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Bulletin 295

Concrete Mixing and Paving

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Construction Procedures of Slip-Form Pavement

GEORGE N. MILES, District Engineer, Colorado Department of Highways, Denver

For purposes of discussion it is necessary to define the paver as the simple, basic slip-form unit first introduced to the construction industry in the early 1950's. Modifications have taken place since that time, but the machine is essentially the same. It travels over a deposit of fresh pre-mixed concrete, vibrating, tamping and forcing it through an orifce which gives dimension, shape and density to the concrete. Critical to these operations and the best functioning of the paver are: (a) the subgrade to be paved must be an accurate presentation of the plane of the finished concrete pavement; (b) the concrete itself must be of proper and uniform consistency and may be a specially designed mixture for best results with the slip-form machine; and (c) best over-all results will accrue to an operation so synchronized that the paver is fed at a constant rate and starting and stopping are reduced to a minimum. These phases of the paving operation are a joint engineer-contractor responsibility, best handled by team operation dedicated to both volume and quality.

The paver presents one of the greatest strides in the production of concrete paving for many years, and shows such a potential toward volume production at minimum cost as to bring about greater use of portland cement concrete paving, heretofore considered too costly by many highway construction agencies.

● THE SLIP-FORM UNIT with which this discussion is concerned is the basic unit first introduced to the construction industry in the early 1950's. It carries none of the electronic control devices that have occasionally been added nor does it involve special finishing equipment or floats that have been added by various contractors to meet specific conditions or requirements. Most slip-form pavers even today are basically the same as the early units. Actually it is a concrete lay-down machine and functions in a manner similar to the machine used to lay bituminous pavings.

As the paver moves forward straddling a deposit of freshly pre-mixed paving concrete, its forward thrusting ram strikes off the mixture in bulldozer fashion, to the approximate volume that will be required to produce the designed pavement width and thickness and begins confining the concrete to the traveling form. As the paver continues forward, a set of vibrators is forced through the mixture, followed by a tamping bar and vibrating screed. An orfice, or extrusion meter, through which the fresh concrete is then forced, gives it dimension, shape, and density while still confined in moving side-forms. The final machine operation belts off the surface and as the attached trailing forms are pulled forward, a burlap drag located on the final form bridge adds texture to the finished surface. As the trailing form slides along the pavement edges, the machine leaves a ribbon of finished concrete paving that is ready for the curing compound. This is the unit and the general operation to which the balance of this discussion is confined. Its most successful use will be contingent on certain basic construction procedures which are outlined briefly in the following discussion. These procedures are not new or unusual to any good concrete paving operation.

Probably the prime concern in using this machine is rideability and because the machine moves on crawler tracks that travel along the surface of the subbase, primary among construction procedures is the accuracy of that subbase. The foundation or base courses must be firm under the paver tracks. Should the tracks dig in, there will be a depression in the concrete as it is finally cast. Should the subgrade present a hump, the paver will follow the grade of this hump and most certainly produce an erratic final roadway surface. The wheel base of the tracks on the machine, being some 22 ft long, tends to produce a uniformly good riding surface, free from choppiness but will not take out inherent humps and hollows or long undulations in a poorly finished grade. The very nature of the paver's operation makes it absolutely necessary that the tracks be presented with a subbase that will be identical to the plane of the pavement surface expected. Thickness of the slab, crown, or other final surface shape is varied by adjustment of the screed.

Beginning with the subbase and continuing through all further courses of foundationing materials, each consecutive layer should be shaped and consolidated to accurate grade control stakes. On the final subgrade surface, such staking might well be set at 50-ft intervals on tangent grades and 25-ft intervals on vertical curves. As the subbase is brought within reasonable limits of elevation, it is occasionally better to relax further elevation controls in favor of the long wheel-based land planers or other leveling equipment. At this point interest lies in achieving a subbase free from long undulations as well as any choppiness.

The use of the best available base course aggregates or cement-treated bases will be of great value to the preparation of the subbase as well as the ultimate service life of the pavement. Such subbase treatment should be designed for sufficient width to accommodate the paver's tracks. If the final subbase has any tendency to displace under equipment traffic and especially in the area of the paver's tracks, consideration should be given to restricting or even denying use of that subbase to the hauling equipment. Uncontrolled movement of haulage equipment can also contribute to non-uniform subgrade density — a particular problem in areas of swelling soil.

