65

HIGHWAY RESEARCH BOARD

Bulletin 265

Concrete Pavement Construction

National Academy of Sciences—National Research Council

publication 778

HIGHWAY RESEARCH BOARD

Officers and Members of the Executive Committee

1960

OFFICERS

PYKE JOHNSON, *Chairman* W. A. BUGGE, *First Vice Chairman*

R. R. BARTELSMEYER, *Second Vice Chairman*

FRED BURGGRAF, *Director* ELMER M. WARD, *Assistant Director*

Executive Committee

BERTRAM D. TALLAMY, *Federal Highway Administrator, Bureau of Public Roads* (ex officio)

A. E. JOHNSON, *Executive Secretary, American Association of State Highway Officials* (ex officio)

LOUIS JORDAN, *Executive Secretary, Division of Engineering and Industrial Research, National Research Council* (ex officio)

C. H. SCHOLER, *Applied Mechanics Department, Kansas State College* (ex officio, Past Chairman 1958)

HARMER E. DAVIS, *Director, Institute of Transportation and Traffic Engineering, University of California* (ex officio, Past Chairman 1959)

R. R. BARTELSMEYER, *Chief Highway Engineer, Illinois Division of Highways*

J. E. BUCHANAN, *President, The Asphalt Institute*

W. A. BUGGE, *Director of Highways, Washington State Highway Commission*

MASON A. BUTCHER, *County Manager, Montgomery County, Md.*

A. B. CORNTHWAITE, *Testing Engineer, Virginia Department of Highways*

C. D. CURTISS, *Special Assistant to the Executive Vice President, American Road Builders' Association*

DUKE W. DUNBAR, *Attorney General of Colorado*

H. S. FAIRBANK, *Consultant, Baltimore, Md.*

PYKE JOHNSON, *Consultant, Automotive Safety Foundation*

G. DONALD KENNEDY, *President, Portland Cement Association*

BURTON W. MARSH, *Director, Traffic Engineering and Safety Department, American Automobile Association*

GLENN C. RICHARDS, *Commissioner, Detroit Department of Public Works*

WILBUR S. SMITH, *Wilbur Smith and Associates, New Haven, Conn.*

REX M. WHITTON, *Chief Engineer, Missouri State Highway Department*

K. B. WOODS, *Head, School of Civil Engineering, and Director, Joint Highway Research Project, Purdue University*

Editorial Staff

FRED BURGGRAF ELMER M. WARD HERBERT P. ORLAND

2101 Constitution Avenue Washington 25, D. C.

The opinions and conclusions expressed in this publication are those of the authors and not necessarily those of the Highway Research Board.

N.R.C. HIGHWAY RESEARCH BOARD

Bulletin 265

Concrete Pavement Construction

Presented at the
39th ANNUAL MEETING
January 11-15, 1960

1960

Washington, D. C.

Department of Materials and Construction

R.R. Litehiser, Chairman
Engineer of Tests, State Highway Testing Laboratory
Ohio State University Campus, Columbus

CONSTRUCTION DIVISION

John H. Swanberg, Chairman
Chief Engineer, Minnesota Department of Highways, St. Paul

COMMITTEE ON CONSTRUCTION PRACTICES—RIGID PAVEMENT

R. L. Peyton, Chairman
Assistant State Highway Engineer
State Highway Commission of Kansas, Topeka

F. L. Ashbaucher, Engineer of Roads, State Highway Department of Indiana, Indianapolis
J. F. Barbee, Rigid Pavements Engineer, Ohio Department of Highways, Columbus
Forrest Cooper, Deputy State Highway Engineer, Oregon State Highway Commission, Salem
Phil Fordyce, Supervising Engineer, Pavement Engineering, Portland Cement Association, Chicago, Illinois
S. E. Hicks, Engineer of Construction, State Highway Commission of Wisconsin, Madison
James W. Johnson, Testing Engineer, Iowa State Highway Commission, Ames
Emmett H. Karrer, Professor of Highway Engineering, Ohio State University, Columbus
B. A. Lefeve, Deputy Chief Engineer, Highways-Parkways-Thruways, New York State Department of Public Works, Albany
William H. Mills, Consulting Engineer, Atlanta, Georgia
Thomas H.F. Norris, Engineer of Construction, Illinois Division of Highways, Springfield
W. E. Reed, Division Engineer, Bureau of Public Roads, Ames, Iowa
Charles E. Shumate, Assistant Chief Engineer, Colorado Department of Highways, Denver

Special Committee on Highway Equipment

M. J. Kilpatrick, Chairman
Chief, Construction Economy Branch, Highway Needs and Economy Division
Bureau of Public Roads

H.E. Diers, Engineer of Maintenance, Illinois Division of Highways, Springfield
Fred B. Farrell, Regional Engineer, Bureau of Public Roads, Chicago, Illinois
H.J. Halm, Paving Engineer, Paving Bureau, Portland Cement Association, Chicago, Illinois
H.H. Harris, Commissioner, Virginia Department of Highways, Richmond
Robert F. McKenrick, Executive Vice President, Construction Industry Manufacturers Association, Inc., Chicago, Illinois
Thomas B. Plummer, Chief Engineer, V.N. Holderman and Sons, Inc., Columbus, Ohio
R.R. Stander, Secretary-Treasurer, Mansfield Asphalt Paving Company, Mansfield, Ohio
J.F. Tribble, Materials Engineer, Alabama State Highway Department, Montgomery

Contents

Construction Practices on Cement-Treated Subgrades for Concrete Pavements

F.N. HVEEM, Materials and Research Engineer, California Division of Highways, Sacramento

FOR A NUMBER of years, all concrete pavements constructed by the California Division of Highways have been placed on specially treated or hardened subgrades. The first project was constructed in 1946 on the coastal highway between San Diego and Los Angeles. This was followed by other projects and for the past ten years no concrete pavements have been placed on untreated subgrades. In the majority of cases, portland cement was used although in certain instances sandy subgrades were treated with asphalt.

By 1944, the Division of Highways was becoming increasingly concerned over the widespread evidence of troubles at the joints in concrete pavements. California had followed the general trend of national practice in the design and construction of concrete pavements. Prior to 1922, pavements 4 in. in thickness were constructed without expansion or contraction joints. Later, when the standard thickness was increased to 5 in., a 2-in. expansion space was left at the end of the pour at noon or at night. These spaces were later filled with mixtures of asphalt and sawdust to form an expansion joint.

Buckles or "blow-ups" were fairly common in the older thin pavements without joints, and after expansion joints were constructed at intervals of several hundred feet, intermediate cracks continued to develop, often accompanied by some small spalling or chipping at the edges. These cracks were unsightly on close inspection, and as cracks in buildings or other concrete structures are usually regarded with concern and considered to be evidence of failure, similarly, it became rather common practice for engineers to class cracks in pavements as evidence of "failure."

In order to counter this natural tendency of concrete pavements to develop transverse cracks through shrinkage, steps were taken to anticipate the cracking and improve the appearance by placing weakened planes at closely spaced intervals. The question of what spacing is appropriate is still debatable and practices vary throughout the United States.

Some 30 years ago expansion joints were required every 60 ft with contraction joints at 20-ft intervals. Following national practice, dowels were placed across the joints, first at 28-in. centers and later at 15-in. spacing. Nevertheless, with all these precautions and features of "modern design," concrete pavements were giving trouble at the joints that became so serious that by 1944 some engineers began to question whether the use of concrete pavements should be continued and at the very least there was a pressing need to find means for preventing troubles that develop at the constructed joints.

An extensive investigation was launched in 1944 for the purpose of determining the causes of troubles at the joints in concrete pavements and, if possible, to recommend a solution or corrective means. A report of a similar investigation conducted by the Portland Cement Association came to hand about this time. This report placed emphasis on the nature of the soils which were found to pump through the joints in concrete pavements. It led to the belief among certain engineers, at least in California, that all that would be necessary to avoid trouble was to eliminate certain types of silty soil from the subgrades. However, the investigation of California pavements conducted during the years 1944 to 1946 indicated clearly that there was no type of untreated soil, even including sand and gravel subgrades, that consistently prevented the development of trouble at the pavement joints. It was also obvious that a certain amount or weight of traffic was necessary to produce pumping and faulting but this level was rapidly being approached or exceeded on the majority of concrete pavements in California even 15 to 20 years ago.

It has been common knowledge for many years that portland cement concrete is subject to volume change due to variations in temperature and variations in moisture content, and the fact that both portland cement and mineral aggregates individually exhibit such characteristics suggests that it would be difficult, if not impossible, to prevent mixtures of these materials from also expanding or contracting. However, the Division's study of pavements brought forth evidence that there is a considerable variation in the volume change properties of different concretes. The data indicated that the coefficient of expansion due to temperature was fairly uniform; therefore the greatest variation was in response to moisture.

Engineers have long assumed that deflections at the end of individual slabs were due to depression of the subgrade because of load transmitted by the unsupported slab ends. The Division's study brought no evidence of increased density of silty or clay soils under the ends of the slab but indicated rather that the primary cause of troubles originated with the warping and curling of the slabs providing space for the accumulation of water between the slab and the subgrade. Simple calculations indicate that even with a small monolithic slab similar to the portion often broken from the longer slabs, pressures on the subgrade under the tandem axles carrying a 32, 000-lb load would not exceed 7 psi if disbribution is assumed to be uniform. Reports of actual tests have never disclosed more than 6 psi. Hence, unit load on a subgrade under an 8-in. concrete slab cannot be of much consequence.

During the period 1925 to 1930, there were a number of resurfacing projects where old concrete pavements had been resurfaced with concrete and it was noticeable that there were no joint problems, almost complete absence of faulting at the joints or cracks, and all in all these pavements had given an excellent performance even where the original pavement was over some poor silt and clay soils. Reports from other states gave accounts of excellent performance of concrete pavements over old macadam surfaces. Also, the evidence produced in California and elsewhere was quite consistent in indicating that the pumping action of slabs under heavy traffic tended to churn up the subgrade soil whenever enough water accumulated beneath the pavement and as a result the supporting soil was pumped out whenever there was enough water present.

Reasoning from these observations, it was concluded that if the subgrade could be treated or modified by some means so that it would resist erosion, then the concrete pavements should give long, fairly trouble-free service. In other words, even though the slabs curl and warp and movement of the slab ends continues, the effects are not too serious provided the subgrade remains in place and maintains its original plane as constructed—conforming to the underside of the slab.

Seeking means for establishing this condition, the use of portland cement appeared to be most logical. The first trial was made in 1946 on a section of mainline highway between San Diego and Los Angeles. Here, the subgrade material was scarified after the side forms were in place and treated with about 5 percent of cement, using road-mixing equipment. Virtually all of the treated subgrades beneath concrete pavements in California have been constructed by the road-mix method whether cement or asphalt was used, although there have been one or two cases where the contractor elected to mix the material in a central plant. A depth of 4 in. was adopted at that time and has become the standard thickness for cement-treated subgrades. After this cement-treated material has been thoroughly mixed, it is compacted by rolling and then trimmed with a subgrade machine in the normal manner. After being trimmed and given a final rolling, the surface is covered with a heavy application of cutback asphalt ranging from 0. 20 to 0. 25 gal per sq yd. It must be emphasized at this point that this application of asphalt has two purposes; first, of course, to provide a curing seal to prevent the loss of moisture and develop the benefits of the cement treatment, but more important, it is intended to provide a surface that will resist erosion. Ordinary soil-gravel mixtures treated with 4 or 5 percent of cement will not resist abrasion under traffic. Cutback asphalt is not necessarily the ideal material but it is considered essential that this asphalt seal be retained by the cement-treated subgrade so far as possible. Emulsified asphalts are often more convenient to use and form an effective curing seal. Emulsified asphalt has been used extensively for cement-treated bases which are covered with an asphaltic concrete pavement. However, any layer of asphalt placed on a subgrade and then covered with a concrete pavement has a strong tendency to adhere tenaciously to the underside of the superimposed concrete slabs and when this happens the asphalt film will be pulled upward and leave the cement-treated subgrade without protection when the concrete slabs curl upward at the ends as invariably occurs at some season of the year or at some time of the day.

Laboratory trials indicated that cutbacks would penetrate the average cement-treated subgrade layer to depths ranging from ¼ in. to ½ in. and, therefore, even though a superficial layer of asphalt adheres to the concrete, it is expected that there will be a sufficient amount of impregnation in the cement-treated subgrade to resist erosion when water is churned back and forth by the pumping action of the slab ends.

It may be noted that two different terms are used and a distinction has been drawn between cement-treated subgrades and cement-treated bases. Asphaltic pavements require a base. In the past cement-treated bases in California have usually been constructed 8 in. in depth and sometimes more. Concrete pavements, on the other hand, were considered to have adequate structural strength if uniformly supported. Therefore, where concrete pavements have been involved, a cement and/or asphalt treatment has been used only to produce an erosion-resistant subgrade. For this purpose, strength and thickness of layer have not been primary considerations. This distinction in terminology has at times created some confusion and future specifications will probably refer to all such treatments as cement-treated base or CTB regardless of whether the superimposed pavement will be portland cement or an asphaltic type. Also, with the increased volume of traffic, consideration is being given to heavier structural sections and it is probable that the cement treatment under concrete pavement will be increased to 6 in. or more with the intention of affording additional support, especially under the outer traffic lane which must sustain the bulk of the heavy vehicles.

One recognized inadequacy with the present methods of construction when the cement-treated subgrade is mixed and compacted after the side forms are in place is the fact that this hardened and treated layer does not extend beyond the width of the concrete slab. It is generally agreed that it would be better design if the cement-treated subgrade were wider than the pavement. Evidence from both the WASHO and AASHO test roads indicates that in general pavements are more vulnerable along the outer wheel track than along the inner wheel track. Therefore, extending the hardened subgrade should give greater protection and would also serve as a support for the adjoining border treatment. Thus far it has appeared to be impractical to place the cement-treated subgrade to a true grade without using side forms and it has been considered to be too difficult to place side forms on top of a cement-hardened subgrade. The problem of placing a wider base may, however, be readily solved with the advent of the slipform paver. It seems inevitable that slipform pavers will, sooner or later, supplant the present methods of placing concrete pavement. If the pavement is placed with a slipform paver there will be no problem in placing the cement-treated subgrade first and to any width and length desired. The ultimate success of slipform pavers will, of course, depend on the ability to produce pavements having acceptable riding qualities. It now seems probable that this problem can be solved. However, if the pavements are to be smooth on the surface it is probable that some variation in thickness of the slab will have to be accepted.

RESULTS

The first project using a cement-treated subgrade has been under traffic for 13 years and is still in excellent condition. Taking the entire experience where there are now 900 miles of this type of construction, for all practical purposes, the problems of pumping joints have been eliminated. Although curling and warping of the slabs have not been eliminated, the adverse developments are so far relatively minor. It cannot be claimed that the cement-treated subgrade is a 100 percent answer to the problems arising from joints in concrete pavements, and it is evident that some of the sections are less effective than others for unknown reasons. There are a few jobs where faulting has developed up to $\frac{1}{8}$ in. and while thus far none of these can be regarded as serious, nevertheless, they furnish evidence that further improvement is possible.

For a few years following construction, there were some doubts as to the suitability of the asphalt-treated subgrades where cohesionless sand was road-mixed with RC cutback for a depth of 3 in. However, a recent survey of all sections over asphalt-treated subgrades indicates that they average up equally well and in some cases better than the cement-treated subgrades. This may be partly due to the fact that asphalt treatment has been used only where clean sands or gravels were in place and have not been applied to soils containing high percentages of clay as has often been the case with cement. Therefore, it can be concluded that with proper selection of materials either cement or asphalt can be used to form a suitable subgrade which will stay in place and withstand the vertical movement and pumping action of the pavement slab ends. It should be further emphasized that the only steel used in California concrete pavements are the tie bars across the longitudinal center joint. Neither dowels nor reinforcing steel are used as standard practice.

It may be of interest to many to note that ejection of material along the edges of the slabs is virtually unknown in California pavements. This phenomena is often referred to as "blowing" in eastern states but has never been observed on any concrete pavements over cement-treated or asphalt-treated subgrade in California.

Figures 1 to 15 show the typical steps and equipment used in constructing a cement-treated subgrade according to California practice.

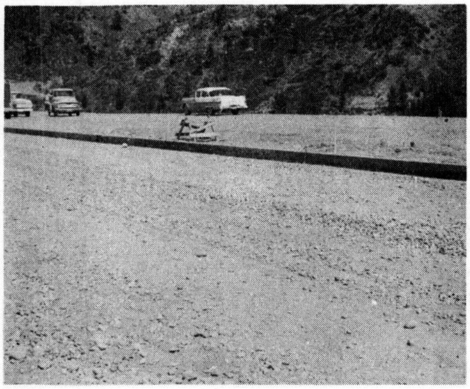

Figure 1. Subgrade material and side forms in place before beginning subgrade operations.

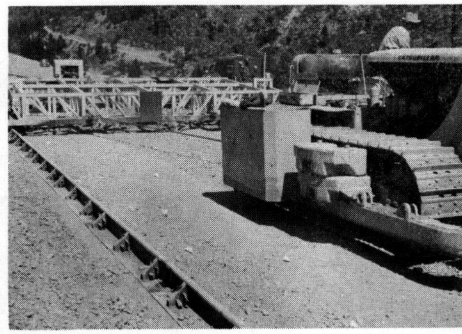

Figure 2. Subgrader (scarifier and windrower) in operation on subgrade material.

Figure 3. Windrower section of subgrader in operation.

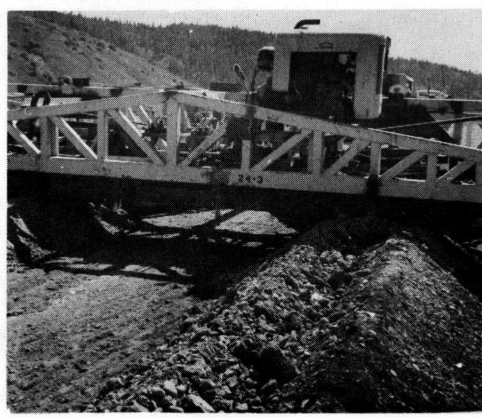

Figure 4. Dual windrows shaped by subgrader.

Figure 5. Cement-treated subgrade—windrow machine.

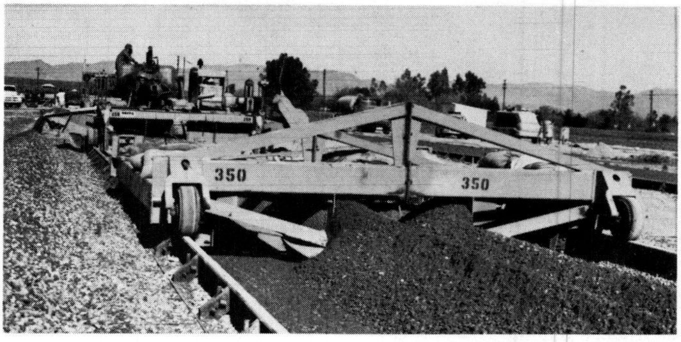

Figure 6. Cement-treated subgrade. Another type of windrow machine.

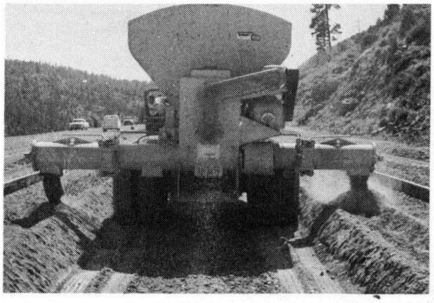

Figure 7. Distributor truck depositing cement in "V" notch of each windrow.

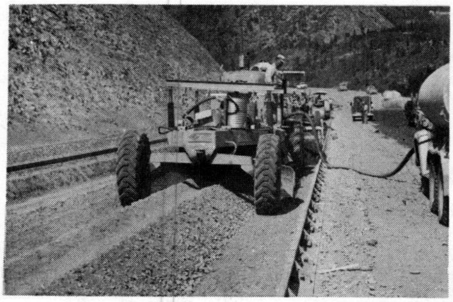

Figure 8. Traveling road mixer in operation on inner windrow.

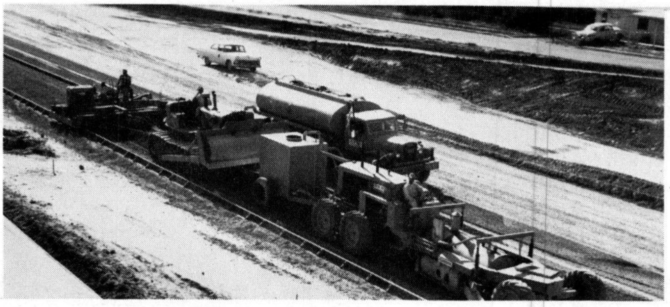

Figure 9. Cement-treated subgrade—mixing.

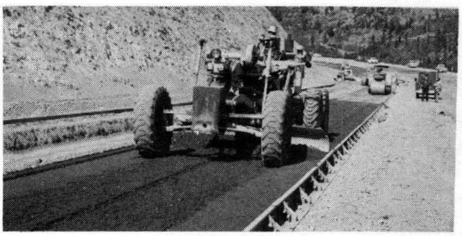

Figure 10. Grader starting to complete spreading of mixed subgrade material.

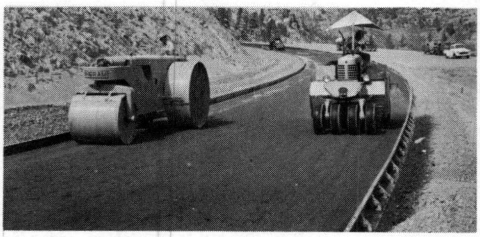

Figure 11. Steel-tired and pneumatic rollers. Note fog spray application by pneumatic roller.

Figure 12. Pneumatic-tired roller on C.T.S. Note fog moisture application.

Figure 13. Subgrade in place—ready for curing seal.

Figure 14. Curing seal "boot truck".

Figure 15. Cement-treated subgrade after application of curing seal.

Adjustment of Concrete Paving Equipment

WARNER HARWOOD, Senior Highway Engineer, Paving Bureau,
Portland Cement Association, Chicago, Ill.

The construction of a concrete pavement has been compared to an assembly-line operation. But here the operation must be carried on out-of-doors, the product is stationary and the machines progress during the paving operation. Changes in weather conditions, concrete characteristics and pavement profile may require changes in the adjustment of the equipment and its operation to secure proper construction.

Any discussion of the proper adjustment of the mechanical equipment requires a brief outline of the function and operation of each machine. For them to properly shape and consolidate the concrete into a pavement slab they must operate at the proper time in respect to pavement placement, at the proper speed and they must be in proper adjustment.

Full advantage cannot be taken of the capabilities of the equipment without a knowledge of the adjustments that can be made in the various machines and the effect of these adjustments on the finishing procedures.

In some cases, pieces of equipment having similar functions are made by several different manufacturers. The details of adjustment may differ between manufacturers and between older and newer models of the same manufacturer, but in general the adjustments follow about the same pattern.

