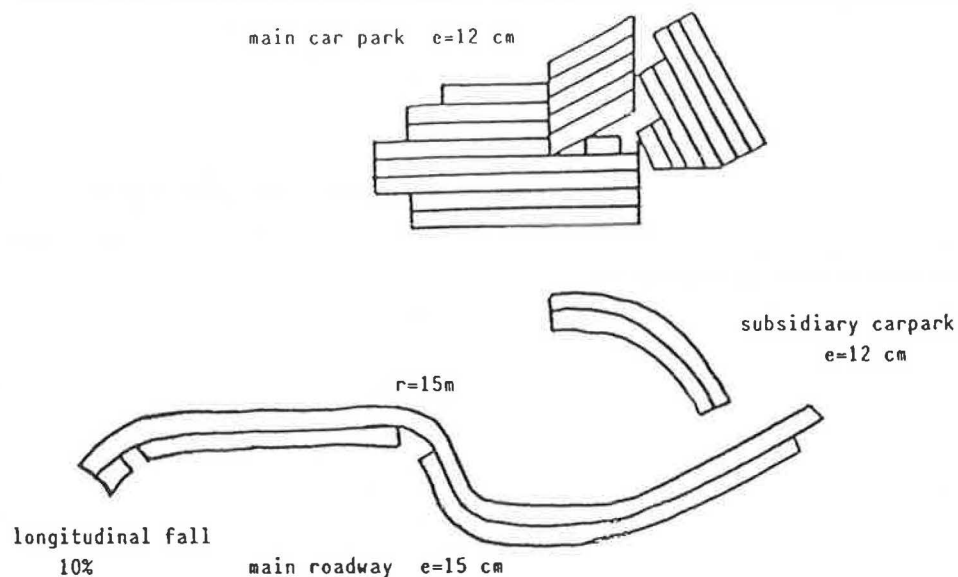


FIGURE 14 Works on small roads: maneuverability of unit enabled work to be carried out without difficulty.



FIGURE 15 Construction of slab. Note sealed appearance of upper surface and straightness of slab edge. Maximum thickness laid was 32 m.

volumetric mass of 2.35 kg/dm³ (147 lb/ft³) was obtained from the 51 core samples taken (2.38 kg/dm³ or 149 lb/ft³ on the test samples) with a standard deviation of 0.03 kg/dm³ (2 lb/ft³).

ADVANTAGES OF THE CONCRETE TOOL

The obvious main advantage of the concrete tool is that it is not necessary to widen either side of the roadway to be constructed. Other advantages include the following:

- The tractor is driven over a section of roadway that has a stable loadbearing capacity. For new roadways the tractor is driven over the sub-base and then is driven over the old roadway to strengthen works.
- The width of the works is not limited to the width of the tractor track. The tool has been designed for 4-m (4-yd)-wide concrete works.

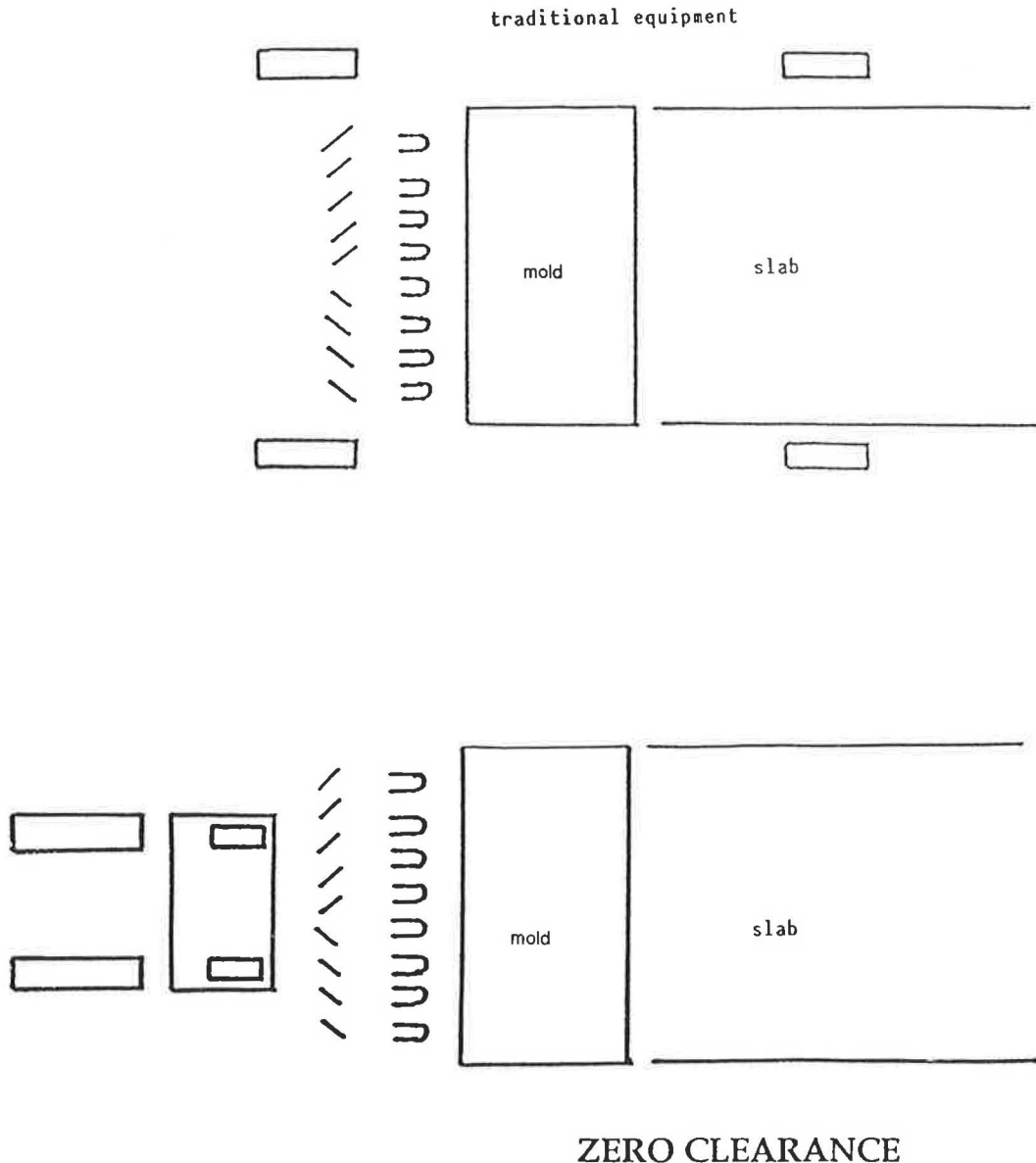


FIGURE 16 Minimal space is required for concrete tool use.

- Investment costs are reduced because the tool is limited to use with materials required for laying concrete.

CONCLUSIONS

Tests carried out with the concrete tool demonstrate that it is entirely feasible to lay a cement concrete roadway with a floating table (Figure 15). Already completed works have shown that the concrete tool-finisher machine is maneuverable, both in tight curves and on steep falls.

Various trials have allowed measuring material and equipment parameters against the quality of the finished layer. Two points demand particular attention: the vibration of the concrete and the ability of the machine to deliver the concrete to the front of the mold. As for other aspects, the concrete tool has the same qualities as those of traditional finishers.

The main advantage of this tool is that it is possible to lay a concrete slab without lateral widening (Figure 16). Other equally important advantages can be ascribed to this equipment, such as extended work width possibilities and reduced costs. This last feature is a result of the adaptability of the concrete tool to all types of tractor.

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