Final subbase shape is often achieved by use of a track-mounted subgrade planer. This unit presents a template that can be varied to produce any given final surface shape — after the general plane of the subbase has been achieved. The planer operates from crawler tracks that travel the same area as the paver itself.

The subbase to be paved must be a firm and accurate presentation of the desired plane of the finished pavement. Once this is accomplished, good rideability can be expected. Other procedures can improve the ride even further but they are not quite so essential.

For the machine to perform at its best, the consistency of the concrete mixture should be maintained as perfectly as possible. Mixtures too wet or inconsistent in either moisture content or aggregate ratios will give trouble both in edge slump and resulting rideability. Because aggregate ratios are readily controlled, the prime complication comes from moisture variation in the aggregate itself. Because it is impractical to run a moisture test and make proper adjustment of each concrete batch, it is necessary to stock-pile aggregates for such period of time as may be necessary to bring about reasonable equalization of moisture content throughout the stock piles. Uniformity of concrete mixture, however obtained, is of prime importance.

It has been the Department's practice to run paving concrete with a maximum 1½ in. slump. The slip-form paver, particularly one equipped with a battery of stinger-type vibrators, produces a final paving shape that tends to stand very nicely after the sliding forms have passed. Slumping at the edges, prevalent in wet or oversanded mixtures, has at most been a matter of ⅜ in. which will occur at the edge and taper out to zero within the first 12 in. from the pavement's edge. This has not been a prevalent condition due to the ease with which it can be handled and it is thought that vehicles traveling the very edge would not notice it perceptibly.

The type of vibrating equipment used with any given machine will probably require minor adjustment of the concrete mix or the vibratory cycle or both. High-speed vibration together with relatively high travel speed of the paver can produce a swell or surge in the concrete as it passes out of the orfice behind the machine. This will tend toward a choppiness in the pavement surface but it is readily detected in the hand straight-edging that normally follows. The straight-edging and any corrective hand finishing must be completed while the concrete is within the trailing forms.

Concrete mixtures dedicated to specific use with the slip-form paver have not been set up, but it is believed this will be done on future work. The following typical paving mixture producing 28-day minimum strength of 3,000 psi has been used with good results:

Class of concrete — Pavement
Air-entraining agent — Protex
Quantity of air-entraining agent — 2 oz
Cement (lb) — 94.0
Fine aggregate (lb) — 173.0
Coarse aggregate (lb) — 346.0
Water (lb) — 41.5
Slump (in.) — 1.75

The following mechanical operations are considered pertinent to good operation of the paver. Smoothest pavements are occurring when proper synchronization between the delivery of concrete and the travel speed of the machine is maintained. Starting and stopping of the paver should be held to a minimum. The start once more tends to produce a surge of concrete as it passes out of the orfice. As a further precaution against this problem, vibrators and tamper bar shall be stopped during any delay in forward movement of the paver. This is also advisable as a precaution against segregation of the aggregates immediately around the vibrators.

Care may well be taken in the manner of depositing concrete from the mixer directly in front of the strike-off ram. The ram, to function best, should be carrying a constant load, from side to side, keeping the ram as nearly uniformly loaded as possible.

Concrete spillage that may get under the tracks of the paver is to be avoided. Occasionally an overload at one corner of the ram will result in such spillage. The tracks, being the key to vertical control, will walk up over that spillage raising the orfice and creating a bump or roll in the final product.

Where hauling equipment is to be permitted on the finished subbase, constant care must be taken that all humps or depressions are smoothed out immediately in front of the paver. This is particularly necessary in the area that the paver tracks will follow. It is also of concern in maintaining a uniform slab thickness.

No comment has been made concerning the edge alignment of the pavement resulting from slip-form operation. Actually this is almost a negligible problem; first, because in running a single 24-ft paving width a deviation of as much as 1 in. from the straight line would be unnoticed; and second, the machine operator simply keeps a suspended plumb bob, on the front of the machine, traveling along a pre-set string line. Normal deviation should be very minor. Curvature up to 4 degrees is negotiated in the same manner and without difficulty.