Although it is not the duty of the resident engineer and inspector to make the adjustments in any piece of equipment they should be able to direct the contractor's personnel in making them. To assist them in this important duty is the purpose of this paper.

● THE BROAD ASPECTS of concrete pavement construction have been set forth in a previous paper (1). This paper is primarily concerned with those aspects that have to do with the proper mixing, placing, compacting and finishing of the concrete into a slab with suitable riding qualities.

To secure this objective constant vigilance is required on the part of the inspector to insure that each piece of mechanical equipment is performing its function. Before any pavement is placed the equipment should be adjusted to conform to expected conditions. During construction minor adjustments will have to be made from time to time to adapt the operations to changes in weather conditions, concrete characteristics and pavement profile. Improper adjustment of any machine in the paving train makes the succeeding operations more difficult if not impossible.

It is not the intention that the inspector should make the adjustments in person. That is the duty of the contractor's personnel. However, an intimate knowledge of the various adjustments that can be made in the equipment is essential if the inspector is to determine if each machine is in proper adjustment.

Before starting any project the equipment should be checked for suitability. The use of any badly worn or inadequate machine should not be permitted. Its use would only result in continuing unsuccessful efforts to keep it in adjustment.

A careful record should be kept of the adjustment settings of each piece of equipment. The time and stationing at which changes are made and the reason therefor should be recorded. By observing the effect on finishing of the various settings the inspector should develop the judgment required to properly direct necessary changes in adjustment.

In starting a project no effort should be made to achieve normal production. A leisurely pace on the first day will permit the crew to familiarize themselves with their duties without working under pressure. Furthermore, it will allow time for making adjustments of equipment without the finishing operations falling too far behind the placing of the concrete on the subgrade.

MIXING

The paver should be carefully checked to insure proper mixing. The items to be checked include any wear of mixer blades, the water system (Fig. 1), the air-entrainment dispenser (Fig. 2), is used, and the timing cycle.

Permissible wear of mixer blades is usually covered by the specifications. The usual limits are either 10 percent or $^3/_4$ in.

The amount of water discharged into each batch must be checked in order to keep accurate records of mix proportions. With the water gage set at various quantities, the water is drained off into a suitable container and weighed. If the amount discharged does not correspond to the gage setting, the indicator dial must be reset to show the correct amount.

While testing the water gage, the entire system should be inspected for leaks that would cause differences in the amount of water discharged into batches that are held in the paver for varying lengths of time.

The air-entraining agent dispenser should be tested as to the amount discharged at various settings. This test should be repeated at intervals as the agent may gum up in the dispenser, with consequent progressive lowering of the amount discharged. As the dispenser fills by gravity flow an air vent is essential and it should be kept clean at all times. The newer dispensers with a clear plastic cylinder are recommended as it will be readily apparent if they are failing to fill completely after each discharge.

Figure 1. Checking the paver water system.

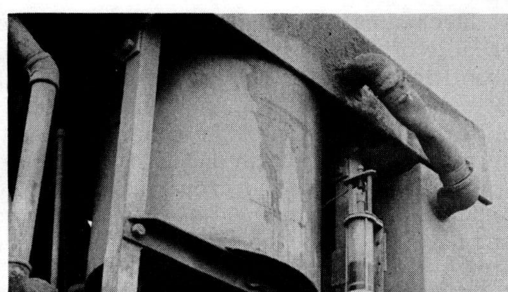

Figure 2. The air-entraining agent dispenser and piping must be kept clean.

To check the timing of the mixing cycle, the mixer should be operated at the manufacturer's recommended speed and a record made of the timing of the various automatic operations. These should be timed with a stop watch beginning when the skip reaches the top of its travel. For a dual-drum paver these include:

1. Time until water valve closes.
2. Time until discharge gate opens.
3. Time until transfer gate opens.
4. Time until discharge gate closes.

As soon as skip lock is released the skip should be started up in order that the operations may continue without interruption.

5. Time until transfer gate closes.
6. Time until discharge gate opens the second time.

The time from the starting of the stop watch until the discharge gate opens the second time is the gross mixing time. Under some specifications the transfer time (namely, the time the transfer gate is open) is not included in the mixing time and therefore should be deducted from the gross mixing time.

All pavers have a method of changing the timing of these operations to insure compliance with the specifications. These vary with different makes and will not be described here.

After operations start, the lapse in time between the skip reaching the top and the time when all solid materials are in the drum should be checked. This lag, if any, should be taken into account in setting the automatic controls.

After operations start some adjustments may be necessary in the automatic timing. When paving with the skip downhill the time the discharge is open may have to be lengthened to permit all of the batch to leave the drum. Conversely, when paving with the skip uphill this period may be shortened.

The U.S. Bureau of Public Roads film, "Lost Mixing Time in Dual Drum Pavers," shows in animated sequences the action that takes place during operations. A study of this film is recommended to inspection staffs and contractor's personnel.

SPREADING

Mechanical spreaders are used on almost all paving projects. These machines are capable of moving heavy loads of low-slump concrete. However, movement of large quantities of stiff concrete places unnecessary strain on both the spreader and the forms. By excercise of a little care and judgment on the part of the mixer operator to secure uniform distribution of the concrete over the subgrade, more uniform consolidation can be achieved, the strain on forms and equipment is greatly reduced, and the spreader operator can leave the proper amount of concrete for finishing.

Spreaders in general use consist of a screw or plow for distributing the concrete and a strike-off. The elevations of the bottoms of the distributing device and the strike-off are adjustable. The relationships of these elevations to that of the top of the forms are indicated on gages that are visible to the operator. Before starting a project the strike-off should be set with ends level with the top of the forms at which time the gage should read "0". If not, the gage should be adjusted to read properly. The controls of the elevation of the distributing device and the strike-off are independent and the bottom of the distributing plow or screw should be set about an inch higher than the bottom of the strike-off.

The ease and success of the finishing operations are dependent to a considerable extent on the uniformity in the amount of concrete left behind the spreader. This in turn is largely dependent on the skill of the spreader operator and his adjustment of the strike-off elevation.

If the mix is harsh and stiff, it will be inclined to tear and therefore the strike-off should be set higher for these mixes than for more fluid and sandy mixes that tend to surge under the strike-off.

Spreaders for use on projects constructed with central or transit-mixed concrete are a recent development. One type consists of a hopper that moves across the slab on transverse tracks (Fig. 3). It is filled at the form line and discharges the concrete through a bottom gate. The amount of concrete deposited on the subgrade can be regulated by changes in the width of opening and the height of the bottom of the bucket above the subgrade. A strike-off behind the hopper can be raised and lowered by the operator for precise metering of the height of concrete left behind the spreader.

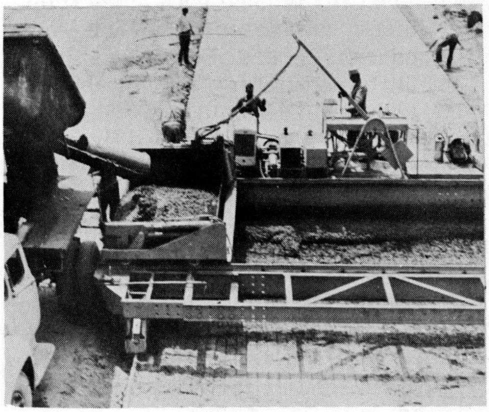

Figure 3. Hopper-type spreader for distribution of ready-mixed concrete.

Spreaders using conveyor belts for concrete distribution have been developed by several contractors for their own use.

If the concrete is to be consolidated by vibration, the pan or spud vibrators are often mounted on the rear of the spreader. It is important that these be operated only when the spreader is in motion. Some type of automatic cutoff to insure that this is always done is recommended.

Most specifications set forth the rate of vibration. This should be checked with a tachometer before starting construction. When pan-type vibrators are used the elevation of the bottom of the pan should be such that the coarse aggregate is far enough below the surface that little or no tearing takes place under transverse screeding. It should not be set so low that an excess of mortar is brought to the surface, but enough should be brought up for finishing. To obtain proper results several trial settings of the elevation of the vibrator will probably be required to secure the correct elevation of the bottom of the pan. The pan vibrators can be raised and if more than one pass is made they should be used only during the first pass.

The purpose of the spreader has been fulfilled if the surface of the concrete is such that the proper amount of concrete for finishing is left throughout the pavement width, and that, if specified, it is properly vibrated.

TRANSVERSE FINISHING

The consolidation of the concrete into a slab of proper shape is accomplished by transverse screeding. If properly performed these operations leave the surface close to final grade.

The transverse finishing machine usually consists of two oscillating screeds (Fig. 4). These are adjustable as to crown and tilt. Before starting a project the alignment of the bottom of the screeds should be checked (Fig. 5). To do this, first center the screed and lift it off the forms. Stretch fine wires taut between the forms at the front and back of the screed. Place uniform thickness blocks on top of the wires at each form and lower the screed on them. Check the alignment of the screed at both front and back edges for compliance with the specified surface contour and make any necessary changes by the front and rear adjusting bolts.

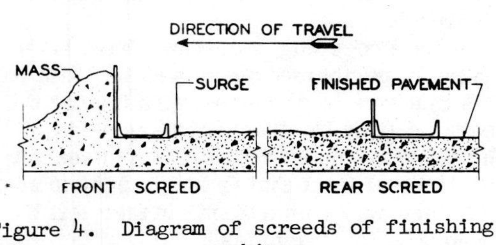

Figure 4. Diagram of screeds of finishing machine.

To assist in consolidation the front screed should be tilted, with the front edge slightly higher than the back. The amount of tilt is dependent on the characteristics of the concrete. Harsh, dry mixes may tear under a flat screed and leave insufficient mortar for finishing. To offset this the screed should be tilted about ¼ in.

If this much tilt is used with more fluid, sandy mixes, an excessive amount would surge under the screed. For these mixes the tilt should be reduced to ⅛ in. or less.

The rear screed should be set flat or with not more than $^{1}/_{16}$-in. tilt. If two finishing machines are used both screeds on the rear machine should have little or no tilt.

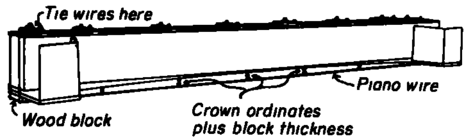

Figure 5. The crown of all screeds should be adjusted to produce proper crown.

The ends of the screeds on conventional finishing machines rest on the forms. As these areas are subject to the greatest wear, removable end plates are provided. These plates should be inspected at intervals for excessive wear. Abrasion up to about ⅛ in. can be compensated for by raising the entire screed by the adjusting bolts. In case of greater wear the plates should be reversed or replaced (Fig. 6).

All finishing machines are provided with transmissions for variations in both forward speed and number of screed oscillations and with adjustable eccentrics for changing the length of the screed stroke. For stiff harsh mixes these should be set for rapid lengthy strokes combined with slow forward motion to assist in working up sufficient mortar for finishing. For more workable mixes the oscillations should be shorter and less frequent in combination with faster forward motion.

In addition to specific adjustments an over-all inspection of the machine should be made for general condition. All wheels should be equipped with scrapers to prevent accumulation of concrete. These should be kept tight so that they will act as snubbers in addition to cleaning the wheels. The lift chains should be long enough to remain slack at the ends of the screed stroke. If too short they will tighten at the end of each stroke and there will be a tendency for the screed to lift off the forms.

Within the last few years several new types of finishing machines have come into use. These are all carried on long wheel-base frames (Fig. 7) and finish the concrete with transverse oscillating screeds and a stationary float. All of them are provided with some method of checking their contour. In addition some of the screeds or floats do not ride on the forms but are suspended from the frame. Their elevation is therefore much less affected by minor form irregularities. Before starting a project these should be set at about the elevation of the top of the forms. The screeds should be set so that each one is slightly lower than the one preceding. In this way the small amount of material necessary for proper finishing will be carried ahead of each screed. After starting a project there will have to be minor adjustments in the elevation and crown of the screeds to produce a proper finish.

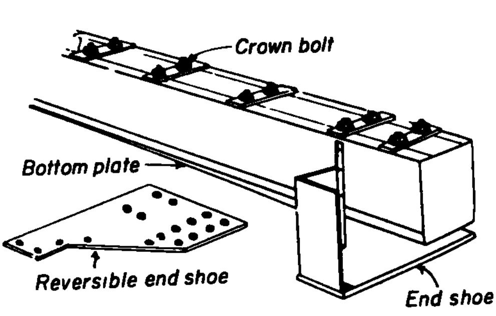

Figure 6. Worn end shoes or transverse screeds should be reversed or replaced.

LONGITUDINAL FLOATING

When used, the longitudinal float is the last finishing machine in the construction train. Its purpose is to correct any minor irregularities so that the surface will meet specification tolerances. To fulfill its function it must be kept in correct adjustment within very close tolerances at all times.

If the preceding operations have been properly performed there will be little for this machine to do beyond eliminating the marks left by the transverse screeds of the finishing machine. In such cases a longitudinal float that is not in proper adjustment may ruin a good surface left by the preceding machines.

Figure 7. Long wheel-base finishing machine.

There will be times when, due to irregular forms, lack of uniformity in concrete proportions or changes in vertical or horizontal alignment surfaces will develop that do not meet specification tolerances. Here again proper adjustment of the longitudinal float is essential if these are to be corrected.

Adjustments of longitudinal floats may vary between manufacturers but in principle they are similar. The purpose is to maintain the float parallel to the top of the forms and at the proper elevation at each point in its travel. All machines suspend the float from transverse tracks at the front and rear of the machine. To maintain proper adjustment the support for the tracks must be stiff enough to resist deflection as the float moves across the pavement.

The first adjustment is to straightedge the float along the centerline and both edges. If not straight it should be corrected before any other adjustments are made.

The height of the tracks that carry the float assembly should be checked to make sure that all four ends are the same distance above the plane of the bottom of the wheels. The proper height for any model is given in the manufacturer's operating instructions. This should be measured from a wire placed under the wheels on each side rather than from the forms as there may be some irregularity in their elevation. The track must be flat when this adjustment is checked (Fig. 8).

The tracks are then set to conform to the design crown. The method of making this adjustment varies considerably between manufacturers. In all cases the float should be weighted with approximately the same load it will carry during construction, including the operator.

One make employs a double track at each end of the float. One of the two is always flat and should be set from a wire stretched from end to end. Each end of the wire is

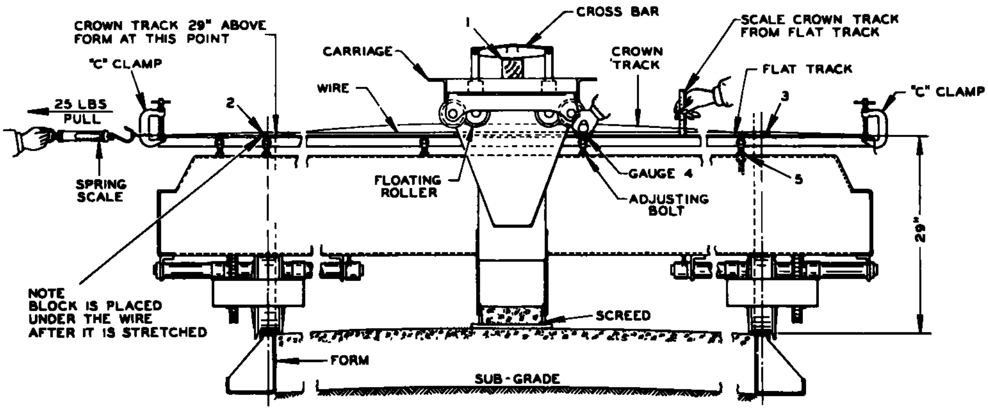

Figure 8. On longitudinal floats with double tracks one is always set flat.

raised on a ½-in. block and the track put in alignment by adjusting bolts. The other track is then set to design crown by measuring up from the flat track.

In this type the crown can be removed in increments by adjustment of quadrants at both ends of the float carriage (Fig. 9). Cranks attached to the quadrants are used to set the screed. Each quadrant is equipped with a scale divided into ten sections so that the proportion of the crown removed can be determined.

Another make uses only one track at each end, which can be changed from full crown to straight position by cams. The position of the cams is controlled by a rod which is moved back and forth by a wheel operating a worm gear (Fig. 10). On the worm are markings to indicate the proportion of the total crown remaining in the track. To adjust this type the cams are first set in the position for a straight track and its alignment checked from a wire. The cams are then turned 90 deg to the position they occupy when full design crown is being used. The length of the cam arms are then adjusted to produce the desired crown.

The float must be parallel to the top of the forms and at the proper elevation. All types are provided with turnbuckles or rods that control the distance between the track and the bottom of the float. Both the height of the float and the relative elevation of the two ends can be adjusted. While the float should normally be parallel to the top of the forms it may be necessary to raise the front end slightly on downgrades and raise the rear end on upgrades.

The float should be parallel to the crown of the slab in a transverse direction. This adjustment is made by centering the screed between the forms and measuring the height of each edge above a wire stretched between the forms. This should be done at both ends of the float. The method of correcting any error requires only the turning of bolts in some models but may involve addition of shims under bearings in others.

It is essential that both the wheels and the forms be free of concrete in order for the float to function properly. All machines are equipped with scrapers that act on the

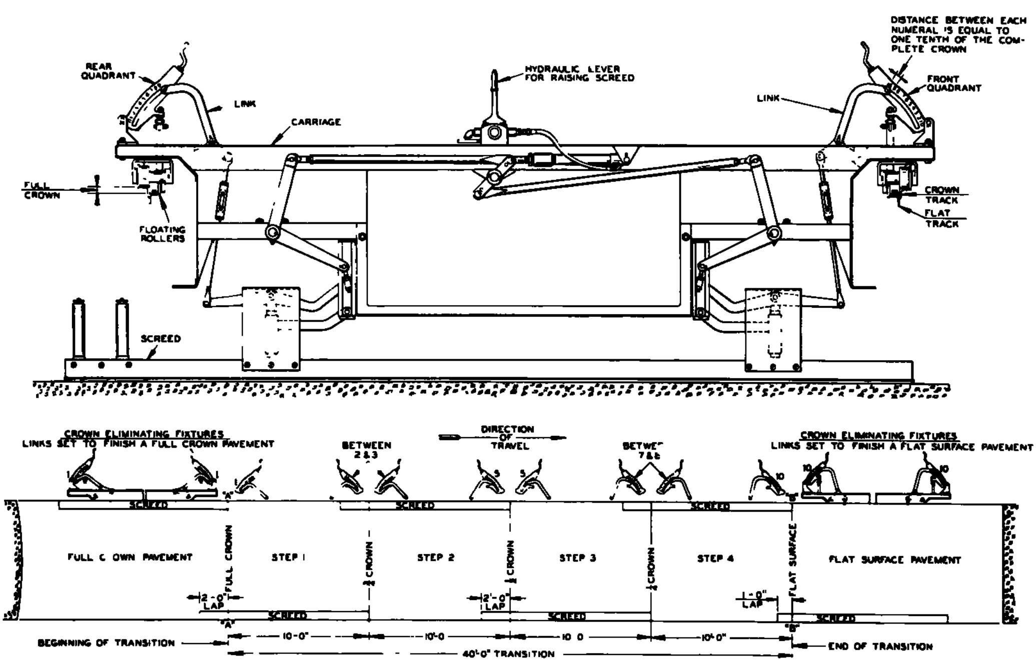

Figure 9. Adjustable quadrants at ends of float assembly permit changes in crown.

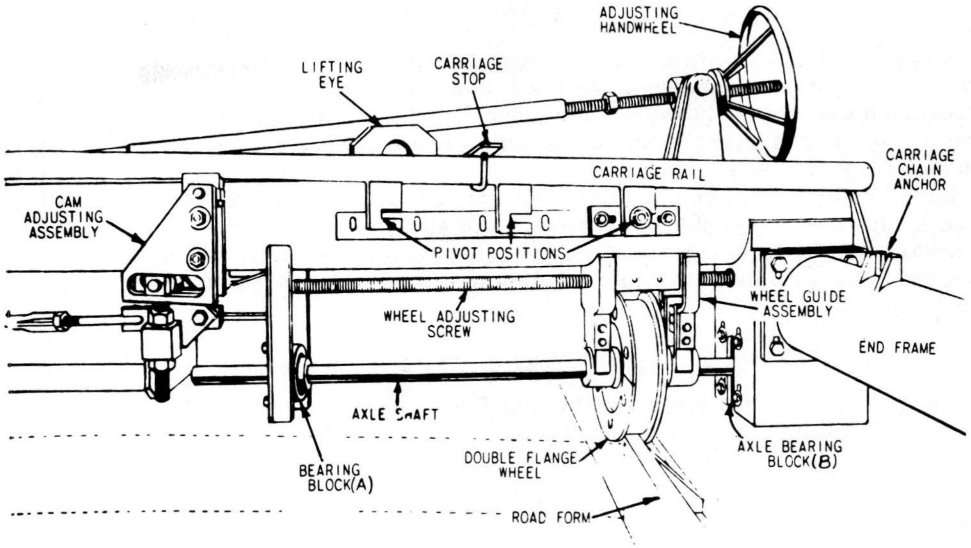

Figure 10. Crown changing cams are changed by use of adjusting handwheel.

wheels and on the forms. They should be kept in tight contact with the wheels or forms at all times.

Chain drives are used for longitudinal movement of the machines and transverse passage of the floats. These are provided with idler sprockets or take-up bolts so that the chains will not become too loose. Loose chains result in excessive slap and racking of the equipment.

MEMBRANE CURING

If membrance curing compund is used the equipment for its use should be checked for compliance with specifications (Fig. 11). These frequently require two coverages and the relationship of forward travel to transverse movement of the spray equipment should meet this requirement. The rate of application can be checked by the coverage obtained per barrel.

Other features that should be checked include the method of agitation of the compound and the height and type of nozzle and amount of pressure. Agitation can be either mechanical or by air as required by the specifications and should be sufficient to keep the pigment in suspension. The nozzle and applied pressure should be such that the compound is discharged as a fine spray. The spray should be protected from fine spray. The spray should be protected from air currents by a hood. The elevation of its bottom should

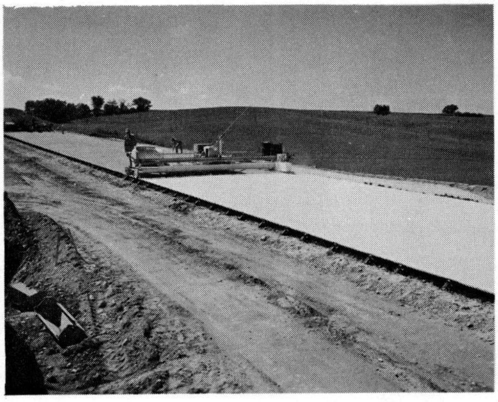

Figure 11. Coverage by membrane cure machine should be adequate and uniform.

be low enough to protect the spray but not so low as to receive an excessive amount of the material.

CONCLUSION

The preceding has outlined the various machines in general use for finishing concrete pavements and described the method of placing them in proper adjustment. It is recognized that not all types of equipment have been covered nor have all factors that require minor adjustment been discussed, but enough has been described to point out the general principles involved.

Each machine must be considered as only one unit in a series and its adjustments must conform to those of the other pieces of equipment in the paving train. Only in this way can full advantage be taken of their capabilities for reducing hand-finishing operations to the minimum and producing pavements having satisfactory riding qualities.

REFERENCE

1. Peyton, R. L., "Criteria for Present Day Concrete Pavement Construction." HRB Bull. 162, pp. 1-7 (1957).

Construction Practices for Placing, Finishing and Curing Concrete Pavement

J. F. BARBEE, Rigid Pavement and Concrete Engineer, Ohio Department of Highways, Columbus

●THE QUALITY OF the riding surface is the element of construction which the traveling public generally uses to judge the quality of any pavement. However, those who are in the highway construction field, want more than a good-riding pavement. The finished pavement must not only be smooth-riding but must also be durable and structurally sound.

A portland cement concrete pavement, therefore, must be so constructed that it will (a) provide a smooth-riding surface satisfactory to the traveling public; (b) be durable when subjected to natural weathering and to chemicals used for snow and ice control; and (c) be capable of sustaining the traffic which it is intended to carry.

The final construction is the culmination of all previous efforts involving many ideas covering research, traffic study, safety, construction materials (including soils), design and finance. This entire procedure, however, is finally judged by how well the construction work is done. This responsibility falls directly on the contractor and his forces and on the project engineer and his assistants.

Every step of construction, starting with the grading operations and continuing through curing and opening of the pavement to traffic, has a definite effect on the rideability, durability and structural integrity strength of the finished pavement. Special attention must be directed to preparation of the grade and subbase, where required, setting of forms, placing and finishing of the concrete and curing if a well constructed pavement is to be obtained.

The subgrade must be thoroughly and uniformly compacted in such a manner that a firm foundation will be obtained which will provide a uniform support for the concrete pavement. The surface of the finished grade should be rolled smooth to the required crown so that it will drain readily.

Observation of equipment used to construct the grade will often indicate soft spots which should be removed. An even better method is to test roll the finished grade with a 50-ton roller (Fig. 1). Test rolling will give positive indications of soft spots. All soft material should be removed, replaced with satisfactory material, and the subgrade recompacted. It is seldom necessary to undercut more than 3 ft to provide a subgrade of adequate, uniform support.

Special subbase treatment is often required. Maximum field density of special subbase material is extremely important to the pavement structure and can only be obtained by continuous control of material grading, moisture content and compactive effort. Sufficient equipment must be provided to insure that uniform density is obtained and that the subbase course in place does not contain segregated areas which may be due to poor material handling.

Special subbase material should be placed a reasonable distance ahead of the paving operation to facilitate "in place" density tests and insure uniform required density. Positive provision for drainage must be made so that the subgrade will not become softened or the foundation saturated. Prevention of damage to subgrade and subbase is always preferable to corrective work.

Tests of both subgrade and subbase should be made frequently to determine that the minimum specification requirements are being met. An effort should be made to obtain uniform density throughout the entire area to be paved in order that the support for the pavement will be as uniform as possible.

Subbases should be brought to fine-grade elevation or slightly above so that fine grading for forms or the area to be occupied by the pavement will involve a cutting and slight removal of previously compacted material. During the operation of the subgrader is a good time to observe the stability of the forms. Whenever there is any deflection of the forms, corrective measures should be taken. If this situation is not corrected, a pavement of variable thickness difficult to finish to proper grade will result.

Figure 1.

Forms are a potential source of trouble because they serve as tracks for all paving equipment, except mixers, in addition to serving as forms for the concrete. As new developments in paving equipment provide more and heavier equipment, the forms play an increasingly important roll in the construction of smooth pavements.

Forms should be set true to line and grade on a thoroughly compacted subbase with uniform bearing throughout their entire length and width. The building of pedestals of earth or other shimming to bring forms to the required grade should not be permitted. Whenever adequate and uniform form support is not obtained, the forms should be removed, the base corrected and recompacted, and the forms reset.

All forms should be checked before setting to determine if they comply with specification requirements for strength, height, base width, straightness, etc. Rejected forms should not be used until they are repaired so that they will comply with requirements. Pin keys should be straight and free-moving in the pockets and capable of holding the forms tight against the pins. The joint locks should not be bent or worn and should be capable of holding the ends of the forms in true alignment.

The pins and locks should be checked just prior to placing concrete and tightened if necessary. At the same time a final visual check should be made to insure that the forms are at a proper line and grade. Smooth-riding pavement with good surface finish is extremely difficult to obtain with poorly aligned and set forms. Form inspection must be continuous for best results.

After the subgrade or subbase has been cut to the desired elevation, it should be recompacted by rolling (Fig. 2) and checked with a pin templet, which has been set to proper crown. Any deviations revealed by the pin templet should, of course, be corrected. This operation must precede that of setting dowel assemblies. Any loose material adjacent to the forms should be compacted or removed.

Prior to paving the subbase should be thoroughly moistened (Fig. 3) to avoid absorption of mixing water from the concrete. Sprinkling, to moisten the subbase, should be done in such a manner that the grade is uniformly moist but not to the extent that the subgrade will become soft or muddy or that pools of water will be formed thereon. With granular bases, it is generally desirable to wet the subbase thoroughly well in advance of paving and then to wet again just prior to placing concrete.

Where dowels are required they must be in place before concrete is deposited (Fig. 4). Where mixers operate on the grade this is extremely difficult and, therefore, it is desirable that pavers operate outside the forms wherever possible.

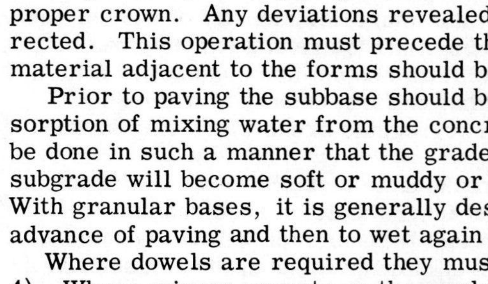
Figure 2.

To function properly dowels must be parallel both to the surface of the pavement and to the centerline of the pavement. To insure this alignment dowels must be securely held in position during the placing and finishing operations. Metal cages used to hold the dowels in place must be sufficiently strong to keep them in proper position.

The subgrade on which the dowel assembly is set must be true to elevation, smooth and properly compacted if the assembly is to set properly. When properly in place the assembly should be anchored in place with steel pins. These pins must be driven at an angle so that they will brace the assembly from lateral and vertical displacement during the placing of the concrete.

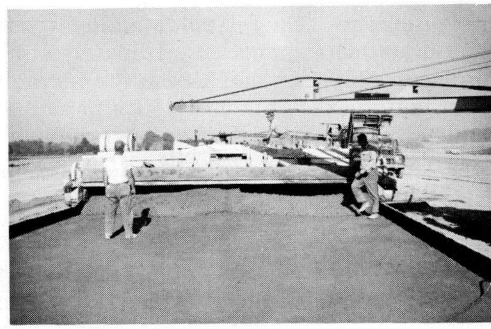

Figure 3.

In the event the dowel assembly is to be placed on granular material which might permit settlement or distortion of the assembly, steel bearing plates should be placed under the assembly. Shimming with loose earth, pebbles, broken tile, etc., must not be permitted. If this type of shimming is contemplated or attempted, it is obvious that either the subbase is not properly prepared or that the dowel assembly is bent or misaligned.

For dowels to function properly they must be greased for at least one-half their length to prevent bonding with the concrete. In dowel assemblies having one end welded to the basket, the free end of the dowel should be coated. The coating should be done in such a manner that the free end has a thin uniform coating, including the underside, and free of large lumps of coating material. Dowel assemblies are often delivered to the job assembled and held together with clips or shipping ties. As soon as the assembly is staked in place, the clips should be removed and the ties removed or cut so that the dowels will be free to function without any restraint. The expansion cap used on dowels placed in expansion joints must always be placed on the free, greased end of the dowel.

Immediately prior to placing, all dowels should be checked to determine if they are properly positioned. Those out of position should be corrected.

It is not within the scope of this paper to cover concrete production. In Ohio paver mixed concrete, central mixed concrete (Fig. 5), and transit mixed concrete, are used and good results have been obtained with all methods. However, good riding qualities depend on uniformity of construction and uniformity begins at the batch plant. If the batch plant produces non-uniform batches no amount of "first aid" or "emergency" actions at the paving operation will produce satisfactory, uniform pavement.

The concrete plant inspector's job is to proportion the materials according to specification and maintain, as closely as possible, a constant condition of workability and quality in the resulting concrete. The two principal sources of difficulty in maintaining uniform concrete appear to be segregated aggregates and varying moisture content of the aggregates.

Prior to starting concreting operations all mechanical equipment and hand tools should be on the project in first class working conditions, checked for conformance to the requirements as set forth in the governing specifications and approved by the engineer. Adjustments of equipment are a function of the contractor's forces. Highway personnel are not expected to adjust or advise the contractor how to adjust and main-

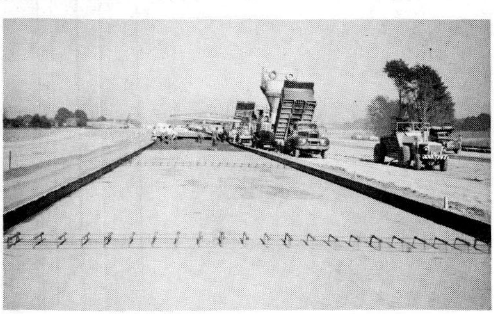

Figure 4.

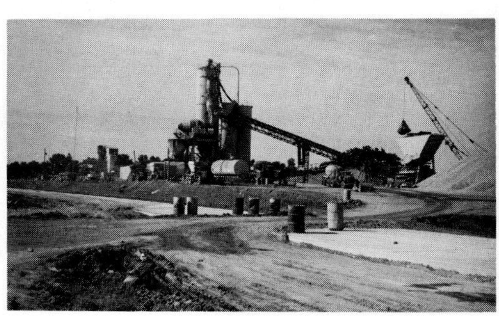

Figure 5.

tain equipment. They should, however, be able to recognize when such equipment is out of adjustment or not co-ordinated with the balance of the paving train.

Reinforcement, generally in the form of welded wire fabric or mesh, is often required in concrete pavement. Its principal function is to hold tightly together the fractured faces of slabs after cracks have formed. Adequate load transmission across cracks is thus assured and the infiltration of incompressible material into the cracks prevented.

Mesh delivered to the work ahead of paving operations should be carefully stacked and kept clean. Prior to use all mesh should be inspected for objectionable scale. Tarnish or sound rust on reinforcing is not objectionable, but scale or excessive rust will flake-off preventing good bond between the steel and concrete. Such reinforcement should not be used unless it has been thoroughly cleaned.

Mesh is generally placed along the rough grade or the shoulder so as to be convenient to the paving operation. When this practice is followed, the mesh should not be placed so far ahead that serious rusting will occur or that dust and mud will accumulate and cake on the reinforcement. All reinforcement incorporated in the pavement should be clean and straight. Many contractors are now using heavy bridges (Fig. 6) attached to and pulled by the first spreader to carry mesh. The mesh is loaded by cranes onto the bridge from trucks. This permits workmen to remain within the forms and minimizes the chance of the mesh becoming badly bent or dirty.

The concrete below the reinforcement should be uniformly distributed on the subbase and then struck-off by means of a mechanical templet to the proper depth. The strike-off should leave a level table without voids or high spots on which to place the mesh. Providing the concrete has been properly struck-off and the mats are reasonably flat it will not be necessary to tramp the mats into place. Furthermore, if they are properly tied the steel will not move laterally or work up into the finishing operations.

Concrete should be deposited on the subbase in such a manner that it requires a minimum of redistribution. Even distribution of concrete on the grade, or, on each course being placed, is the first step towards a smooth-riding job. The most even distribution in initial placing will result in minimum variation in final settlement of the surface. If concrete is deposited in piles or windrows, unequal consolidation may take place. This may never be overcome throughout the finishing procedure and can be the cause of unequal settlement and rough surfaces developing after finishing has been completed. Concrete spreaders are powerful pieces of equipment and will handle heavy accumulations of concrete. This is no reason, however, to permit improper distribution. Where an excessive amount of concrete is pushed and rolled along by the spreader segregation will probably occur.

Care must be taken to insure that batches are not dumped directly on or against dowel assemblies. In the case of expansion joints or formed contraction joints using

Figure 6.

Figure 7.

separation plates, the concrete should be shoveled around the assembly. This precaution is not as critical where open dowel baskets for sawed transverse joints are to be used because the spreader will force the concrete through the assembly without disturbance if proper staking procedures are followed.

On all but small paving projects (10,000 sq yd or less) an approved spreader should be used. If the pavement is reinforced, two spreaders are needed for a high-speed paving operation, one to strike-off for the steel and one for the second layer. Three types of spreaders are in general use: the screw type, the paddle type and the hopper type (Fig. 7). The latter is designed for use with central or transit mixed concrete.

The initial placing of the concrete should be such that it will be fairly uniform on the grade and in such quantity that a slight excess is carried ahead of the spreader as it levels the concrete to a relatively uniform surface. The spreader strike-off should be set so that it leaves sufficient concrete to provide a uniform roll (4 to 10 in.) of concrete ahead of the following screed.

Concrete should be vibrated (spading may be used) along the forms and dowel assemblies. At transverse joints the vibrator should be inserted vertically at regularly spaced intervals, not just dragged over the surface. The vibration should be just enough to thoroughly settle the concrete around dowel and forms so that voids or honeycomb will be eliminated. All vibrators should be checked for compliance with specifications. Form vibrators, generally mounted on the first spreader, should not operate except when the spreader is moving forward.

In addition to the spreading equipment, other equipment used will generally include either one or two transverse finishing machines followed by a longitudinal float, or a combination float finisher (Fig. 5). Sometimes a transverse finishing machine is used ahead of the combination float finisher, the number of pieces of equipment used generally being dependent on the contractor's rate of placing.

The work of the transverse finishing machine is generally an intermediate step in the process between placing and spreading the concrete and the final mechanical finishing. This machine should consolidate the concrete and leave the surface with a uniform texture screeded to a reasonably correct elevation for final finishing.

The transverse finishing machine should be checked prior to use to determine if it is in satisfactory working condition. End plates should be inspected for wear and reversed or replaced if necessary. The screeds should be checked for straightness or crown if one is required. The amount of tilt for each screed cannot be determined until construction begins. However, for air-entraining concrete, at the start of paving operations, set the front screed for about $^3/_{16}$-in. tilt and the rear for 0- to $^1/_{16}$-in. tilt.

Normally, 4 to 10 in. of concrete are carried on the front screed and about 2 to 3 in. on the rear screed. This should be continuous across the width being placed. The amount of concrete carried on the screeds (both forward and rear) controls the amount of surge past the screeds for any given mix. If the concrete is too high, an excess will pass and an overload will be left for the following equipment. If there is a deficiency at any point in the width of lane, a low spot will develop at that point. If the head varies continually, the surge will vary continually and a wavy or rough surface will be left. At the start of a day's work, there should be a small initial accumulation in front of the forward screed to provide a working supply for filling in low areas. As the work progresses, this accumulation should not be allowed to build up; but should be maintained almost constant. The work of distribution and of transverse screeding must be co-ordinated to give uniform, acceptable results.

As work progresses, the height and tilt of the screeds must be adjusted to compact the particular mix being used and to permit (and control) the amount of surge required. Screeds should always work with the screed wearing plates working directly on the forms. With extremely stiff mixes, there is likely to be an absence of surge, which with combined tearing, screeds the surface below the top of forms. The center of the screed should then be raised slightly, leaving the end plates to work on the forms with the remainder of the screeds raised. This will permit the required amount of concrete to pass the forward screed. The rear screed should always be at correct crown along the rear edge and work directly on the forms.

The combinations of traction, speed and screed motion to be selected depend on the concrete mix and consistency, and on the grade and super-elevation of the pavement. With stiff mixes, the screed speed should be rapid and lengthy and the traction speed relatively slow. This will provide extra working of the concrete and aid in compaction and in providing mortar on the surface for finishing. With more fluid mixes, the screed action should be decreased, both in speed and length; and the traction increased. This will prevent over manipulation of the concrete which might cause flowing to the low side of the forms, excessive surge past the screeds, or pooling of excessive mortar on the surface.

The relation of traction and screed speeds is important. In most machines, the speed controls are independent and the proper combination can be determined by trial without difficulty inasmuch as a change in speed of either screeds or traction can be made simply by shifting a lever. The change of length of screed stroke requires work be stopped and the screed drive readjusted. However, once adjusted, further changes in screed length should not be necessary unless control of the concrete mix is poor. Poor control of the concrete mix should not be tolerated.

The wheel scrapers should be tight so that they will keep the wheels clean. It is essential that the tops of forms and the wheels of all finishing equipment be free of concrete and mortar.

Care must be used when crossing transverse joints which include either a metal plate or expansion joint material. A good method is to remove concrete from the front screed, move the screed forward and set it down on the joint assembly and then continue screeding. Care must be taken to eliminate the possiblity of bumping the joint or of catching the cap over a joint where caps are used.

When the longitudinal finishing machine is used, the operation of longitudinal finishing or floating is the last mechanically controlled operation in the paving process. The work which follows consists only of the smoothing by the scraping straightedge and of texturing the surface. Good work by the longitudinal finishing machine will produce a surface that is practically satisfactory without further smoothing. Under these conditions, the work of the scraping straightedge is largely one of checking, and of correcting occasional, minor high and low spots.

The wheel and form scrapers should be adjusted squeaking tight to insure that all concrtete is removed from both the wheels and forms. The float should not rock or jump at the end of each stroke or where reversal of transverse motion occurs. The primary purpose of the longitudinal finishing machine is to float the top surface and to remove minor irregularities. It is not a heavy duty screed; and the preceding operations must be controlled so that it is not forced to become a heavy duty screed.

When properly adjusted and operated, the screed should carry a small roll of concrete along all but about the rear 2 ft of its length (Fig. 8). The mortar should roll, not flow. The forward speed should be such that the screed will make two complete passes over each area or 2 machines may be used each making one pass. The operator must continuously observe the amount of mortar carried on the screed, keep it distributed along the length of the screed, and prevent the mortar from falling off the rear end to form a ridge.

Whenever the size of the roll begins to decrease at a given point, a low spot is evident. If there is insufficient mortar in front of the screed to fill the low spot the machine should be stopped, fresh concrete added, and the floating continued. Whenever excessive filling or cutting are required the paving operation should be reviewed and any equipment out of adjustment or being improperly operated should be corrected. Precise control and attention to varying conditions are necessary if acceptable riding surfaces are to be obtained.

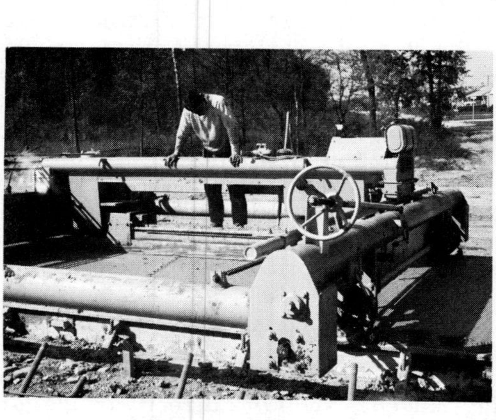

Figure 8.

Proper timing is of prime importance in the operation of the longitudinal finishing machine. For best results, it is desirable that initial settlement of the concrete be largely or entirely completed before the longitudinal finishing begins. If the concrete has not been properly compacted and is still in the early stages of shrinking when the longitudinal finisher passes, the final surface may eventually be rough. Finishing too soon is probably the reason why pavements acceptable for straightness at the time of straightedging are rougher than expected the following day.

The combination float finisher is often used to provide the final mechanical finish on concrete pavement. Several types are now used to finish 24-ft pavement, the most common being equipped with 2 screeds and a float. It is generally used following a combination spreader and finisher, however, it has been used following either a spreader only and in some cases a conventional transverse finishing machine. The front screed of this machine is a conventional reciprocating screed which rides on the forms.

The rear screed and float, however, are suspended from a long wheel-base platform and do not receive any support from the forms. The elevation of both the rear screed and the float is determined by adjustment of the hangers which connect them to the platform. As a result, minor variations in forms do not significantly affect the plane of operation of either the rear screed or the float. The key to smooth finishing with this machine is probably the rear screed because it is the final cutting tool and operates from long straightedge essentially free from influence of deviations in the forms.

Concrete must be accurately metered to this machine. Better results are obtained when spreaders and auxiliary screeds (when used) operating ahead of the machine leave just enough concrete so that a uniform roll of approximately 4 in. is carried on the front screed (Fig. 9). When this condition does not exist, the equipment operating ahead of the float finisher should be adjusted so that such a roll is obtained.

Both screeds and float must be accurately set. The front screed should have just enough tilt so that it will pass sufficient concrete to form not over a 2- to 3-in. roll on the rear screed. When this roll reduces in size, fresh material should be carried back and so placed that a uniform roll is obtained. It is essential that the roll in front of the rear screed be kept uniform for optimum results. The rear screed cuts off any excess concrete and leaves the pavement surface of the desired crown and grade. The float, when set to proper crown and almost flat longitudinally, just makes contact with the surface which it trowels to a smooth surface free of screed marks (Fig. 10).

Another type of float finisher in common use has only one screed plus a float and is attached to and moved by a transverse finishing machine (Fig. 11). The operations of the screed and float of this machine are similar to the rear screed and float of the previously described machine. Several other machines operating on the long wheel-base princple are in use. Some have trailing diagonal floats. Regardless of design all will provide a good finish when in proper adjustment and operated in accordance with good practice. As is the case with the longitudinal finisher, proper timing of operation is of prime importance with better results being obtained after initial shrinkage has taken place (Fig. 12).

The combination float finisher is primarily designed for a one pass operation. If all operations prior to the pass of this machine are as they should be, it will rarely be necessary to make more than one finishing pass. More than one pass will not generally improve the surface but only bring an excess of fine material to the slab surface. If the forward speed is properly adjusted, the machine will move forward at a uniform rate and stops will be eliminated. It is true with the machine, as it is with other types of finishing equipment, that continuous operation (without stopping) provides smoother pavement.

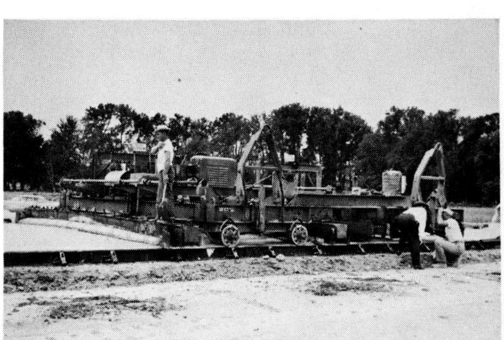

Figure 9.