As in any other concrete paving operation, use of the slip-form paver on level or near level grades will produce best results, however, the slip-form unit has been used on grades up to 5 percent and no serious problem in rideability or choppiness that would not be experienced in an ordinary formed paving operation, has been found. If it is a practical thing workwise, the operation of the paver upgrade will produce a smoother riding surface than will its operation downgrade. It is felt that grades up to 4 percent deserve little or no consideration as to direction of operation, however in excess of 4 percent grades, an attempt is made to operate that paver on the uphill approach. The mere fact that the machine demands uniformly stiffer concrete mixtures that will tend to stand rather than slump, actually reduces the problem. Further, the problem of edge slump is foremost in the contractor's mind. As a result, it receives more than normal attention, thus often achieving better riding concrete surfaces on the steeper grades than otherwise would result.

In November 1959, using the Bureau of Public Roads roughometer, a device for measuring roughness in terms of total vertical inches per mile of roadway, it was found that on a 20-mi project involving horizontal curvature of one degree and maximum 3 percent grades, the average roughness was 78 in. per mile. Variation in this measurement indicated that there were sections of roadway showing as little as 66 in. per mile and other sections running as high as 94 in. per mile. Here the slip-form paver was used to place a 24-ft ribbon of concrete 8 in. thick. This particular section carried no crown whatsoever but was sloped at 0.015 ft per foot from the median to the outside shoulder. The 24-ft width was placed in one pass and all contraction joints were sawn. Sawn joints have been used for the last eight years, formed joints being used only at the end of the day's operation or at a bridge approach where the new pavement is being brought into a structure approach slab.

To form joints in conjunction with the slip-form paver presents only this problem: that more hand finishing is necessary at each of the joints and of course this hand finishing must be done rapidly because the paving slab will only be within the area of the traveling form for a very short while unless it is desirable to shut the paver down while the joint is finished.

The 78 in. per mile of roughness measurement certainly is not a record nor is it particularly good but it is believed that no more roughness than this is not a critical thing. It might be well to consider that at the time the measurement was made the pavement had been in use for some three months. Also that this particular pavement slab was placed over several areas of swelling-type soil. Therefore, it might be expected that there is some contribution to this early roughness by reason of the action of that soil.

At this time it is very difficult to form a comparison directly between the roughometer figures or any other measure of roughness, resulting from the use of the slip-form paver as compared with conventional paving methods. The Department has many formed jobs but they are quite old and relatively few that would be comparable with the more recent paving work. After any section of concrete paving has been put to use for even a short period of time it is no longer comparable with another one in a totally different location and over a totally different subgrade soil. Thus it is felt that any comparison would lead only to erratic thinking in terms of slip-form results. Actually the slip-form paver has been used in projects where as little as 42 in. per mile of roughness has resulted. These projects have been placed over ideal subbases and up to this time are more the exception than the rule.

Being favorably impressed with the slip-form paver from Iowa operation, it was first used in Colorado in the summer of 1955 under special provisions of the Department's standard specifications. Being further impressed with the early results and the apparent economy, the specifications were revised to permit regular use of the machine. This revision was permissive but broad, saying, "Where a slip-form paver is employed, all reference in the preceding parts of this specification referring to forms shall be considered to be non-applicable and procedures shall be adopted which will result in a satisfactory end product". This revised specification presumed that an equal product would result.

The Department's experience, since permitting the slip-form method, has been surface smoothness that was equal to, and in most cases better than that obtained with conventional forms and the usual equipment train. Therefore, the Department is continuing to make this an acceptable method of construction. Specification for surface tolerance is the same — ⅛-in. from a 12-ft straight edge — regardless of the method the contractor chooses to use. In fact, with new developments in electronic controlling devices being introduced today, more accurate control of the slip-form operation becomes possible. This is still relatively new equipment and many further improvements can be expected. Even now, the equipment with some modification, has been used to lay a reinforced concrete pavement using woven wire reinforcing fabric.

It is no longer a speculative matter regarding the cost of pavement placed with the slip-form as compared with the conventional paving methods. Fifty cents or more per square yard of pavement can be saved. Greatest economy has yet to be realized by use of the slip-form machine. This is due in part to the limited number of the machines in use and the fact that those contracting agencies who have the slip-form paver find they do not have to squeeze their cost accounts too tightly to become a low bidder. Thus it is felt that they are not yet bidding at the most efficient level of operating cost plus reasonable profit. It is further believed that the maximum volume of which the unit is capable has not been reached in most contract operations. The machine is presently capable of producing up to 10 ft per minute of 8-in. concrete slab if properly fed and operated under reasonably good conditions. As a practical matter, however, no paving effort will feed the machine at such a rate. Usually production has been controlled by the capacity of a single dual-drum paving mixer. This operation produces 2,000 ft per day, or somewhat less than one-half the slip-form paver's capacity.