All mechanical paving and finishing

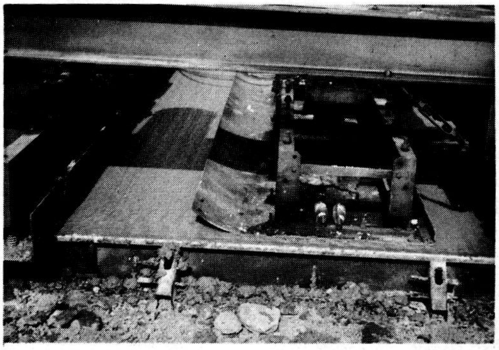

Figure 10.

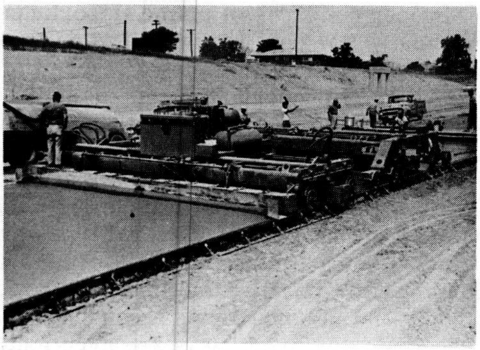

Figure 11.

equipment must be kept clean. The bottoms of screeds, floats and pans must be absolutely smooth. Accumulations of hardened conctete (or of oil and grease) which might drop on the pavement must be continuously cleaned off. All machines should be thoroughly cleaned at the close of each day's operation.

A crown check should always be made at the start of paving operations to determine that all equipment is properly set and functioning as it should. Whenever deviations in crown from that specified are found, immediate steps should be taken to correct the situation. Checking crown and adjusting equipment and operations should continue until the proper crown is being obtained. Periodic checks of crown should be made throughout construction and equipment adjusted as necessary.

After the mechanical finishing is completed, but while the concrete is still plastic, minor irregularities and score marks in the surface should be removed with a scraping straightedge (Fig. 12). Where necessary, excess water and laitance should be removed from the surface transversely by a scraping straightedge and wasted over the forms. A number of different types of straightedges have been used satisfactorily, all must be strong enough to maintain a true straightedge and yet light enough to handle. Straightedges should be checked periodically to make sure they are straight.

Long-handled floats are sometimes used to smooth and fill in open-textured areas in the surface (Fig. 13). This should be done prior to straightedge finishings. If open-textured areas persist, it is well to check the aggregate grading, mix design and method of placing the concrete, because a properly proportioned mix should not require hand floating if the preceding mechanized equipment is in proper adjustment.

The slab and formed joints should be edged as soon as the concrete becomes stiff enough to remain firm without running back in the groove. The edge should first be

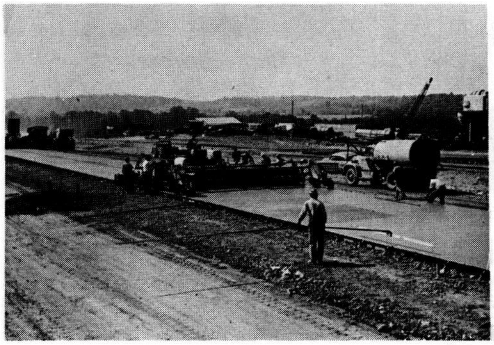

Figure 12.

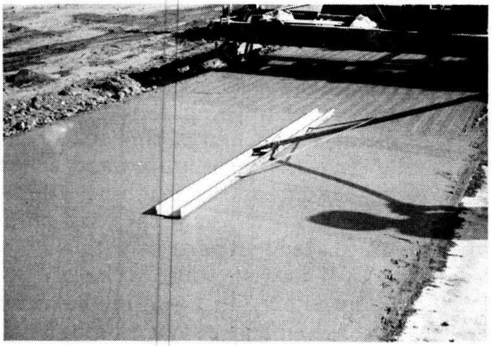

Figure 13.

cut with a small trowel and then followed by the edger held flat with the pavement surface. Because texturing follows edging, this operation must not be permitted to lag. Mortar should never be dragged into the joint when texturing the pavement surfaces.

When most of the water sheen has disappeared, but before the concrete becomes non-plastic, the final surface texture should be applied. This final finish is generally developed by brooming or by use of a burlap drag which leaves the surface with a gritty non-skid texture. If the texturing is done while the concrete is too plastic or after it has started to harden, the resulting texture will not have the desired gritty uniformity.

Where burlap is used it should be at least 3 ft in width and of sufficient length to cover the slab so that the entire slab can be textured in one operation. The burlap must be kept clean and moist, and free of ravelled edges. The leading edge of the burlap may be fastened to a traveling bridge leaving at least 1 ft in contact with the surface (Fig. 14). If the drag is to be pulled by hand it should be attached to a rigid bar. It can than be lifted clear of the pavement and rolled around the bar where it will remain moist and pliable.

No tool marks or other disfiguring blemishes should be present on the surface after final finishing, and texturing should be uniform over the entire pavement surface.

Proper curing is essential if the potential strength and durability of the concrete is to be realized. Curing must keep the concrete moist and warm to insure adequate hydration of the cement and protect the concrete from early shrinkage due to changes in temperature and/or loss of moisture before it has developed sufficient strength to resist the resulting tensile stresses.

Any of several methods of curing will give satisfactory results if correctly accomplished. Regardless of the method used, the curing material should be applied as soon as it can be placed without marring the surface. This normally is about the time the water sheen disappears from the concrete surface. During windy, hot, dry weather, it is important that the finishing be completed rapidly and curing placed before the surface dries out to the extent that shrinkage cracks may develop. If curing is delayed, fog spray the surface with water.

Where membrane curing is used the mechanical equipment should be so adjusted that uniform and complete coverage is obtained (Fig. 15). Timing of the application and pressure of the spray should be so that the texture of the pavement is not harmed. All membrane must be thoroughly agitated so that when applied it will provide a uniform water-impermeable film. Nozzles must be examined periodically for wear and, when found unsuitable, replaced. This is especially true with pigmented membrane.

Prior to application or use of curing materials, they should be inspected to insure that all specification requirements are being met.

Sawed construction joints are now used extensively. The joints should be sawed in a progressive manner and as soon as possible without excessive ravelling of the con-

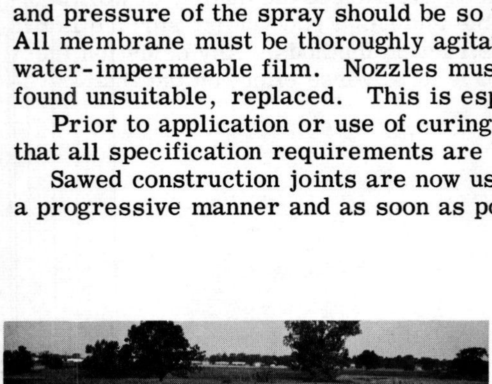

Figure 14.

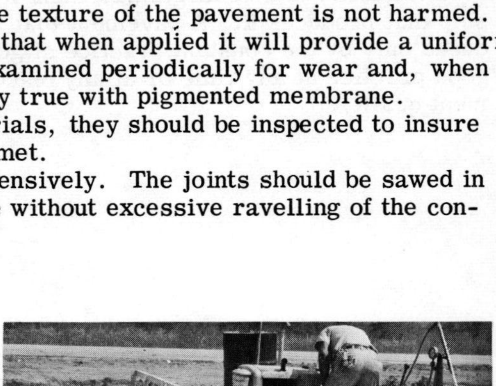

Figure 15.

crete. Slight ravelling is not objectionable and actually is a good indication that sawing is being done at the proper time. Pavement placed in the morning should generally be sawed the same day—possibly 6 to 8 hr after placing—and sawing continued until all joints are cut. Concrete slabs tied to a previously placed slab may be sawed without difficulty providing sufficient equipment is available so that sawing may be done at the proper time.

Whenever a crack occurs ahead of the saw cut, sawing on the joint should be immediately stopped and the saw moved ahead several joints. There, cut a joint or several joints, then return and cut the intervening joints. Whenever a crack occurs sawing is not being performed soon enough and sawing operations should be immediately modified so that such cracking does not reoccur. Sawed joints should be flushed immediately after sawing. Longitudinal joints may be sawed up to 7 to 10 days after placing.

During warm weather, forms are generally removed approximately 24 hr after the concrete is placed. During cold weather the time at which forms may be removed is usually based on whether the concrete has attained sufficient strength to prevent damage to the pavement surface or edges. As soon as the forms have been removed, the edges should be checked and all honeycombed areas filled flush to the surface of the pavement edge with good quality concrete.

Joints should be checked to make sure the ends are cut through to the edges and all concrete at expansion joints is removed. Curing should be applied to the pavement edges as soon as the forms have been removed and patching and cleaning of joint ends has been completed.

Joints are sealed to prevent infiltration of incompressible matter and surface water. All joints should be sealed before the pavement is opened to traffic or in event of a temporary fall close down. Sealing may be done at any time after curing is complete. Sawed joints are generally sealed immediately after sawing. Joints should be thoroughly clean and dry when filled.

Prior to final acceptance of the pavement, any unsatisfactory joint seal should be removed and replaced and all low spots brought up to the desired level. Also any high spots should be cut off and the excess material removed.

The quality of a concrete pavement is a direct reflection of the quality of workmanship that produces it. A pavement that is durable and has a good riding surface is produced only by the constant practice of good construction methods. Any deviation from good practice at any time or at any place will have an adverse effect on the final pavement quality.

Construction Practices for Materials Control and Batching Operations for Rigid Pavement

W. M. STINGLEY, Concrete Engineer, State Highway
Commission of Kansas, Topeka

● IT HAS BECOME necessary in many areas, due to expanded programs, to spread the work load of available engineering personnel. Because this situation is not likely to change soon, every effort should be made to provide for proper training of new men. This paper outlines the duties of a proportioning plant inspector and provides solutions for some of his problems.

Many states have set up various systems of employee training. The system which seems most workable for men who will supervise work of the type discussed is one in which small groups are trained on a local basis.

Winter schools, of not more than ten or twelve men, make it possible for each man actually to run each test. He will be able to ask as many questions as necessary, and not be lost in a large class. The men brought into such a class generally represent a wide range of education and experience, and require some individual attention. The men available to instruct in such schools, who have had recent practical experience, will ordinarily do better with smaller groups also. Some of the construction divisions in Kansas have followed up these primary schools with more advanced training in following years with good results. Every organization has men who have had years of experience. If confronted with a school teaching task, they will take pride in the job and do it well. Without exception, the instructor will also benefit, almost certainly to a greater degree than any of his pupils.

Many paving specifications need review because of operational speed-up and changed conditions. A recent check of the specifications in Kansas turned up nine clauses which have appeared for years, and which are not applicable to present conditions and practices. Every statement of this kind, which the inspector knows is unworkable or is no longer necessary because of changed equipment or conditions, weakens his position in his relations with the contractor. Many contractors complain, with justification, that they must bid the engineer, or the district in which the work is located, because of different interpretations of vague or outdated specifications.

A large part of the plant inspector's problems are directly or indirectly due to the vastly greater quantities of materials handled now as compared to a few years ago. Many plant sites once considered adequate are now so cramped as to make their operation under existing specifications difficult or impossible. At the same time, greater numbers of projects are handled simultaneously by engineering forces, and available inspectors are often less experienced. Many jobs are operated with too little equipment at the batch plant, though every effort has been made to speed up the work at the pay off or mixer end.

At the start of a project the batch plant inspector should have an understanding with the contractor as to the site, equipment, methods, and materials to be employed. If any of these will lead to failure to meet the specifications, the contractor is entitled to a warning that enforcement will be rigid. If the planning involves not an infraction of the specifications, but inefficient operation, the warning is still in order, and is to the advantage of both contractor and owner. Both have a common goal—a better job.

Fortunately, one way in which the inspector's work has become easier is in the changed attitude of many contractors and their forces. Many contractors now realize that they cannot operate efficiently with cramped facilities and make a practice of setting up 2- and 3-stop plants with ample space. Almost without exception, every paving contractor in business today is making an honest effort to produce work which will reflect credit to and further the reputation of his organization. In the past most batch plants were set up in railroad yards. Materials were received almost entirely by rail, and arrangements were made for stockpile room either between or beside the tracks. This was a convenient and workable arrangement for everyone concerned. Paving progressed in a leisurely manner, compared to the present, and volumes of material used could be handled in the space available.

Lack of room to operate properly is never a valid excuse for stockpiles which are not bermed to prevent segregation, or for the intermingling of different sizes, or for uneven moisture due to loading bins directly from cars. It is difficult to prevent a coned-up and segregated stockpile if there is simply not room to build it properly. If sufficient quantities of aggregates of uniform moisture content are to be kept always available, stockpiles properly bermed to prevent segregation must be so large that it is practically impossible to handle two or more sizes of aggregate through one weighing setup, unless a belt-fed plant is installed, and these are not too well adapted to long jobs. Many pavers now follow the practice of setting up, for each size aggregate, a unit consisting of a stockpile, one or more cranes, and a bin with weighing hopper. These units may be separated by a few hundred feet or by a mile or more, but in any case, are so arranged that batch trucks and trucks delivering materials can operate in a smooth-flowing pattern. The first stop, after returning from the mixer can be at the sand bin. If separate cement boxes are not required, the cement stop may be next, and lastly the coarse aggregate. If cement boxes are used, the cement will be loaded last.

The same rule of adequacy applies to equipment. It generally is neither the duty of the inspector nor within the scope of his authority to require that two cranes be used instead of one, or three rather than two, for handling aggregates. It always is his duty and right, however, to see that lack of adequate equipment is not used as an excuse for waiving specifications requiring proper handling of these aggregates. In most cases the specifications are adequate but are not enforced, for the reason that they cannot be enforced, with the amount of equipment, or space, that has long been considered as "standard" for paving work. The inspector must not be influenced by standards of the past. His responsibility is to insure that equipment, space, and methods are adequate for the present.

SPECIFIC DUTIES OF THE BATCH PLANT INSPECTOR

There is a logical sequence for the inspector to follow in fulfilling his responsibility. First, he must organize his work, and thinking on an orderly basis. His duties are divided into three phases:

1. Preliminary inspection.
2. Operational control.
3. Reports.

Preliminary Inspection

The plant inspector's duties start during the time that materials are being accumulated. Before any concrete is batched, there are four duties to be performed. They are:

1. Approval of plant layout and stockpiling.
2. Inspection of equipment.
3. Inspection of materials.
4. Mix design.

Plant Layout and Stockpiles.—Although the selection and arrangement of the plant site is the contractor's privilege, it has been pointed out that, the inspector has a duty both to the owner and to the contractor to insure the provision of adequate space and working arrangements. He must accomplish this goal by showing its advantages, and necessity, to the contractor.

Even where ample space is provided, the inspector must see that other, more specific requirements are met. Segregation must be prevented, degradation kept to a minimum, and moisture uniformity assured. Segregation of coarse aggregate is common if it is handled as a single material. The stockpile should be built in lifts of not more than 4 ft, with a distinct berm between lifts to prevent roll and subsequent segregation. Enforcement will not be too difficult at the start of the job but will become increasingly difficult as the job progresses. Moreover, unless the coarse aggregate is divided into two or more "one size" aggregates, stockpiled separately, segregation will undoubtedly occur.

Degradation of aggregate is also a serious deterrent to good concrete production. Most specifications prohibit rough handling, tracked equipment and stockpiling with trucks. The plant inspector should rigidly enforce such specifications. He should also retest aggregates which have been stockpiled through the winter or for long periods. In one instance, -200 mesh material has been known to increase from $\frac{1}{2}$ to 7 percent during a winter season.

Proper stockpiling for an adequate period of time is the most important means of assuring moisture uniformity. Changes in methods of delivery of aggregates to the site have increased the problem. With the nearly watertight steel cars now in common use, excess water has little chance to drain off, and stockpiling for moisture uniformity is more necessary than ever. The inspector is there to see that moisture is uniform when aggregate goes into the bins, regardless of the circumstances.

Inspection of Equipment.—Although the inspection of equipment will be a continuing duty throughout the operation of the plant, an early and thorough inspection of scales, batching equipment and trucks will minimize later difficulties.

Scales. The scales should be checked after the bins have been allowed to stand loaded for at least 24 hr or until all settlement has taken place. Solid footings must be required under all bins to minimize settlement, and all supporting assemblies must be solidly constructed. The most elaborate and expensive system of hoppers and scales will produce poor results on poor footings.

Wind protection of scales is often slighted, or built in such a way as to fail in its intended purpose. The errors caused by wind may be small, but are of a type which do not tend to balance out. The effect of the wind on a sloped hopper side is well-recognized. However, a wind blowing across a flat horizontal surface will cause equal or greater inaccuracies in weighing. All knife-edge supported parts must be fully protected from wind.

Batching Equipment. In addition to checking the footings and structural stability of the batching equipment, the inspector must be certain that the plant will accommodate the batch trucks which may be used. If the truck beds are all the same height, it is not too difficult to arrange the discharge pipes at the cement batcher so that little cement will be lost as batches are loaded. Because most projects operate with a variety of trucks, it will be necessary to construct the plant so that the discharge pipes can be raised or lowered enough to take care of all the trucks being used without excessive blowing or spillage. Here again, the inspector should remember that he is not directly responsible for shortcomings in the equipment, but that by insisting on proper operation he can control the situtation.

Trucks. Batch truck beds should be checked. They must be big enough to handle batches for present day mixers without spillage over the side or from one compartment to another. Compartment doors should be tight and have a positive locking system to prevent multiple dumping at the skip. It does little good to weigh out the components of batches to the pound and then mingle one batch with another in the truck or skip.

Inspection of Materials.—Either all or part of the aggregates are now commonly delivered by truck, and delivery may be continuous throughout the day, and perhaps, night as well. It was once possible to keep a record of railroad car numbers which could be checked against test reports with reasonable assurance that tested and accepted material was being received. It is now difficult even to be sure that aggregate is coming from the right plant, let alone stockpile or bin at that plant. Only by close coordination with the materials inspector at the producing plants can there be assurance that accepted material is being delivered. If there is doubt, retesting must be done.

Foreign material may not be too harmful, generally, but is unsightly. Surveys of year-old and older pavement reveal an astounding variety of included junk—boards, burlap, paper cups, corn stalks, straw, weeds, grasshoppers, mud balls, mud chunks from stockpile cleanup, old hats, and even sledge hammer heads. Most of this assortment originates at the mixer end, but every effort must be made at the plant to eliminate that which gets in there or is present when delivered. The area to be used for stockpiles should be cleaned and smooth, in order that as little aggregate as possible will be lost at the job's end. In addition to inspecting the aggregate the inspector is generally expected to see that all the incidental materials are undamaged and from tested stock. These include wire mesh, load transfer devices, air-entraining agents, joint sealing material, curing compounds, mixing water, and perhaps subbase material, although inspection of this last item can be a full-time job.

Mix Design.—The mix proportions must next be determined. So many methods are used in different areas that no attempt is made to go into this procedure in detail. In any case, however, the specific gravities of the aggregates and cement, the free moisture or absorption of the aggregates, and the unit weights of dry and rodded materials will be needed. Trial batches should be made and cement content should be checked from these trials. If air entraining is required, the approximate amount of agent to be added may be determined by trial batch, but probably with no great accuracy. The first batches through the paving mixers must be checked for air content under actual operating conditions, and these tests must be continued through each day.

Operational Control

During batching operations the batch plant inspector is responsible for the delivery of batches to the mixer which are accurately weighed, composed of proper proportions of materials which comply with the specifications, and are accompanied by information as to the water needed to produce concrete of proper slump. In carrying out these functions, he should be guided by the concept that the entire paving project is a line operation, from raw material source to finished slab. As is true of all such operations, the quality and volume of the end product are equally dependent on each step along the line, and no amount of extra effort at one stage can compensate for error or inefficiency at some other. The inspector should also realize that uninterrupted batching, although secondary to accuracy, is an important consideration. High volume, and lowered costs, are eventually passed along to the owner on following jobs. The specific duties of the inspector during batching operations include:

1. Continuous checking and reporting of aggregate moisture.
2. Scale checking and supervision of scale inspectors.
3. Preparation of test specimens, care of molds, curing, testing.
4. Maintenance of proper stockpiles.
5. Daily cement checks.

Supplying Continuous Batch Information to the Mixer Inspector.—Uniformity in the finished product depends on accurate information on water needed at the mixer, to a greater degree, than on any other single factor. Not only the properties of the concrete but the riding qualities of the completed slab are dependent on this information.

Because free moisture in aggregate must be considered a part of the total water in the mixed concrete, a continuous program of moisture testing must be pursued. The aggregate samples should be taken from the aggregate weigh hoppers and tested without delay. Some provision should be made for rapid communication between the inspectors at the mixer and at the batch plant, and these men must keep each other continuously informed of changes of moisture conditions. This information is supplied to the inspector at the mixer by the batch plant inspector in the form of a moisture and proportioning report, often referred to as a batch slip. This report includes the project number, date and time of day, and the mix ratio. It shows the pounds of each material on a saturated and surface dry basis, and the actual weight set on the scales after corrections have been made for free moisture or absorption. It shows either the total gallons or pounds of water in the mix, and the amount of water to be set on the mixer measuring device. This quantity will vary from total water by that amount that is deducted to compensate for free water in the aggregate, or that is added to allow for absorption. The slip should also show the calculated air free unit weight of concrete and weight of materials in a one-sack batch. The batch slip should be made in triplicate, and the third copy retained in a bound pad.

Two copies should be sent to the mixer inspector at the start of each day's work, and whenever changes of any kind occur during the day. The inspector at the mixer should receive both copies, set the water on the mixers, and record on each copy the time, station and amount of air-entraining agent added. When test specimens are made during the day, the station at which they are made and their identifying numbers should be added to the information on the report. If it is necessary to use a quantity of water that differs from that shown on the slip, the actual amount of water added, the station, and the slump and unit weight of concrete, are recorded and one copy of the report is sent back to the plant inspector. The batch plant inspector can then make the necessary corrections on a new set of slips, and again send two copies to the mixer. At the end of each day, the batch slips should contain an accurate record of most of the pertinent information needed for daily construction reports.

Scale Checking and Supervision of Scale Inspectors.—Scale checking should be an everyday procedure. With a set of 50-lb test weights, cement and aggregate scales should be loaded to the batch weight. In addition, at frequent intervals during the day, spot checks should be made. These can consist of simply returning the beams to zero and checking for balance, or a single 50-lb weight can be added to a loaded hopper and the reading noted. Scale weight lock screws should be kept tight.

Checks should be made for dust. Dust on the beams may cause only small errors but the errors are all in one direction. One pound of dust on the lever system can become several pounds at the weigh hopper, in favor of the owner in a sense, but an error nevertheless, and to be avoided.

The plant inspector should frequently check that no material fails to leave the weigh hopper when it is dumped. He or his scale inspectors should note the disappearance of a truck from the string. Truck breakdowns generally occur on the portion of the trip when they are loaded. Batches spending several hours in a stalled truck with cement and damp aggregate intermingled must be dumped. Even separate cement compartments, which generally have no bottoms, are not capable of protecting the cement overnight if aggregates are other than bone dry.

Test Specimens.—An important part of the control of a paving operation consists of the making, transporting, curing and testing of strength specimens. It is a simple matter to show a new man how to do each test, but unless it is also explained to him why it is necessary to perform each operation in a prescribed manner, he will surely find short-cuts which will reduce the reliability of the test results. He should, for example, be given the reason for a specified rate of loading when breaking a test beam in flexure. He may be told, or discover by accident, that a higher compresssive strength may be developed by a period of drying out just prior to delivering cylinders to the laboratory.

Time should be taken to point out to the new man, and some of the old ones, the pertinent AASHO and ASTM sections which prescribe standard procedures for the different tests. It should also be explained that it is strengths obtained by these standard methods that are wanted, not strengths due to an "improved" procedure of his invention.

Daily Cement Checks.—The amount of cement used should be checked constantly. Particularly where air entraining is required, it is easy to get into serious trouble. Neither the theoretical cement content nor the cement content derived from the unit weight of fresh concrete should be considered sufficient evidence that all is well. These methods should be used but at least once a day the total volume of concrete poured should be checked against the actual car load weight, or bulk truck weight, of cement used. This is not easy to do at a predetermined hour of the day, so opportunities must be watched for, such as when the cement bins are allowed to run dry between cars or trucks. The cement scale inspector should be alerted to assist in finding spots for this check.

Reports

In any kind of construction work uniformity is the goal, so far as materials are concerned. When dealing with concrete, complete uniformity must be recognized as impossible. The list of possible variables is so long, and so many are not controllable on the project, that it is safe to say that no two projects ever built are similar, let alone identical.

If there is no uniformity, then there must be records if concrete paving procedure is to be improved. Most construction people think they are buried in record keeping, and they do spend much of their time writing project reports. However, if a person has ever checked back through the field reports in a search for a reason for either exceptionally good or bad performance of a section of pavement, he knows how incomplete the data can be.

He will find test reports by the hundred, but he will find it difficult to determine where a particular brand of cement or lot of aggregate was used. Someone on the project knew at one time almost every detail of how the work was done, with what materials, and why changes were made. The plant inspector cannot keep complete records of the entire project, but his records should be as complete, and as permanent, as possible.

The proportioning plant inspector should keep, in bound field books, a record of every shipment of material. This record should include the source, the test number, the quantity, and where it was used. It should include the amount of cement used each day, and as nearly as possible, the location of the cement represented by each test number, the actual cement factor based on car weights of cement received, the over or under run, the mix proportions, the air content, the slump, and the source of mixing water. Any changes made during the day in cement brand, water, other materials, and of procedure should be noted.

He should keep a bound book with a record of scale checks, both full scale checks and those of the spot variety. He will, of course, need to record test specimen data which should include date made, from what location, how cured, when tested or sent to the laboratory for test, and the results. Any possiblity of damage such as from freezing or handling should be noted.

The control of air entraining is more a matter of record keeping than of computation. Using a given quantity of air-entraining agent the resulting air entraining will be found to vary with changes in temperature, slump, humidity, mix time, percentage of sand and gradation of sand, wind, and manner in which the agent is added. The record should show all of the foregoing factors and the quantity and brand of agent and the resulting air content. Some agents are sold in different concentrations and this should be recorded.

Accidents are seldom found in the job records, yet if improvement is to be made in materials and procedure, the accidents must be recorded. Far more can be learned from a project on which some things went wrong, than from one that was without incident, provided that it is possible to find out just what did happen.

Perhaps at 9 a.m. it is discovered that the sand scale has been set 400 lb light, or heavy, since the start up at seven. The chances are good, that when such a thing occurs the brand of cement has just been changed, and duly recorded. Some years later it will be easy for someone on a condition survey to come to erroneous conclusions as to the effect of the difference in cement.

Two things remain to be impressed on the new inspector, and no amount of training in the mechanics of the operation are of any avail without them. He must be made to realize the importance of his duties, and he must be confident of the backing of his superiors. The rate at which the owner's money is being spent on a high-speed paving job should be used to prove to him the amount of money involved in, for example, a one percent error in cement content. Unless he and the contractor both know that the inspector is truly the representative of the engineer in charge of the project, he cannot hope for complete success.

A Study of 34-E Pavers

D. O. WOOLF, Highway Physical Research Engineer, Division of Physical Research, U. S. Bureau of Public Roads, Washington, D. C.

This paper summarizes data obtained in 16 studies of the mixing of portland cement concrete in 34-E dual-drum pavers, conducted by 13 state highway departments. Determinations were made of the desirable time of mixing and the amount of overload which could be permitted. The results indicated that the highest strengths were attained at a 60-sec mixing time, exclusive of transfer time, and that an overload of 10 or 20 percent could be tolerated. It was also found that little loss in strength of the concrete resulted when the mixing time was reduced to 40 sec, exclusive of transfer time, but when the mixing time was reduced to 30 sec a loss in strength of 5 to 6 percent occurred. A mixing time of more than 60 sec exclusive of transfer time, was found to be undesirable because it involved waste of effort and resulted in loss of strength without gain in the uniformity of the concrete.

●IN DECEMBER 1957, the U.S. Bureau of Public Roads suggested that a study of the production of portland cement concrete in 34-E dual-drum pavers be made by interested state highway departments, to determine the most desirable mixing time and the permissible overload, if any. State highway specifications showed that, exclusive of the transfer time required to move the concrete from the first to the second drum, some states permitted a mixing time of as little as 50 sec, while other states required mixing times of as much as up to 120 sec. Some state specifications permitted no overload, but others allowed overloads of from 10 to 20 percent. It was believed that factual information on the effect of mixing time and of amount of overload might permit the more rapid production of concrete without reduction in quality. Lower cost of the concrete in place should then be obtained.

The program proposed by the U.S. Bureau of Public Roads suggested that mixing times of 30, 60, and 90 sec, exclusive of transfer time, be used. Because most states used a mixing time of about 60 sec, this was taken as a standard of comparison. The 30-sec time was suggested as part of the program to provide concrete which might possibly be undermixed; the 90-sec time was intended to determine if extended mixing of concrete would abrade the aggregate to such an extent that excessive fines would be produced, causing the strength of the concrete to suffer. The states were informed, however, that these times could be changed to suit their particular interests, if they so desired.

As proposed in the program, many states used an overload of 10 percent in their studies, and in some cases an overload of 20 percent was used. Where the project contractors objected to the larger overload because of possible resultant wear on their equipment and waste of material, the 20 percent overload was omitted.

The suggested program also recommended that for a given combination of mixing time and overload, samples for test be taken from each tenth batch of 90 consecutive batches of concrete. It was further recommended that three samples be taken from each batch sampled, one sample representing each one-third of the concrete as discharged from the bucket. Specimens for compression and flexure tests were made from certain of the batches sampled and tests for air content, unit weight, and uniformity of composition were made on certain other batches.

SCOPE OF DATA

The studies of the effect of mixing time and overload on the quality of portland cement concrete produced in 34-E dual-drum pavers were made by 13 state highway departments; 2 studies were made by each of 3 states, resulting in a total of 16 studies. The locations of the studies are given in Table 1. Information concerning the type of mixer used, the coarse aggregate, the nominal mixing times, and the overloads, is given in Table 2.

Data from the studies are presented on the effect of mixing time and overload on the compressive and flexural strengths of concrete. Also reported are determinations intended to show the uniformity (or lack of it) of single batches of concrete, as well as variations from batch to batch of concrete prepared under presumably the same mixing conditions. The types of tests made by the several states are given in Table 3.

Some of the states prepared formal reports at the conclusion of their individual studies, while others supplied test results in an informal manner. The data obtained by all states were so extensive that only a review of them can be included in this paper.

TABLE 1

HIGHWAY CONSTRUCTION PROJECTS IN THE STUDY OF 34-E DUAL-DRUM PAVERS

State	Project Number	Date of Study	Highway Route Number	Location
Alabama	I-65-3 (14) (15)	Oct. 1958	U.S. 31	25 miles north of Birmingham
California	III-Pla-17-A, Roc, B.	July 1959	U.S. 40	Near Roseville
Delaware	F-12 (4) S-US-48 (2)	July 1958	Del. 8	Dover, Division St. and Forrest Ave.
District of Columbia	F-55 (1)	June 1958		Irving St. N.E.
Florida	I-4-1 (2)	July 1958	U.S. 4	Near Plant City
Kansas	F-0 92	Oct. 1958	U.S. 36	Beattie Corner to Nemaha County line
Michigan	I-02-5 (6)	June 1958	U.S. 12	Upsilanti, near Willow Run Airport
Nebraska	F-250 (7)	Oct. 1958	U.S. 77	Wymore to Kansas State line
New York (1)	BT-57-1	Aug. 1958		Near East Chatham 20 miles west of Albany
New York (2)	I-1119 (11)	Oct. 1958		
Ohio (1)	I-196 (5)	June 1958	U.S. 25	Wapakoneta bypass
Ohio (2)	I-529 (11)	Aug. 1958	U.S. 40	Kirkersville bypass
Virginia (1)	F-FG-018-1 (1)	Sept. 1958	U.S. 29	Lynchburg bypass
Virginia (2)	U-101-1 (3)	Oct. 1958	U.S. 29	Arlington County, Lee Highway
Washington	Cont. 5733	Oct. 1958		Olympia
West Virginia	S-2 (4)	Oct. 1958	W.Va. 14	Charleston to airport

TABLE 2

TYPE OF PAVER, AGGREGATE, AND PRINCIPAL VARIABLES USED IN THE 16 STUDY PROJECTS

State	Paver	Coarse Aggregate		Principal Variables	
		Type	Maximum Size	Nominal Mixing Times Used	Overload
			Inches	Seconds	Percent
Alabama	A	Stone	1½	30-50-90	0-10-20
California	B	Gravel	1½	30-50-70	0-10-20
Delaware	A	Stone	2	40-70-90	0-10-20
District of Columbia	A	Gravel	2	30-50-70	0-10-20
Florida	B	Stone	2	30-60-90	0-10-20
Kansas	A	Sand-gravel	1	50-60-70-90	0-10-20
Michigan	A	Slag	2	30-50-70	0-10-20
Nebraska	C	Stone	1	30-50-60-90	0-10-20
New York 1	B	Stone	2	40-50-60-90-120	0-10-12-20
New York 2	B	Crushed gravel	2	60-90-120	10-20
Ohio 1	B	Stone	1½	40-50-75	0-10-20
Ohio 2	A	Gravel		50-75	0-10-20
Virginia 1	B	Stone	2½	30-60-90	0-10-20
Virginia 2	D	Gravel	2½	30-60-90	0-10
Washington	B	Gravel		45-60	10-20
West Virginia	C	Gravel	2	30-40-50-60	0-10

Of particular interest, among data excluded here, were those that would permit comparing the air content of concrete as determined by the Chace air meter and standard pressure or volumetric meters, and comparisons between the results of slump cone and Kelly ball tests. It is expected that these data will be summarized and reported at a future time.

The study was unusual in that it involved considerable effort and cooperation on the part of a number of state highway departments and highway contractors. The skillful handling of difficult field testing operations by the personnel involved, often under un-

TABLE 3

VARIOUS TESTS ON CONCRETE PERFORMED BY THE STATES[1]

State	Tests for Compressive Strength on Cylinders[2]			Tests for Flexural Strength[3]			Tests for Uniformity of Plastic Concrete							
							Washout			Air Content[4]				
	7 days	14 days	28 days	7 days	14 days	28 days	Fine	Coarse	Unit Weight	Pressure	Chace	Slump	Kelly ball	Willis-Hime
Alabama	x	-	x	x	-	x	x	-	x	x	x	x	x	-
California	-	x	-	-	-	-	x	x	-	x	-	-	x	-
Delaware	x	x	x	-	x	-	x	x	x	x	x	x	x	-
District of Columbia	x	x	x	-	x	-	x	x	x	x	x	x	x	x
Florida	x	x	x	x	x	x	-	-	x	x	x	x	x	-
Michigan	-	-	x	-	-	x	x	x	x	-	x	x	x	-
Nebraska	x	-	x	x	-	x	-	x	x	x	x	x	x	-
New York	-	-	-	-	-	-	-	x	x	x	x	x	-	x
Ohio 1	-	-	x	x	x	-	-	x	x	x	x	x	x	-
Ohio 2	-	-	x	x	x	-	-	x	x	x	x	x	x	-
Virginia 1	-	-	x	-	x	-	x	x	x	x	x	x	x	x
Virginia 2	x	x	x	x	-	x	x	x	x	x	x	x	x	x
Washington	-	-	x	-	-	x	-	-	x	-	-	x	x	-
West Virginia	x	x	x	x	x	-	x	x	x	x	x	x	x	-

[1]No information was received from Kansas
[2]Michigan and New York used cores to test compressive strength
[3]The District of Columbia conducted a 3-day test for flexural strength
[4]Alabama and Michigan used the rollermeter method for testing air content

favorable conditions, contributed greatly to the success and value of the study.

PROCEDURE PROBLEMS

In determinations of the mixing time, in this article, the transfer time between drums was not included. It has been stated by some that the concrete is mixed during this transfer process. However, in their reports different states reported different lengths of transfer time, even for the same make of paver, and it was believed that it would simplify the presentation of the material if only the mixing time in the drums was considered. The values reported by the states for mixing times are shown in Table 4.

The original program proposal recommended sampling of every 10th batch for testing. Some states believed that sampling of every 10th batch might be too frequent, and sampled every 20th batch instead. Where the testing staff was limited, this allowed ample time for the test procedures. Some states questioned some of the methods of test proposed, and modified or eliminated them in accordance with their experience or needs. One state cast only a few specimens for strength tests, and drilled cores from the pavement for the strength tests of record. Other differences were found among the individual studies. In general, however, the recommended program was followed sufficiently to permit use of most of the data obtained.

One of the most controversial items in the suggested program was the method of obtaining the three samples of concrete representing a single batch or bucket load. It was recommended originally that three pans be placed on the subgrade, slightly separated to cover the area over which a bucket load of concrete would be distributed. However, some difficulty was found with this method of sampling. When the pans were placed directly on the subgrade, the wave of concrete from the bucket frequently knocked the pans aside. On some projects, to correct this difficulty, the pans were held in

TABLE 4

AVERAGE MIXING TIME, IN SECONDS, AS GIVEN BY THOSE STATES WHERE MIXING AND TRANSFER TIMES WERE RECORDED[1]

State	Nominal Mixing Time	No Overload		10 Percent Overload		20 Percent Overload		Average Actual Mixing Time
		Transfer Time	Actual Mixing Time	Transfer Time	Actual Mixing Time	Transfer Time	Actual Mixing Time	
Alabama	30	11	30	15	30	11	29	30
	50	11	49	11	49	11	49	49
	90	11	79	11	75	11	79	78
California	30	10	21	10	23	10	24	23
	50	10	40	10	39	10	38	39
	70	10	60	10	60	10	60	60
Delaware	40	9	41	9	41	9	41	41
	70	9	70	9	70	9	70	70
	90	9	90	9	90	9	90	90
District of Columbia	30	12	29	12	30	12	30	30
	50	12	45	12	45	12	50	47
	70	12	70	12	70	12	69	70
Kansas	50	10	39	10	54	10	51	48
	60	10	60	10	57	10	53	57
	70	10	60	10	62	10	61	61
	90	10	75	10	76	10	77	76
Ohio 1	40	8	41	9	43	8	42	42
	50	8	51	9	54	9	51	52
	75	9	66	9	66	9	65	66
Ohio 2	50	10	50	10	50	12	49	50
	75	10	65	10	65	12	64	65
Virginia 1	30	-	27	-	28	-	28	28
	60	-	58	-	60	-	60	59
	90	-	89	-	87	-	90	89
Virginia 2	30	-	29	-	36	-	-	32
	60	-	58	-	63	-	-	60
	90	-	93	-	96	-	-	94

[1]Florida (30, 60, 90 sec), Michigan (30, 50, 70 sec), Nebraska (30, 50, 60, 90 sec), and West Virginia (30, 40, 50, 60 sec) did not include transfer time in mixing times stated. New York included a transfer time of 9 sec in mixing times of 40, 50, 60, 90 and 120 sec. No information of transfer time was furnished by Washington (45, 60 sec).

place by concrete shoveled against their sides. Another method found to be effective was mounting the pans on legs about 12 in. high (Fig. 1).

Some states adopted the practice of having the bucket load dumped on the subgrade either in a ribbon or in an oval-shaped pile. Samples possibly representing different sections of the bucket-load were then taken from the concrete. At first it was questionable whether the samples so obtained could be considered to represent the first, middle, and last third of the concrete batch discharged from the mixer. However, it was pointed out that the first one-third of the concrete discharged from the bucket might not be the same as the first third of the concrete discharged from the mixer. Due to restraint of the sides of the bucket, the first one-third of concrete discharged from the bucket may include some of the second one-third of the concrete discharged into the bucket. For this reason, no consideration was given in this report to differences between the methods used to obtain these one-third-bucket-load samples. Although such differences existed, it may be considered that the collective samples for each mixing time and overload are reasonably representative of the entire mixing load.

EFFECT OF MIXING TIME ON STRENGTH

As shown in Table 2, the states used widely different nominal mixing times, and some differences in overloads. There also was a variance in the materials used and in the methods of testing compressive and flexural strengths. To place each set of data on a uniform basis for comparison, the strength obtained for a 60-sec mixing time, or with no overload, was adopted as the standard of comparison. Strengths obtained for other mixing times, or for overloads, were then compared with these values.

In six of the studies, a 60-sec mixing time was not used. To permit comparison of the data obtained with those for the other projects, the determined strengths were plotted against mixing time and a curve drawn through the points. The value shown on this curve at intersection with the 60-sec abscissa was taken as the base measure.

To keep the reporting of data concerning mixing time within reasonable bounds, some liberties have been taken in their presentation. The mixing times are shown at 5-sec intervals, and a value for strength obtained with an acutal mixing time of 48 sec, for example, is shown for 50 sec. However, if there was only one determination of strength of concrete for a given time of mixing, this was not shown in the charts. In many instances the elimination of these single values removed wild results and showed to better advantage the trend of the remaining mutually supporting data.

Data reported by each state of the effect of mixing time on the compressive and flexural strength of concrete are shown in Figures 2 and 3. The varying strengths reflect the materials used and the methods of testing employed. Some states used cantilever beam testing machines and obtained flexural strengths much higher than those using center-point loading.

Data averaged for all of the studies to show the effect of mixing time on the compressive strength are plotted in Figure 4. The curve in each portion of the figure presents the best considered average. In the lowest portion of the figure, the curve represents an average of the other three curves. Similar curves for flexural strength are shown in Figure 5.

The same finding (that the compressive and flexural strengths of concrete prepared with the mixers and materials used were at a maximum for a mixing time of 60 sec) is evident in Figures 4 and 5. Marked increase or decrease in mixing time resulted in a reduction in strength, but this reduction was of no great moment. For a mixing time of only 30 sec the compressive strength was reduced only 6 percent and the flexural strength only 5 percent. For a mixing time of 90 sec the compressive strength was reduced only 7 percent and the flexural strength only 3 percent. A reduction in mixing time to 50 sec caused a reduction in compressive strength of about 0.5 percent and no decrease in flexural strength.

Figures 6 and 7 present the effect of overload on the compressive and flexural strengths of the samples tested. The curve representing the average for all determinations of compressive strength shows that a decrease of 5 percent in strength resulted for an overload of 10 percent. For a 20 percent overload, a decrease in strength of

Figure 1. One of the methods used in obtaining sample concrete.

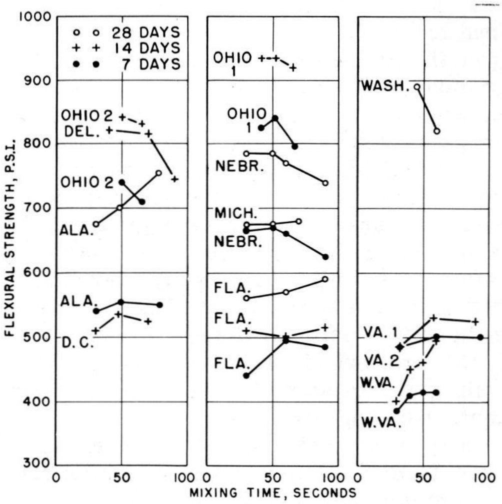

Figure 3. Effect of mixing time on flexural strength, by state.

only 1 percent resulted. In the flexural strength determinations, overloads of 10 and 20 percent each caused a reduction in strength of only 2 percent.

Some inquiry has been made of the reason for the lower compressive strength of concrete prepared with an overload of 10 percent than with an overload of 20 percent. It was speculated that the greater overload caused the drum to operate more efficiently; however, if this were the reason a mixer with an overload of 10 percent would be expected to operate more efficiently than one with no overload. Such was not found to be the case if strength tests of concrete are used to judge the efficiency

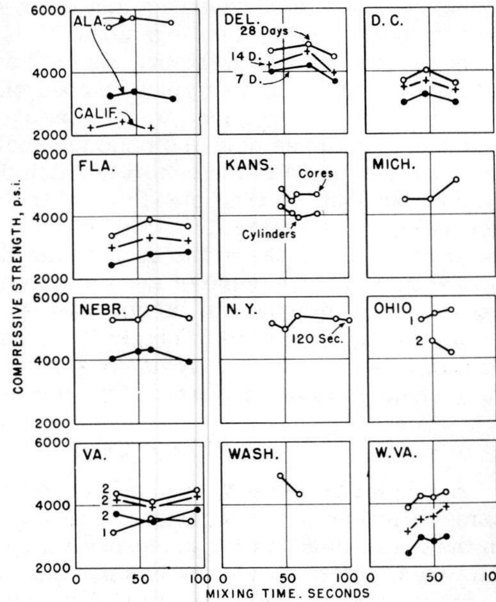

Figure 2. Effect of mixing time on compressive strength, by state.

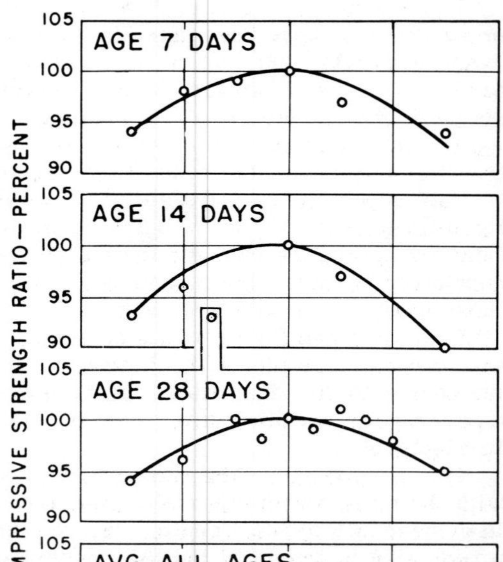

Figure 4. Average effect of mixing time on compressive strength.

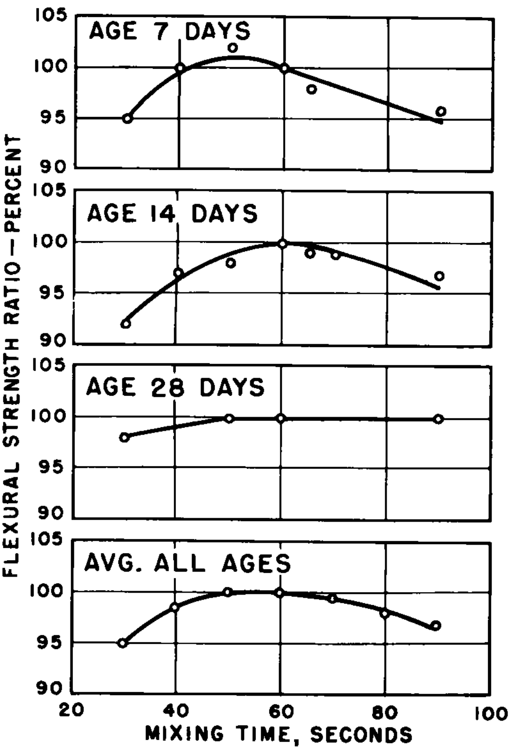

Figure 5. Average effect of mixing time on flexural strength.

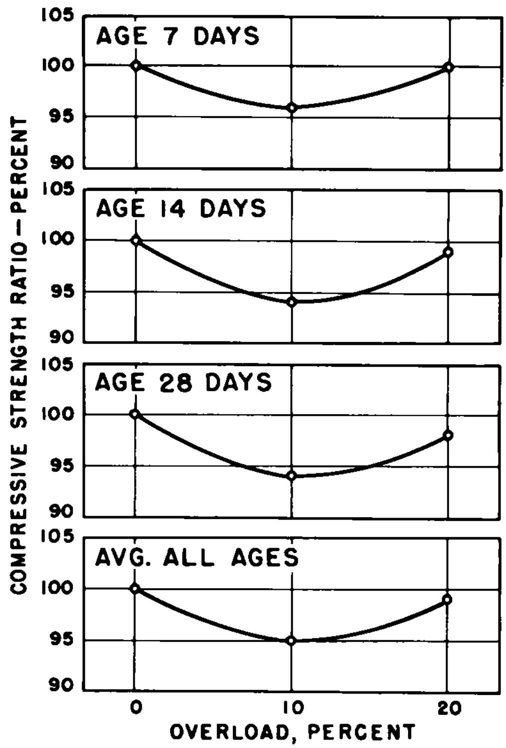

Figure 6. Average effect of overload on compressive strength.

or rather the effectiveness of a mixer. Some other reason must apply to these test results.

Most specimens were prepared, cured and tested in accordance with standard ASTM methods. No concern need be given to this phase of each investigation, as the data were apparently affected but little by variations in the preparation of specimens. With this accepted, it may be assumed that variations in the strength of the concrete are due to the mixing procedures used, or the weather conditions over which there was no control.

Further study was given to the effect of overload on the compressive strength of concrete, reported in Table 5. It was observed that in Florida the strength for no overload was considerably higher than that for 10 percent overload at all ages and for 20 percent overload at an age of 7 days. It was believed that a detailed study of the results from this state might be warranted. It was also noted that in the Virginia No. 2 study and in the West Virginia study the results for a 10 percent overload ranged from slightly lower to considerably lower than for no overload, and that no tests were made for an overload of 20 percent. It was believed that these results might have influenced the general average to an unwarranted extent and that they might well be excluded from consideration.

To examine more carefully the results of the Florida tests, the compressive strengths obtained for each combination of mixing time and overload were plotted against age at test. It was believed that if there had been any unusual features affecting the test results, these would be shown by some exceptional behavior in rate of gain of strength. As shown in Figure 8, all of the Florida tests made for concrete prepared with 90-sec mixing time produced an unusual behavior in rate of gain of strength. In two of the three cases, the strength at an age of 14 days was lower than that at 7 days. In the third case, the strength at 7 days appears to be quite low and that at 14 days somewhat high.

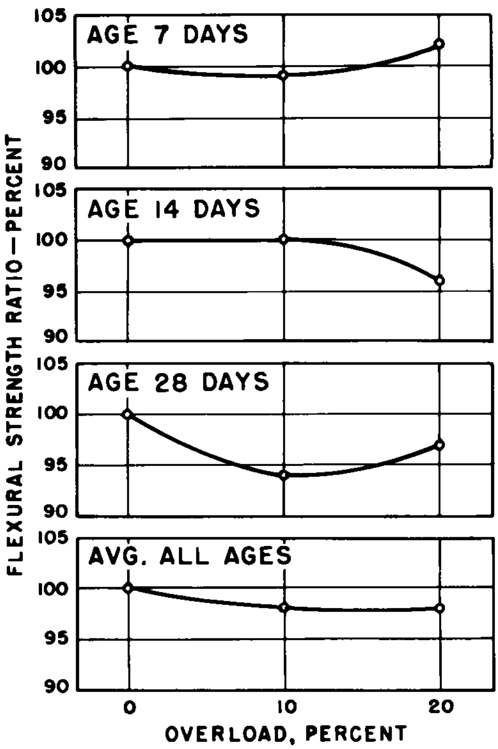

Figure 7. Average effect of overload on flexural strength.

Why these results had this unusual behavior is not known, but there is indication that they were caused by some feature other than the variables of record and it is believed that these results may justifiably be excluded from consideration. Consequently, in consideration of the effect of overload on compressive strength, all three sets of specimens mixed for 90 sec in Florida were rejected.

Figure 9 presents revised trends of the effect of overload on compressive strength with the questionable and incomplete data excluded. Even with these data excluded, it was found that the strength for an overload of 10 percent was slightly lower than that for an overload of 20 percent, and both overloads furnished less strength than no overload. The maximum amount of reduction in strength is only 4 percent which in view of the more rapid production of concrete gained by overloading, may be considered of minor consequence.

In the tests to determine the effect of overload on flexural strength, certain test specimens yielded irregular results, as shown in Table 6 and Figure 10. In no case however, were all specimens for a given time of mixing involved, and all data

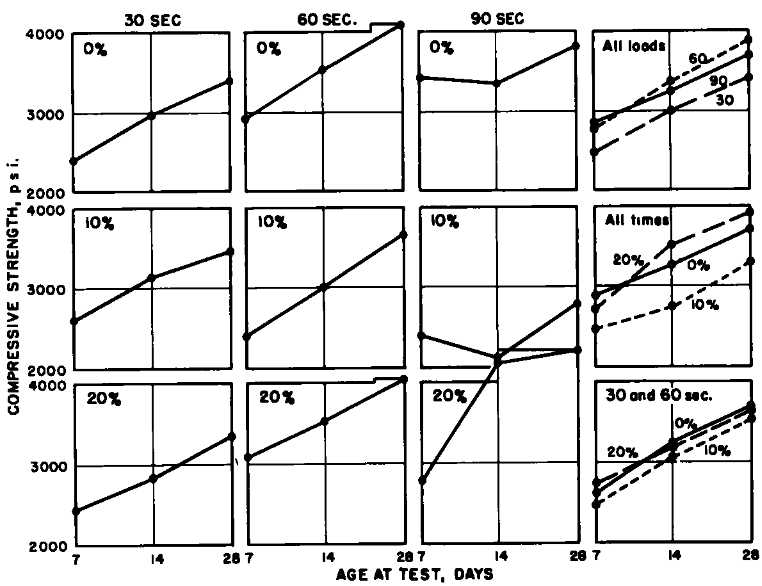

Figure 8. Compressive strength for each set of variables using Florida test data.

TABLE 5

EFFECT OF OVERLOAD ON COMPRESSIVE STRENGTH

State	Tests at 7 Days for Unit Compressive Strength					Tests at 14 Days for Unit Compressive Strength					Tests at 28 Days for Unit Compressive Strength				
		10 Percent Overload		20 Percent Overload			10 Percent Overload		20 Percent Overload			10 Percent Overload		20 Percent Overload	
	No Overload (psi)	Strength (psi)	Strength Ratio[1]	Strength (psi)	Strength Ratio[1]	No Overload (psi)	Strength (psi)	Strength Ratio[1]	Strength (psi)	Strength Ratio[1]	No Overload (psi)	Strength (psi)	Strength Ratio[1]	Strength (psi)	Strength Ratio[1]
Alabama	2,890	2,950	102	3,320	115	-	-	-	-	-	5,720	5,260	92	5,740	100
California	-	-	-	-	-	2,300	2,240	97	2,130	93	-	-	-	-	-
Delaware	4,010	4,020	100	3,760	94	4,280	4,310	101	4,120	96	4,730	4,640	98	4,550	96
District of Columbia	3,140	3,130	100	2,950	94	3,580	3,560	99	3,380	94	3,880	3,800	98	3,660	94
Florida	2,920	2,470	85	2,760	95	3,290	2,750	84	3,560	108	3,760	3,360	88	3,940	105
Kansas[2]	-	-	-	-	-	-	-	-	-	-	4,560	3,620	80	4,150	91
Michigan	-	-	-	-	-	-	-	-	-	-	4,630	4,920	106	4,610	100
Nebraska	4,160	4,000	96	4,320	104	-	-	-	-	-	5,560	5,390	97	5,300	95
Ohio 1	-	-	-	-	-	-	-	-	-	-	5,370	5,440	101	5,450	101
Ohio 2	-	-	-	-	-	-	-	-	-	-	4,300	4,050	94	4,790	111
Virginia 1	-	-	-	-	-	-	-	-	-	-	3,620	3,330	92	3,240	90
Virginia 2	3,740	3,690	99	-	-	4,260	3,990	94	-	-	4,440	4,170	94	-	-
Washington	-	-	-	-	-	-	-	-	-	-	-	4,630	-	4,660	-
West Virginia	2,940	2,560	87	-	-	3,640	3,410	94	-	-	4,240	4,100	97	-	-
Average	-	-	96	-	100	-	-	95	-	98	-	-	94	-	98

[1] Ratio to strength for no overload

[2] Kansas tested cores at 28 days with the following results No overload, 5,030 psi, 10 percent overload, 4,430 psi, 20 percent overload, 4,530 psi

TABLE 6

EFFECT OF OVERLOAD ON FLEXURAL STRENGTH

State[1]	Tests at 7 Days for Unit Flexural Strength					Tests at 14 Days for Unit Flexural Strength					Tests at 28 Days for Unit Flexural Strength				
		10 Percent Overload		20 Percent Overload			10 Percent Overload		20 Percent Overload			10 Percent Overload		20 Percent Overload	
	No Overload (psi)	Strength (psi)	Strength Ratio[2]	Strength (psi)	Strength Ratio[2]	No Overload (psi)	Strength (psi)	Strength Ratio[2]	Strength (psi)	Strength Ratio[2]	No Overload (psi)	Strength (psi)	Strength Ratio[2]	Strength (psi)	Strength Ratio[2]
Alabama	515	550	107	575	112	-	-	-	-	-	785	640	82	710	90
Delaware	-	-	-	-	-	795	820	103	760	96	-	-	-	-	-
District of Columbia	-	-	-	-	-	545	530	97	500	92	-	-	-	-	-
Florida	470	490	104	460	98	525	515	98	480	91	555	595	107	575	104
Kansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Michigan	-	-	-	-	-	-	-	-	-	-	680	665	98	680	100
Nebraska	680	640	94	640	94	-	-	-	-	-	810	735	90	765	94
New York	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ohio 1	825	800	97	835	101	955	875	92	960	101	-	-	-	-	-
Ohio 2	720	730	101	730	101	840	845	101	820	98	-	-	-	-	-
Virginia 1	-	-	-	-	-	515	520	101	505	98	-	-	-	-	-
Virginia 2	505	485	96	-	-	-	-	-	-	-	-	-	-	-	-
Washington	-	-	-	-	-	-	-	-	-	-	-	865	-	845	-
West Virginia	415	400	96	-	-	430	470	109	-	-	-	-	-	-	-
Average[3]	-	-	99	-	102	-	-	100	-	96	-	-	94	-	97

[1] California Kansas, and New York reported no tests for flexural strength

[2] Ratio to strength for no overload

[3] The average ratio to strength for no overload at all ages was 98 for both 10 and 20 percent overload

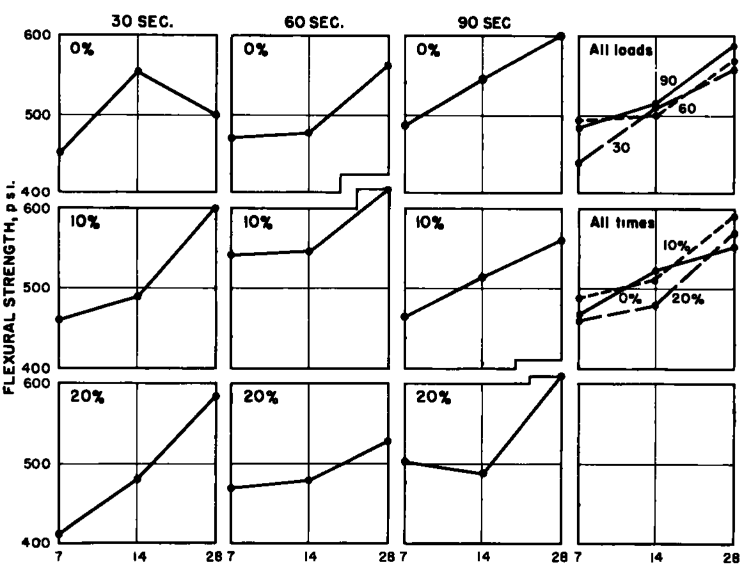

Figure 9. Average effect of overload on compressive strength excluding questionable and incomplete data.

obtained were used to determine average trends for all of the studies.

EFFECT OF MAKE OF PAVER

It was hoped that sufficient data could be obtained from the projects using the same make of paver to determine whether that make of paver processed concrete in a manner sufficiently different from the other pavers to warrant comment. It was considered desirable to limit the data used to that representing two or more projects and four mixing times.

The results obtained for a single make of paver showing the effect of mixing time on strength are shown in Figure 11. By comparison with Figures 4 and 5, it will be seen that there is little differences between the curves for this single make of mixer and the curves for all makes over the range of 50- to 70-sec mixing time. It is probable that more difference in effectiveness of mixing will be found between individual mixers of any make than between groups of mixers of different makes. In two of these studies the mixers used were found, on initial inspection, to contain a considerable amount of hardened concrete. Removal of this concrete unquestionably improved the effectiveness of the mixers.

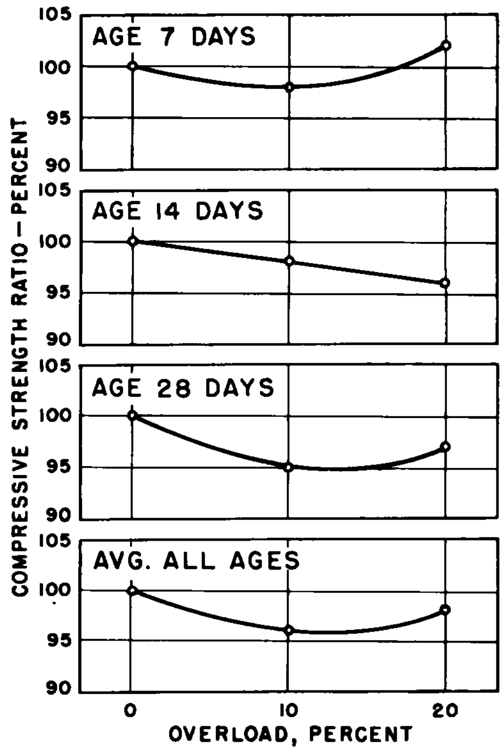

Figure 10. Flexural strengths for each set of variables.

TESTS FOR UNIFORMITY OF PLASTIC CONCRETE

It would be expected that insufficient mixing would be evidenced by marked differences in the results of tests of the three portions of a bucket of concrete, possibly by a greater than normal weight per cubic foot, and by low air content. Excessive mixing would be expected to be detected by excessive fines in the concrete, and possibly by a low air content.

Almost all of the states made and reported test determinations which were intended to be used to show the uniformity of the plastic concrete. These tests included determinations of the cement content by the Willis-Hime and Dunagan methods, washout tests for fine or coarse aggregates, tests for unit weight of concrete, tests for consistency using the slump cone and Kelly ball methods, and pressure, volumetric, and Chace tests, for air content.

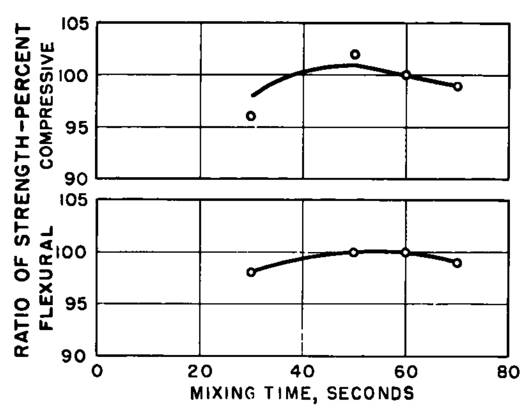

Figure 11. Effect of mixing time on strength, determined from one make of paver.

The data furnished by the states were studied, and a selection of these data was made to determine the uniformity of the concrete produced with the various mixing times and overloads. For ease in presentation and comparison, these data are shown in Figures 12-20. In each figure, sample data reflecting various characteristics of the concrete are shown with reference to individual combinations of mxing time and overload. Data for the first one-third of the bucket load of concrete are indicated by a circle; for the second third, the data are indicated by a cross; and for the last third, by a triangle. The solid lines in the figures connect the average value for a bucket load.

Generally, the data plotted for each one-third portion is an average taken from three loads of concrete. These loads, obtained from different batches and on different days, could have been influenced by changing weather conditions, characteristics of the materials used, or by the personal equation of the operators. However, the sample loads indicate a general trend which may be considered adequate for this study and are not intended to cover all minute details which might influence such determinations.

For most of the reporting states, data covering tests for unit weight, washout, and air content were available. In the other states, data for slump were available.

Unit Weight

A marked variation in unit weight of concrete for a single batch of concrete or for several batches mixed under the same conditions would indicate either a harsh concrete or insufficient mixing. If a marked variation was found, and the same one-third portion generally had the greatest or least weight of the samples representing the same bucket load, it was assumed that the mixer was not operating properly and was furnishing undermixed concrete. For a given combination of aggregates, high unit weights, closely grouped, indicated well-mixed concrete.

General trends for all data from short to long mixing times were also of interest. If the trend appeared toward greater weight, an improvement in mixing was assumed. If the trend was toward lesser weight, this was taken to indicate overmixing and reduction in size of the aggregate.

Washout

The results of the washout tests were shown by several different methods. In some cases, the states determined and reported the amount of fine aggregate in the concrete or the grading and fineness modulus of the aggregate. In others, the amount of coarse aggregate was determined. Some states reported the grading of all aggregate, and choice had to be made as to which data would give the most information.

The results of these tests were expected to determine if extended mixing of concrete would abrade the aggregate to a marked extent. This could be demonstrated if there was a decrease in the fineness modulus of the fine aggregate, or an increase in the amount of fine aggregate and decrease in the amount of coarse aggregate. Undermixing of the concrete was indicated by the nonuniformity of the distribution of aggregate in the three portions of a bucket load.

Air Content

The air content of the concrete was determined by use of pressure or volumetric methods, including the Chace air meter test as one of the latter methods. When available, data obtained with a pressure meter, or a volumetric method using a large sample of concrete, were preferred over data obtained with the Chace air meter.

The air content of air-entrained concrete was believed to be an excellent indication of the thoroughness of mixing the concrete. Insufficient mixing would be indicated by low amounts of air and by variation of the amounts of air between portions of a batch. With excessive mixing, it was believed that some of the air would be lost, but in this case the air in each portion of a batch would be practically constant.

Slump

The slump is a measure of the workability of concrete. A concrete can have a high water-cement ratio and at the same time have a low slump due to harshness of the mix.

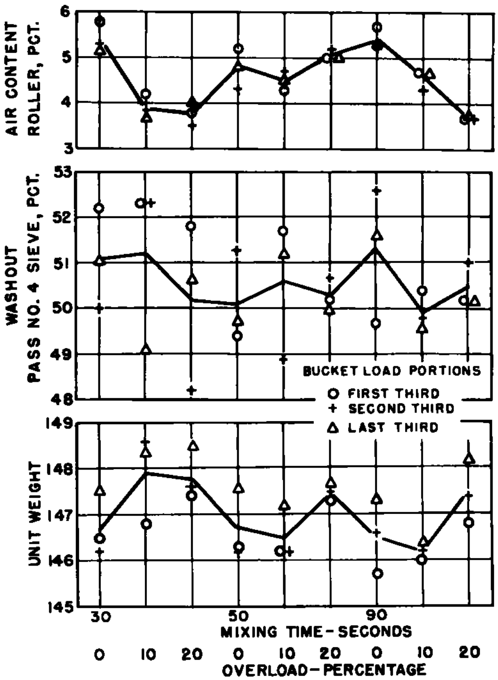

Figure 12. Test determinations on uniformity of concrete in the Alabama project.

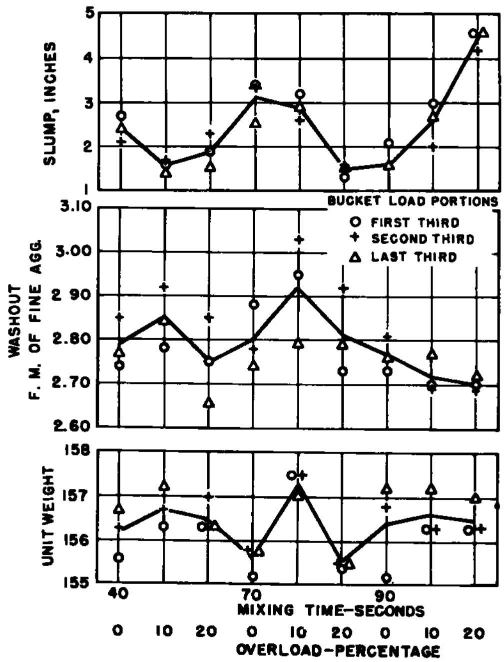

Figure 13. Test determinations on uniformity of concrete in the Delaware project.

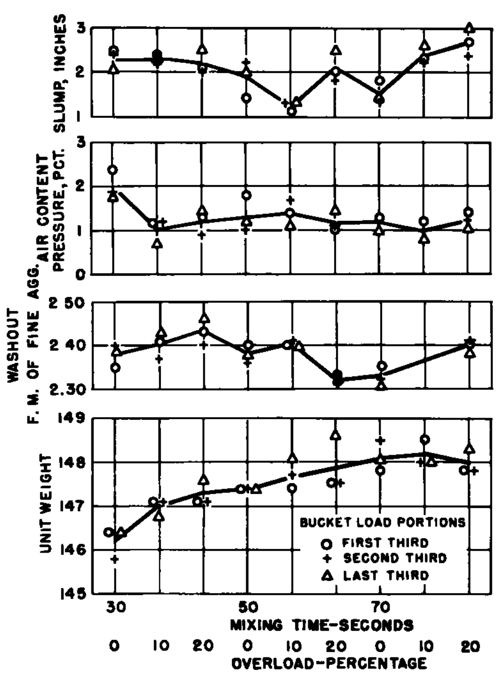

Figure 14. Test determinations on uniformity of concrete in the District of Columbia project.

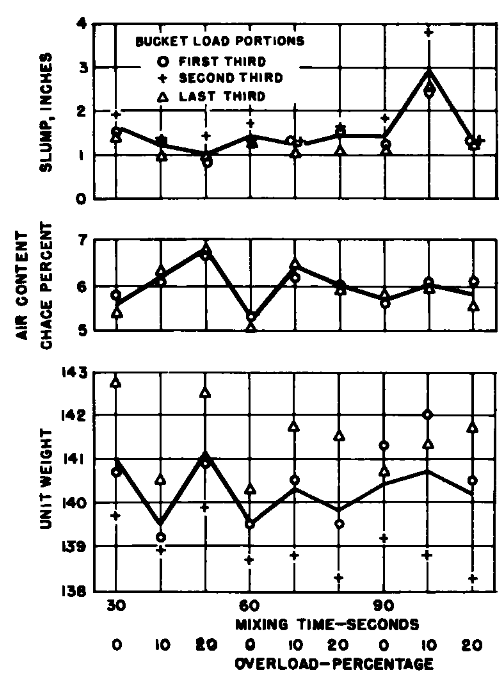

Figure 15. Test determinations on uniformity of concrete in the Florida project.

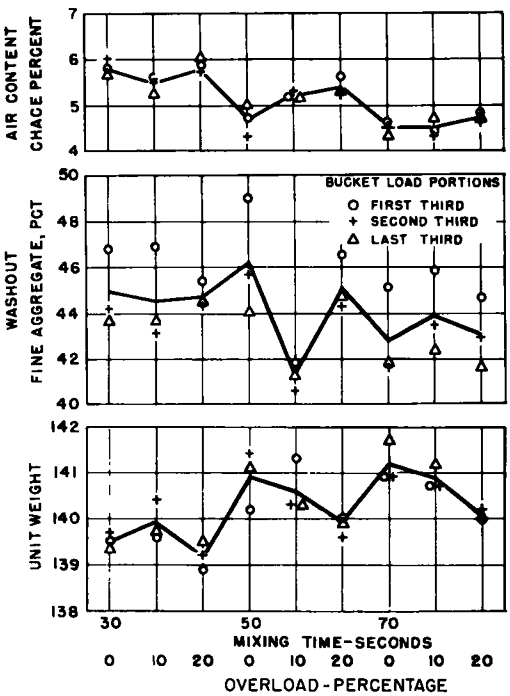

Figure 16. Test determinations on uniformity of concrete in the Michigan project.

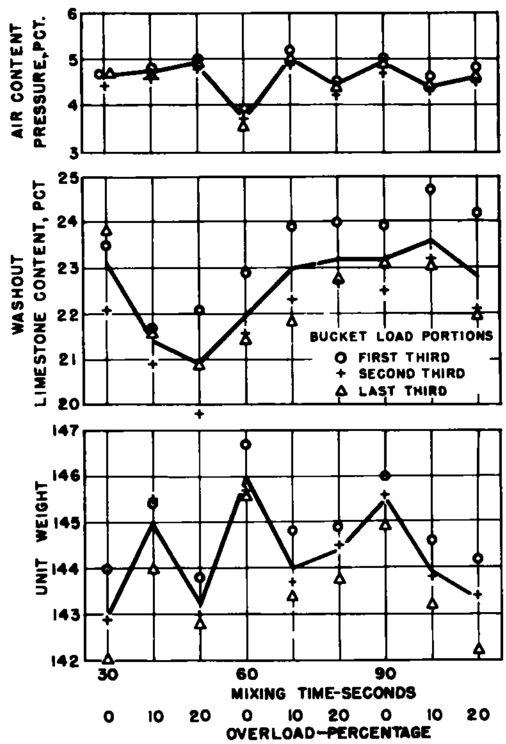

Figure 17. Test determinations on uniformity of concrete in the Nebraska project.

In very few instances were the concretes produced in these studies found to have poor workability, and it is believed that these cases can be ignored. The slump can be used with other data to deduce whether thoroughness of mixing was obtained.

Other Determinations

Other determinations made on portions of a bucket load of concrete included the Willis-Hime test (1) for the cement content of concrete, and the Dunagan method (2) for determining the composition of concrete. The Willis-Hime test, made by the District of Columbia, New York and Virginia, yielded disappointing results in that they differed greatly from the known cement content. It was found that the principal reason for the results obtained was failure to dry the samples sufficiently. Because all of the water was not driven off, the cement grains still retained water and were not separated from the sand portion of the mortar during the centrifuging operation. This resulted in a test determination showing a low cement content of the concrete.

The District of Columbia made determinations of the composition of the fresh concrete using the Dunagan method. The results varied tremendously and indicated variations within and between batches of concrete which were beyond the realm of the possibility. Without doubt, some feature was overlooked in the performance of these tests which resulted in inappropriate test data.

REVIEW OF UNIFORMITY BY STATES

A review of the data for some of the individual state projects was made to determine information of interest with respect to uniformity of concrete. Such information is presented in the following:

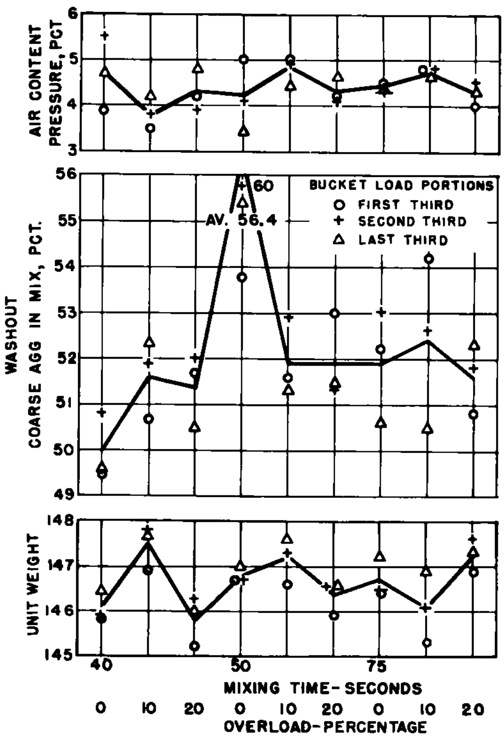

Figure 18. Test determinations on uniformity of concrete in Ohio project No. 1.

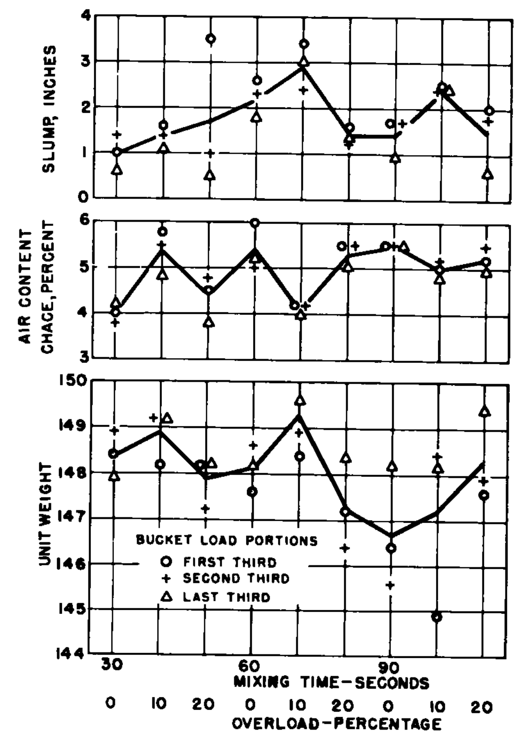

Figure 19. Test determinations on uniformity of concrete in Virginia project No. 1.

Alabama

The results from the Alabama project (Fig. 12) showed a slight over-all decrease in unit weight with increase in mixing time. With an overload of 20 percent, however, higher weights were obtained for each mixing time than for no overload. In 8 of the 9 combinations of mixing time and overload, the last portion of the concrete discharged by the bucket had the greatest weight. These facts collectively were assumed to indicate that the mixer was not operating to best advantage, and that an overload of 20 percent was an aid in obtaining better mixing of the concrete.

Determinations of the material passing the No. 4 sieve in the washout test showed some wide variations within a bucket load of concrete—especially for the 30-sec mixing time. Each of the loads had an equal amount of sand, or more in the first one-third of the bucket load than in the second or last third portions. These variations indicated an insufficient mixing for a 30-sec period. The general trend for all washout test results showed no increase in amount of fine aggregate with increase in mixing time and overload. This would indicate that even for a 90-sec mixing time, there was no more abrasion of aggregates than for shorter periods of mixing time.

The air content tests, using a volumetric method, produced uniform values for the different portions of a bucket load. In two of the three mixing times, increase in loading resulted in a reduction in the amount of air. The air contents for a 30-sec mixing time with no overload and with 20 percent overload were the same as those for the same loads at a 90-sec mixing time. It would appear from these results that a 30-sec mixing time is sufficient to obtain well-mixed concrete, and that further mixing is of little value.

Delaware

Data from the study in Delaware (Fig. 13) showed no over-all trend for unit weight except for a higher weight for each mixing time with a 10 percent overload. In 7 of the 9 cases, the weight of the last portion from the bucket was equal to or greater than that of other portions. This indicated that a greater percentage of stone was present in the last portion and further suggested that the mixer was not functioning properly.

In the washout tests, the high value of fineness modulus of sand for the 70-sec mixing time with a 10 percent overload was matched by a similar high value for unit weight. These values were considered as sports, representing a nonuniform condition such as the use of unusually coarse sand. The other values for the washout tests showed no unusual features other than the prevalence of coarser sand from the center of the bucket load and the progressive decrease in fineness modulus for the 90-sec mixing time.

The progressive increase in fineness of the fine aggregate was almost matched by an increase in the slump of the concrete for the batches involved. Althougth data for the water content of the concrete were not immediately available, the variations in the values of slump were related to the variations in the unit weight values or the fineness modulus of the fine aggregate. Where an increase or decrease in slump occurred a decrease or increase in unit weight was found or an increase or decrease in the fineness modulus of the sand occurred. Considering all values given, the previously mentioned failure of the mixer to furnish well-mixed concrete must be repeated. It appeared that extended mixing of the concrete did abrade the aggregate to some extent. It was also found that the first sample taken from each bucket load generally had a lower-than-average unit weight, a finer-than-average sand, and a higher-than-average slump.

District of Columbia

The results obtained in the District of Columbia study (Fig. 14) were unique in showing an increase in unit weight for each increase in mixing time and overload except for the 20 percent overload at 70-sec mixing time. No corresponding trends were developed in the data for fineness modulus of fine aggregate, air content, or slump. It appeared that the uniformity of concrete was improved by increase in mixing time and load, the additional overload serving to promote the mixing action.

Florida

The results obtained in the Florida study (Fig. 15) in some respects were quite unusual. Except for one nonconforming group of data, uniform results were obtained for the slump of concrete. The tests for air content made by the Chace method, also produced one sport, but otherwise the variations were insignificant. Neither set of data can be used to explain variations found in the tests for unit weight. In the concretes mixed for 60 and 90 sec, those with a 10 percent overload

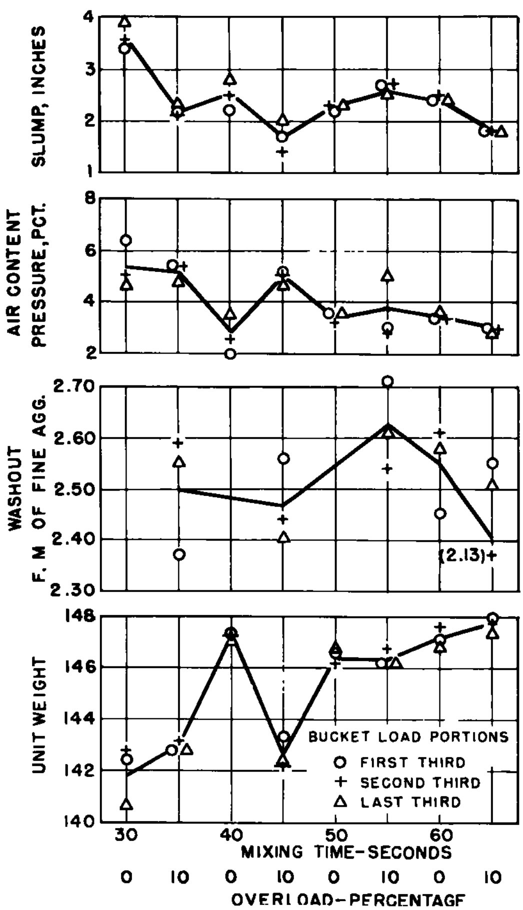

Figure 20. Test determinations on uniformity of concrete in the West Virginia project.

had slightly greater average weights than those with no overload or 20 percent overload; whereas in the concretes mixed for 30 sec, those with a 10 percent overload had the least weight.

In view of the marked variation in unit weight for the separate portions of all batches of concrete, and the fact that the last portion of each bucket load had the greatest weight in 7 of the 9 combinations of mixing time and overload, it appeared that the concrete mix was harsh and failed to respond adequately to increases in mixing time. A possible exception to this may be shown by the low slump. With a slump averaging only 1¼ in., more variation in unit weight must be tolerated within a batch than for higher slump concrete.

Michigan

Data results obtained in the Michigan study (Fig. 16) in which slag was used as the coarse aggregate, reflected in some respects the opinion that slag concrete is usually somewhat harsh. However, similar behavior was detected in data from other projects in which gravel was used.

In the tests for unit weight, an increase in time of mixing was accompanied by an increase in the weight of the concrete. In the concretes mixed for 50 or 70 sec, increase in overload resulted in a decrease in the unit weight, and in the concretes mixed for 30 sec, those with a 20 percent overload had lower weights than those with no overload. These data indicate that an increase in mixing time and elimination of overload may furnish more uniformly mixed concrete for the particular mixer and concrete used in this project.

The washout tests showed a slight decrease in the amount of fine aggregate with an increase in mixing time and overload. The results of the air content tests showed a reduction in the amount of air with increase in mixing time and overload. This could mean that a 30-sec mixing period was sufficient to develop maximum air content in the concrete, and that longer mixing periods permitted some of the air to be lost. It is noted that the data for air content and unit weight are associated. An increase of air content was associated with a decrease in weight, and selection of a most desirable set of mixing conditions definitely does not result in these determinations.

Nebraska

For the study in Nebraska (Fig. 17), the aggregate used was a mixture of sand-gravel and limestone. In conducting the washout tests, one determination made was the amount of crushed limestone found in the mixed concrete.

The tests for unit weight of concrete indicated some large variations both within and among batches. The general trend of these data indicated a slightly higher unit weight for concrete mixed for 60 sec than for the other concretes included in the study. In 8 of the 9 combinations, the heavier concrete was found in the first portion of a bucket load, indicating that more large aggregate was contained in this portion than in the second or third portions. No relation between unit weight and air content results were found except for one batch mixed for 60 sec with no overload. This concrete had the highest unit weight as well as the lowest air content.

The Nebraska report stated that a visual inspection of all test batches used did not disclose any poorly mixed concrete. This is of considerable importance as it may indicate that the variations shown in Figure 17 may be of no significance with respect to concrete placed on the roadway.

Ohio Project No. 1

In the first of the two studies conducted in Ohio (Fig. 18), marked variations in unit weight were found, but the data showed no trends which could be associated directly with amount of mixing time or overload. The amount of coarse aggregate recovered from the concrete in the washout tests appeared irregular for the 40-sec mixing time, and one group of results for the 50-sec mixing time indicated a temporary lack of control at the batching plant. However, the results found for air content appeared to be quite uniform.

It was reported that inspection of the concrete as it was placed on the subgrade revealed only a few batches on which question might be raised regarding uniformity of mixing. Possibly uniformity in grading of the coarse aggregate and in batching the materials were of equal importance to the performance of the mixer.

Virginia Project No. 1

It was reported for Virginia project No. 1 that the concrete was harsh and difficult to finish but this was corrected during the study. However, some of the variations of the data shown (Fig. 19) may have been caused by this condition. Consequently, only a few comments on these data may be warranted.

It is interesting to note that the unit weight of the 30-sec concrete was reasonably uniform, and that greater variations within batches were found for concrete mixed for 90 sec. On the other hand, the air content for the 30-sec concrete varied more from batch to batch than for the 90-sec concrete. In the slump tests, the concrete mixed for 30 sec with a 20 percent overload had a wide range between portions of the bucket load, but this could have resulted from use of the harsh concrete.

West Virginia

The study in West Virginia (Fig. 20) was hampered by cold weather and therefore some of the washout tests were not made. The notable variations in unit weight were in close agreement with corresponding variations in air content and slump. In general, the concrete mixed for 50 or 60 sec was more uniform among batches than the concrete mixed for shorter periods, whereas very uniform concrete throughout a bucket load was found for all mixing times.

CONCLUSIONS

The data obtained by the states were so extensive that only a considerable condensed review can be included in this paper. Based on a painstaking study of all material reported, the following conclusions have been drawn.

The results of strength tests included in this investigation showed that for 34-E dual-drum pavers, the greatest strength was obtained with a mixing time of 60 sec, not including transfer time between drums. This mixing time could be reduced to 40 sec, exclusive of transfer time, with but very little reduction in the strength of the concrete. Reduction of the mixing time to 30 sec, exclusive of transfer time, caused a reduction in strength of 5 to 6 percent. Concrete mixed for 30 sec occasionally showed segregation but generally could be placed and finished without difficulty. In some studies it was found desirable to increase the water-cement ratio slightly for concrete mixed for only 30 sec.

A mixing time of more than 60 sec, exclusive of transfer time, was found to be undesirable, because it involved waste of effort and resulted in loss of strength without gain in the uniformity of the concrete. Little evidence of excessive abrasion of the aggregate was noted, however, even with mixing times as long as 90 sec.

Overloading of 34-E dual-drum pavers above their rated capacity caused a reduction in strength of 1 to 2 percent for an overload of 20 percent, and a reduction of 2 to 4 percent for an overload of 10 percent. The greater reduction for the smaller overload may have been fallacious, or it may have been possible that the mixers used in these tests actually performed better with a greater load. Data to clarify this point were not available.

In studies of the uniformity of concrete produced by 34-E dual-drum pavers, it was found that the quality of concrete depended on the operations preceding the paver mixing operation. If a harsh mix was fed to the paver, extended mixing time still furnished a harsh concrete. If a properly sized and proportioned mix was used, most, if not all, of the mixers studied in this investigation furnished well mixed concrete after only 30 sec of mixing.

It should be noted that some contractors objected to an overload of more than 10 percent on the grounds that their equipment would not handle it. Also, some contractors were not able to use a mixing time shorter than 50 sec, due to their inability to supply materials to the paver.

In general, it is believed that the results of the strength tests of concrete were more indicative of the effectiveness of the mixers used than were the results of tests for uniformity of concrete. The tests made for the latter purpose were of considerable value, but if studies of this type should be conducted in the future, a marked increase in the number of tests for compressive strength would be recommended, with elimination of the flexural strength tests and a reduction in the tests for uniformity. If it could be devised, a test for cement content in the mixed concrete which could be made in entirety on the project would be recommended, with another test for water content of the concrete.

REFERENCES

1. "Cement Content of Freshly Mixed Concrete." ASTM Bull. 239, pp.48-49 (July 1959).
2. Dunagan, W. M., "Method of Determining the Constituents of Fresh Concrete." Proc., Am. Conc. Inst., 26:202-210 (1930).

Cost vs Mixing Time on Dual-Drum Paving

MORGAN J. KILPATRICK, Chief, Construction Economy Branch, Highway Needs and Economy Division, U.S. Bureau of Public Roads

Many paving contractors can consistently produce portland cement with controlled mixing time in the range of 35 to 45 sec. The increased tempo required for operating a paver with a short cycle and the consequent short mixing times has been achieved in part through use of larger and faster batch trucks having greatly improved stability during batch dumping operations at the skip. Another essential element in achieving increased production has been the contractor's demonstrated awareness of the importance of eliminating unnecessary time losses which eat up valuable production time. Technological advancements in supporting equipment have helped to maintain the stepped-up pace.

Savings ranging from 10 cents to $3.08 a cubic yard are indicated if all mixing time specifications are reduced to 45 sec. Below 45 sec the savings are less than 10 cents per cu yd for each 5-sec reduction. Quality, of course, is an important consideration in dealing with mixing time problems.

●THE KEY to high-speed paver performance centers around the ability of the paver operator to run a short skip cycle, the batch truck driver to dump his batches into the skip on schedule, and to a lesser degree on the coordination between these and other operations in front of and behind the paver. Careless or sluggish performance by either the paver operator or the batch truck driver which results in delays can effectively stifle the orderly flow of material as well as disrupt both supporting and dependent operations.

A short paver cycle (a paver cycle is the interval between successive batches of concrete; the minimum time for a cycle is normally controlled by the batchmeter) means short mixing time and clearly it means also that there is less time in which to perform essential operations at the paver without incurring delays. Delays not only disrupt the orderly flow of material but they also extend the paver cycle. Extended paver cycles inevitably result in longer mixing time, thus nullifying the time saving advantages of operating with a short cycle. Most delays become apparent at the skip and it is here that one can find not only a place to measure qualitatively the contractor's management but also the clue to interdependence of mixing time and batch truck performance.

If the paver operator is slow for any reason in getting the skip down, the batch truck driver has less time in which to dump without a delay occurring even though he may perform his job within the allotted time. If, on the other hand, the batch truck driver fails to keep his truck within a few feet of the skip between batches, does not back up promptly when the skip comes down, or fails to have the dump bed raised before backing to the skip, he may be slow in disposing of his batch and the paver operator will be delayed subsequently in raising the skip to begin a new cycle. In each case the paver cycle is extended by the delay and mixing time is thereby increased.

Many contractors have successfully mastered the problems of getting essential coordination and performance at the skip as well as keeping attendant supply lines moving. They have, in fact, become so successful, due to adroit management and good equipment, that sustained production at the rate of 98 batches per hour has been recorded using one paver. For intermittent periods lasting up to 2 hr this rate reached 110 batches. In other words, the paver discharged a batch of concrete every 33 sec including delay time. When a small number of lengthy supply delays, due to lack of batch trucks, were eliminated from the computation this figure was further reduced to the remarkable time of one batch every 30 sec. Remember, this is an average. Thus, it should not come as a surprise that individual paver cycles were being completed in 24 sec and less when delays did not occur. Mixing time (mixing time as used in this report is defined as the interval between entry of all solid material into drum and beginning of discharge for the batch in question) during the 24-sec cycles was less than 30 sec.

Figure 1 shows job average performance data for a group of 47 dual-drum pavers on which production studies were made. Individual studies usually covered a period of 2 to 4 weeks. Note that each of the four jobs with the fastest performance had an average cycle including minor delays of less than 40 sec.

To the engineer these fast cycles pose two problems. One is quality control, usually expressed in terms of mixing time, and the other is cost. Quality control, although important, is not a consideration of this report. Mixing time, per se, is discussed only in relation to production rates and cost.

For any given paver cycle time there is a maximum mixing time that can be obtained when the paver is adjusted and operated in a manner consistent with the manufacturers' recommendations. Any other method of operation has the effect of reducing mixing time in relation to paver cycle time. Although other methods of operation are common, often involving beating the batchmeter, it will be assumed in this report that paver operations are in accord with the manufacturers' recommendations.

Design of dual-drum pavers permits two batches to be mixed simultaneously during a portion of the paver cycle. Mixing time which can be obtained with any given paver cycle is equal to twice the paver cycle minus three constants plus a smaller constant. This is expressed by the following formula:

$$\text{Mixing time} = 2X - D - T - C + DL$$

In which

X = paver cycle time,
D = discharge chute open time,
T = transfer chute open time,
C = charging lag time—from close of transfer chute by skip vertical until all solid material is in the drum,
DL = discharge lag time—from opening of discharge chute until concrete appears.

Normal values for discharge and transfer chute open time are 9 sec each, for the charging lag a value of 4 sec is possible, and the discharge lag is usually about 1 sec. Obviously, any increase in the time taken for the first three constants will reduce mixing time in relation to the paver cycle time.

By substituting in the formula a 33-sec paver cycle and constants just noted, the following mixing time is obtained:

$$\begin{aligned}\text{Mixing time} &= (2 \times 33) - 9 - 9 - 4 + 1 \\ &= 66 - 21 \\ &= 45 \text{ sec}\end{aligned}$$

Performance records show that paver cycles can be completed regularly in 30 sec and sometimes in 24 sec. With a 30-sec paver cycle the maximum mixing time without delays becomes 39 sec. If the occasional 24-sec cycle is used then mixing time is 27 sec.

The aforementioned paver cycle values and consequent mixing times represent actual performance on only one job. Therefore, the performance requirements for completing a short paver cycle will be examined. During the paver cycle the skip must be raised, the mixing drum charged, the skip returned to the ground, and then the skip reloaded. The skip cycle is seldom accomplished in less than 15 sec and it took an average of 20 sec on jobs studied. The difference between the skip cycle time and the paver cycle time is available for reloading the skip. During reloading of the skip the batch truck must back up and cover the skip, dump its batch and pull away, and the paver operator react to the truck being clear before starting the skip to begin a new cycle.

Batch trucks on fast moving jobs consistently cover the skip in 2 or 3 sec. On some jobs the trucks can then dump and pull away from the skip in another 3 to 5 sec. On several other jobs up to 85 percent of the batches were dumped in less than 8 sec. This is indicated by curves A and B in Figure 2. Note, however, that such performances

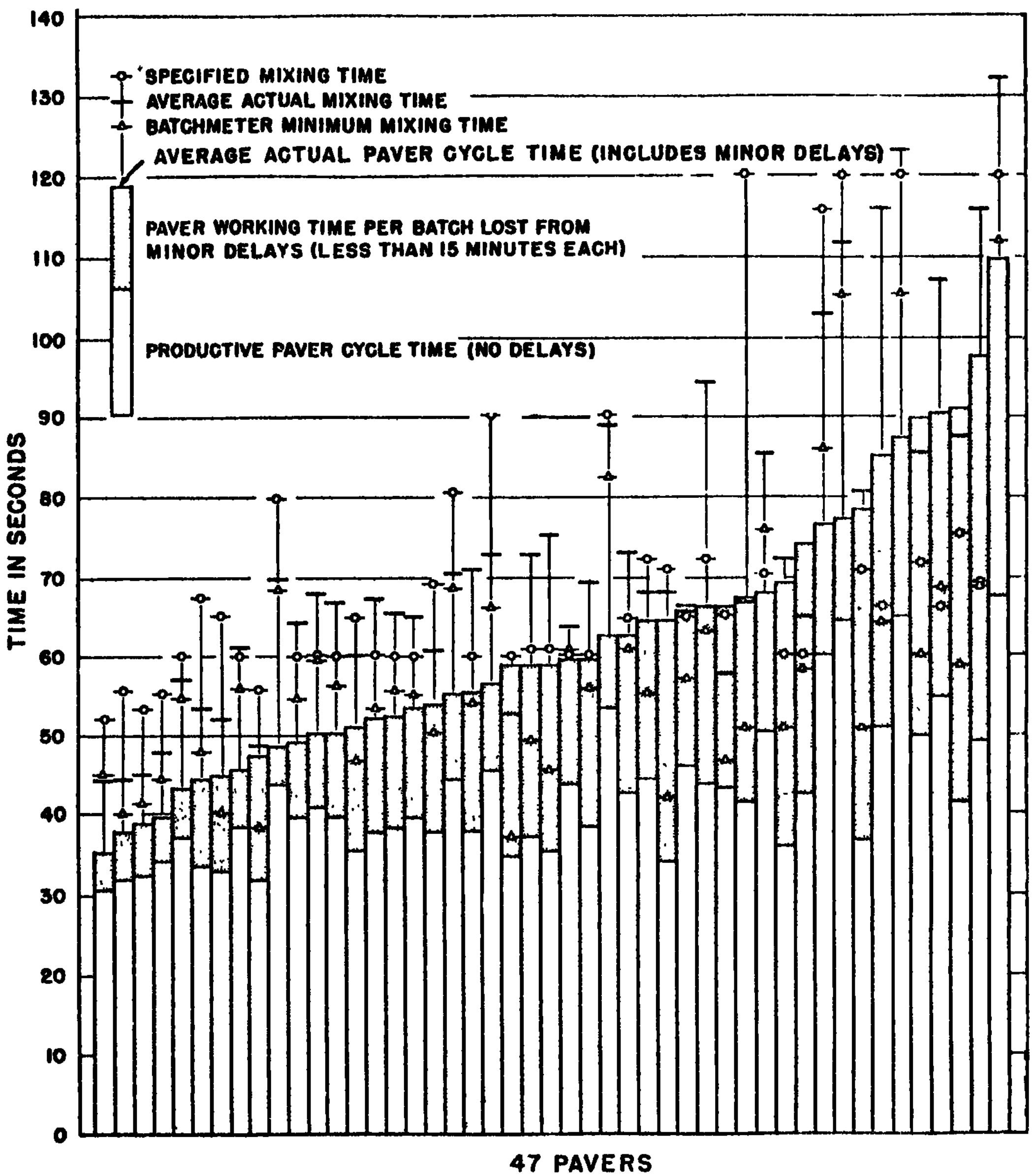

Figure 1. Comparison of 34-E dual-drum paver performance by a group of 47 pavers.

were attained only with 4- or 5-batch trucks. The best performance with 2-batch trucks (curve C) shows 85 percent of the batches took 15 sec or less. After a batch truck clears the skip the paver operator usually required about 2 sec before he actually started a new cycle.

By using a 15-sec skip cycle, 3-sec backup time, 8-sec dump time, and 2-sec operator reaction time, a paver cycle of 28 sec is derived. If 5-sec dump time is used, which is the fastest performance encountered on jobs studied, then the paver cycle becomes 25 sec. A 28-sec paver cycle will give 35-sec mixing time and a 25-sec cycle will give 29-sec mixing.

When a 15-sec dump time is used, such as indicated for 2-batch trucks, a paver cycle of 35 sec is derived and mixing time becomes 49 sec. If the 85 percentile value for curve D is used as dumping time, which is good performance with 2-batch trucks, the paver cycle is increased to 40 sec and mixing time becomes 59 sec.

Two methods have been used in arriving at a minimum paver cycle time and the re-

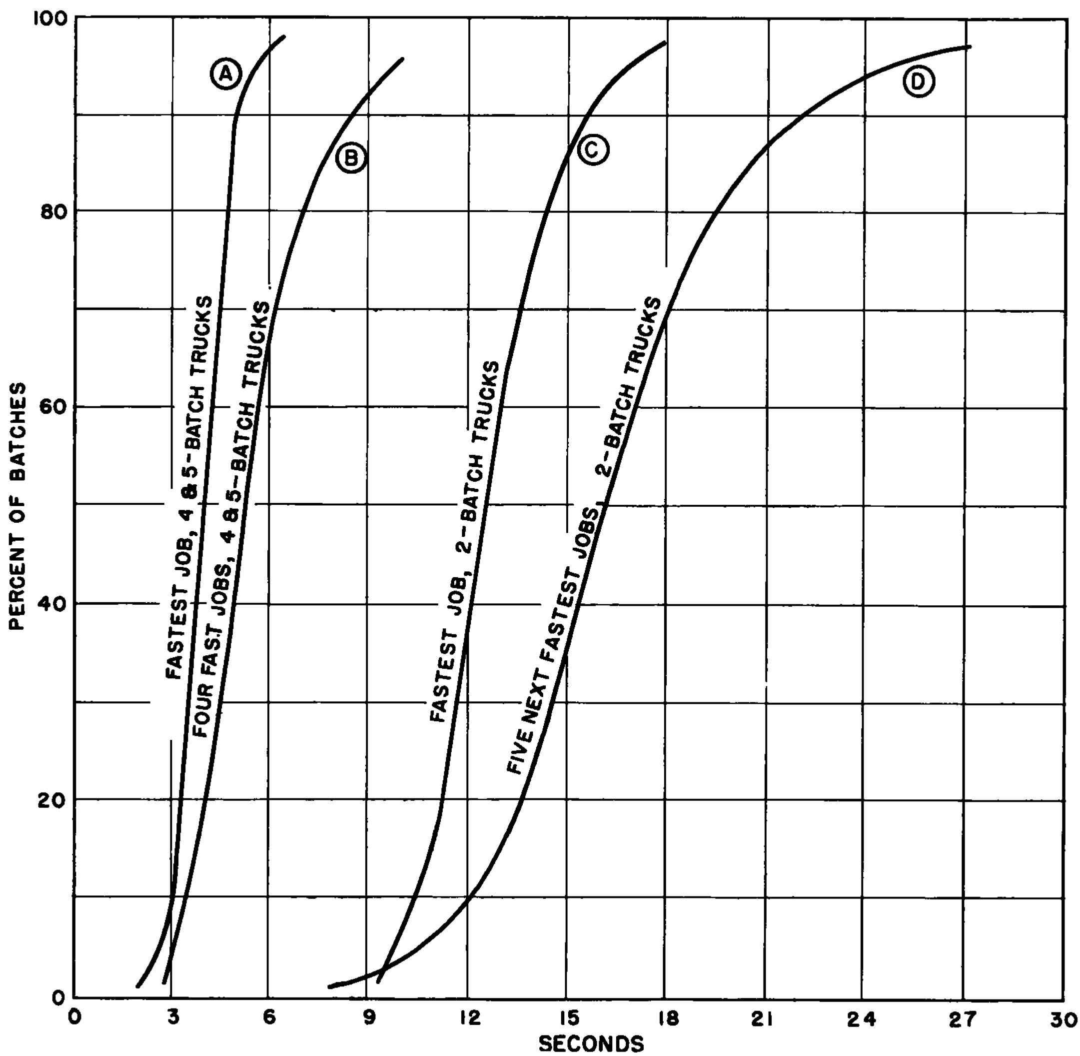

Figure 2. Cumlative frequency distributions of average time to dump one batch into the paver skip and get the truck out.

sulting mixing time which can be attained on fast jobs. In one case study data revealed that the operator ran for a 2-hr period with an average paver cycle of 33 sec which would permit mixing time of 45 sec. When a few long delays were removed from the computation, the cycle was reduced to 30 sec and mixing time to 39 sec. Mixing time was further reduced to 27 sec for individual batches. In the second case paver cycles were derived from performance data obtained from numerous jobs. A 28-sec cycle was found to be entirely possible and 25 sec could be attained in some cases. These cycles would produce mixing times of 35 and 29 sec, respectively. However, no allowance was made for delays.

In considering the problem of delays, it is a notable fact that as a general rule, more delay time per batch is lost by pavers with a long paver cycle than is lost by pavers with a short paver cycle. This paradoxical fact is plainly evident in Figure 3, in which the difference between curves A and B represents delay time. This difference is also shown by curve C. Note that as the paver cycle time per batch is reduced, paver delays also become less. The most logical explanation for this paradoxical pattern of delay trends on dual-drum paving jobs would seem to be that as the permissible production potential increases with shorter paver cycles, management becomes more alerted and more responsive to the needs and possibilities for reducing or eliminating delays.

Regardless of peculiarities relating to the magnitude of delays, it is an inescapable fact that they influence costs. Delays tend to push costs up, other things being constant. With equal assurance it can be said that mixing time requirements influence costs when delays remain constant.

The cost of operating a paving outfit tends to be a fixed amount and is almost independent within reasonable limits of the rate of production. Labor and equipment costs run about $350 per hour. When production is 50 batches per hour the unit cost is $7 per batch. However, if production goes up to 70 batches per hour, which is entirely possible with good performance by batch trucks, the unit cost drops to $5. The reduction is $2 and it is important. However, if production is increased by another 20 batches, to 90 per hour, the additional reduction is only $1.10 or a total of $3.10. This amount, incidentally, is a function of the percentage increase or decrease in production.

Data presented in Figure 3, curve D, indicate hourly production rates, including only delays of less than 15 min each, go down from a high of about 92 to a low of 35 batches per hour as paver cycle time increases. When the data used included only those pavers where 50- and 120-sec mixing time specifications were in force the production rates averaged 85 and 40 batches, respectively, per hour. Because of the fact that certain delays in excess of 15 min occurred while a full labor force was employed on these jobs, the rates of 85 and 40 batches were reduced accordingly to 75 and 34 batches, respectively. Thus, with the premise of a fixed

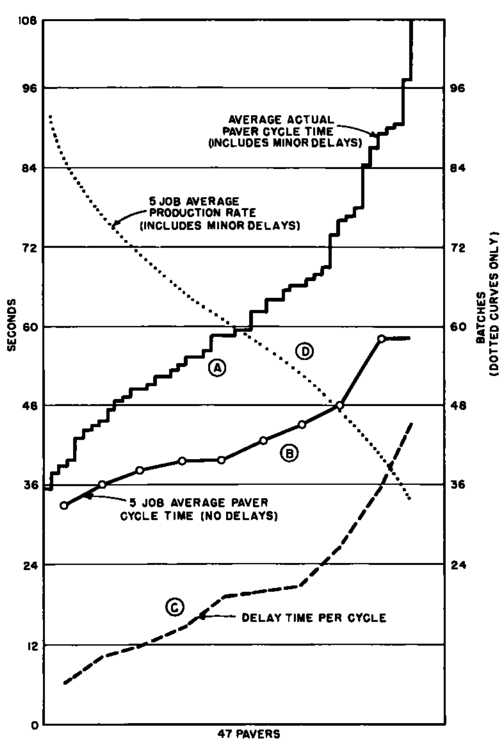

Figure 3. Comparison of 34-E dual-drum paver performance by a group of 47 pavers.

cost at $350 per hour, the cost differential between 75 and 34 batches per hour becomes $5.63 per batch or $4.06 per cubic yard with a normal 37.4-cu ft batch. Further adjustment is desirable under certain circumstances to account for the fact that where 50-sec mixes are used the batch size is usually about 40.8 cu ft. Thus, the difference per cubic yard increases to $4.34 when comparing 75 batches at 40.8 cu ft per batch with 34 batches at 37.4 cu ft per batch.

Specific cost data are not available for each rate of output in batches per hour. It may be assumed, however, that hourly costs are somewhat less when producing 34 batches per hour than for 75 batches per hour. The effect of this is to reduce the unit cost differential. To illustrate, let it be assumed that the $350 per hour cost go down by 10 percent for the 34-batch rate and increase by 10 percent for the 75-batch rate. Instead of having a differential of $4.06 per cubic yard it drops to $2.98.

What has been said thus far about unit costs is largely hypothetical but it serves to establish a means for computing the cost differential due to variations in mixing time specifications.

Another source of information on this subject, and one used quite frequently, is a comparison of bid prices per cubic yard and specified mixing times for portland cement concrete placed on Federal-aid projects. This is shown for the year 1957 in Figure 4.

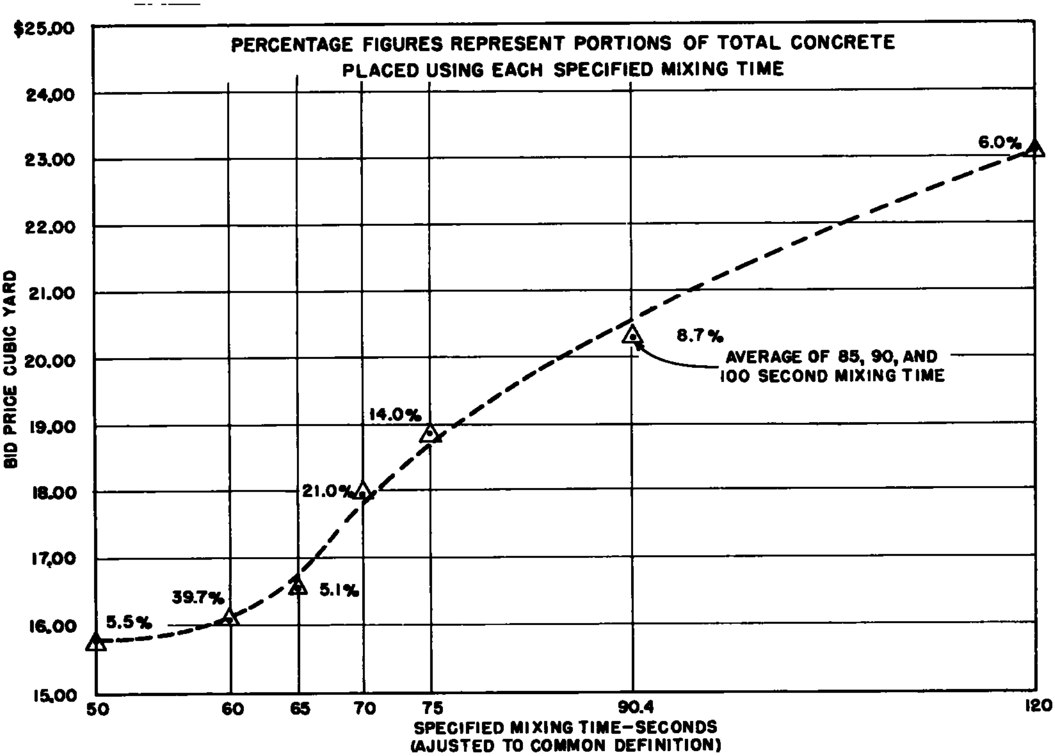

Figure 4. Comparison of bid price per cubic yard and specified mixing time for portland cement concrete placed on Federal-aid projects.

It may be noted that from a low bid price of $15.75 per cubic yard for 50-sec mixing there is a gradual increase in bid prices to $23.15 for 120-sec mixing. The difference is $7.40. It is more apparent than real. If this is a true indication of the differential which results from a 50- to 120-sec range in mixing time, then it also means that the labor and equipment cost of running a paving outfit exceeds $700 per hour. Such an hourly cost is unrealistic if not impossible and cannot be accepted at face value as representing an average.

A more plausible explanation appears to be that about one-half of the $7.40 difference could be charged to mixing time and that the balance represents costs generated by different design practices, longer hauls, variations in labor productivity, wage rates, climatic conditions, materials prices, etc. In this case it is not without significance that most states with longer mixing times are in the northeast whereas those with shorter mixing times are in the south and southwest where year-round work is possible.

It is believed that the so-called fixed hourly cost premise offers a greater degree of logic as a basis for the determination of possible savings which might result from reduced mixing time. To develop along this line an amount for any change, either an increase or a decrease in mixing time, the following values were used as control points and intermediate readings were then taken from a straight line projection through these points:

Mixing time seconds	120	50
Production—batches per hour (37.4-cu ft batch)	34	75
Hourly cost for labor and equipment	$350 less 10%	$350 plus 10%

Remember, an increase in the percentage adjustment of the hourly cost reduces the unit cost differential.

After making the necessary computations the following unit costs per cubic yard were derived:

Mixing Time (sec)	Unit Cost
120	$6.69
90	4.84
75	4.33
70	4.18
65	4.05
60	3.92
50	3.71
45	3.61
40	3.52
35	3.44

The difference in unit cost per cubic yard between each mixing time interval is given in Table 1.

Figure 4 showed the distribution of total concrete produced under each mixing time interval on Federal-aid projects during 1957. Using this distribution and a yearly program of 20 million cu yd (the 1958 Federal-aid program, except secondary projects, totaled approximately 18 million cu yd of pavement concrete) it was determined that the following quantities would be associated with each mixing time interval.

Mixing Time (sec)	Quantity
120	1,200,000
90	1,740,000
75	2,800,000
70	4,200,000
65	1,020,000
60	7,940,000
50	1,100,000
	20,000,000

TABLE 1

AMOUNT OF REDUCTION IN UNIT COST PER CUBIC YARD IN CHANGING FROM ONE MIXING TIME INTERVAL TO ANOTHER

Mixing Time From (sec) \ To (sec)	90	75	70	65	60	50	45	40	35
120	$1.85	$2.36	$2.51	$2.64	$2.77	$2.98	$3.08	$3.17	$3.25
90	-	0.51	0.66	0.79	0.92	1.13	1.23	1.32	1.40
75	-	-	0.15	0.28	0.41	0.62	0.72	0.81	0.89
70	-	-	-	0.13	0.26	0.47	0.57	0.66	0.74
65	-	-	-	-	0.13	0.34	0.44	0.53	0.61
60	-	-	-	-	-	0.21	0.31	0.40	0.48
50	-	-	-	-	-	-	0.10	0.19	0.27
45	-	-	-	-	-	-	-	0.09	0.17
40	-	-	-	-	-	-	-	-	0.08

TABLE 2

COMPUTATION OF POSSIBLE SAVINGS DUE TO DECREASED MIXING TIME

Mixing Time			
Current Specs (sec)	Reduced to (sec)	Total Cubic Yards	Total Savings per Year
120	90	1,200,000	$2,220,000
90 & above	75	2,940,000	3,719,400
75 & above	70	5,740,000	4,580,400
65 & above	60	10,960,000	7,297,400
60 & above	50	18,900,000	11,266,400
50 & above	45	20,000,000	13,266,400
50 & above	40	20,000,000	15,066,400
50 & above	35	20,000,000	16,666,400

From a performance standpoint many of today's contractors can use mixing times between 35 and 45 sec to increase their productiveness. In general, their production will approximately parallel and be limited somewhat by performance of the paver operator and the batch truck driver. Four-batch trucks are essential for short paver cycles. More and more contractors are using this size of truck and it can be said that the industry is ready for shorter paver cycles and the resulting shorter mixing times. A considerably more realistic consideration, however, is evident from an examination of the data in Table 2. Substantial savings amounting to over 13 million dollars are indicated if all mixing times are reduced to 45 sec. It is of major significance, however, to note that only 2 of the 13 million total is obtained by the reduction from 50 and above to 45 sec.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.