In the slip-form paving operation, as in any other, the equipment will perform in as satisfactory a manner as the contractor's organization and skill will permit. A poor job can be done; but just as surely, if there is effort and care put into the operation of that paving unit, an excellent product will result.

Specifications and Construction Controls to Obtain Smooth-Riding Bridge Decks

J.W. MCKNIGHT, Regional Paving Engineer, Portland Cement Association, New York, New York

Construction procedures and specification provisions that will produce smooth riding bridge decks are presented.

It is pointed out that the basic principles that produce smooth-riding concrete surfaces are the same for pavements placed on grade and bridge decks. The need for uniform and accurate subgrades is analagous to the need for determining elevations that reflect correct use of actual camber measurements and calculated deflections due to dead loads applied during bridge deck construction.

For bridge decks to ride as smoothly as adjacent pavements, the screed guides or rails that support paving equipment on bridge decks must be set with the same accuracy and precision employed in setting side forms for concrete pavements on grade.

The criteria for proper placing and finishing of concrete placed on grade should be followed in placing and finishing bridge decks. The important difference in the two procedures is the technique of working in the limited space on a bridge deck. Careful planning is required to include all the necessary steps in finishing.

To insure adequate planning and procedures essential to produce smooth-riding bridge decks, the specifications should include requirements regarding: (a) the placing and finishing equipment; (b) the supports for screed guides or rails, and determination of elevations for guides or rails; (c) the properties of the concrete mix; (d) minimum methods for placing, consolidating, and finishing bridge deck concrete; (e) curing methods; and (f) preconstruction conference of engineer and contractor leading to preparation of detailed plan for bridge deck placing and finishing.

● HIGHWAYS and highway bridges are built to accommodate the needs of the motoring public. These needs are (a) uninterrupted traffic flow, (b) safety at high speed, and (c) driving comfort as affected by the riding quality of the pavement. The principal part of a highway observed by the user is the driving surface of the pavement. If the pavement is rough riding, the driver is prone to condemn the entire structure — highway or bridge.

The highway users' opinion of rideability makes no allowance for the manner in which the pavement is supported. The riding quality requirements for a bridge deck are therefore the same as for a pavement on grade. The requirements for a smooth-riding pavement are (a) a smooth, true grade line without long waves and dips, (b) a uniform surface and uniform cross profile, and (c) a smooth surface as indicated by testing with a straightedge.

The grade line of the pavement and initial surfacing control are determined by the forms when the pavement is on grade, and by the screed guides when the pavement is a bridge deck. Both forms and screed guides must be adequately supported to maintain a true position with respect to the subgrade. In setting screed guides on a bridge there is, of course, the additional consideration of subgrade deflection when the concrete is placed.

Uniformity of surface, cross profile and surface tolerance on a bridge deck are affected by the same factors that affect these characteristics of a pavement on grade. Space limitations on a bridge deck require somewhat different techniques for handling, placing and finishing concrete than are usually employed for a pavement on grade. However, the basic considerations are the same in both cases.

Smooth-riding concrete bridge decks can be constructed. The fundamental principles which apply to construct a smooth-riding pavement on grade apply to construct a smooth-riding pavement on structure. These fundamentals, briefly stated, are: (a) accurately set forms, or screed guides, securely supported; (b) a uniform concrete mix, properly proportioned for the job; (c) proper concrete handling and placing methods; (d) uniform strike-off, screeding and consolidation; (e) longitudinal floating; (f) straightedging by experienced pavement finishers; (g) uniform texturing; and (h) adequate curing.

Understanding and cooperation on the part of design engineer, construction engineer, and contractor are essential to a satisfactory job. The starting point is an accurate structural design and adequate specifications with respect to materials, concrete mix, and methods for handling, placing, and finishing the concrete. Considerable emphasis should be placed on the necessity for sufficient and adquate construction equipment and finishers experienced in use of the long handled 10-ft scraping straightedge.

Prior to the start of construction, a conference between construction engineer and contractor should determine: (a) type and adjustment of screed supports or guides; (b) equipment to be used; (c) material supply; (d) procedure for placing, finishing and curing concrete; and (e) number and qualification of men required.

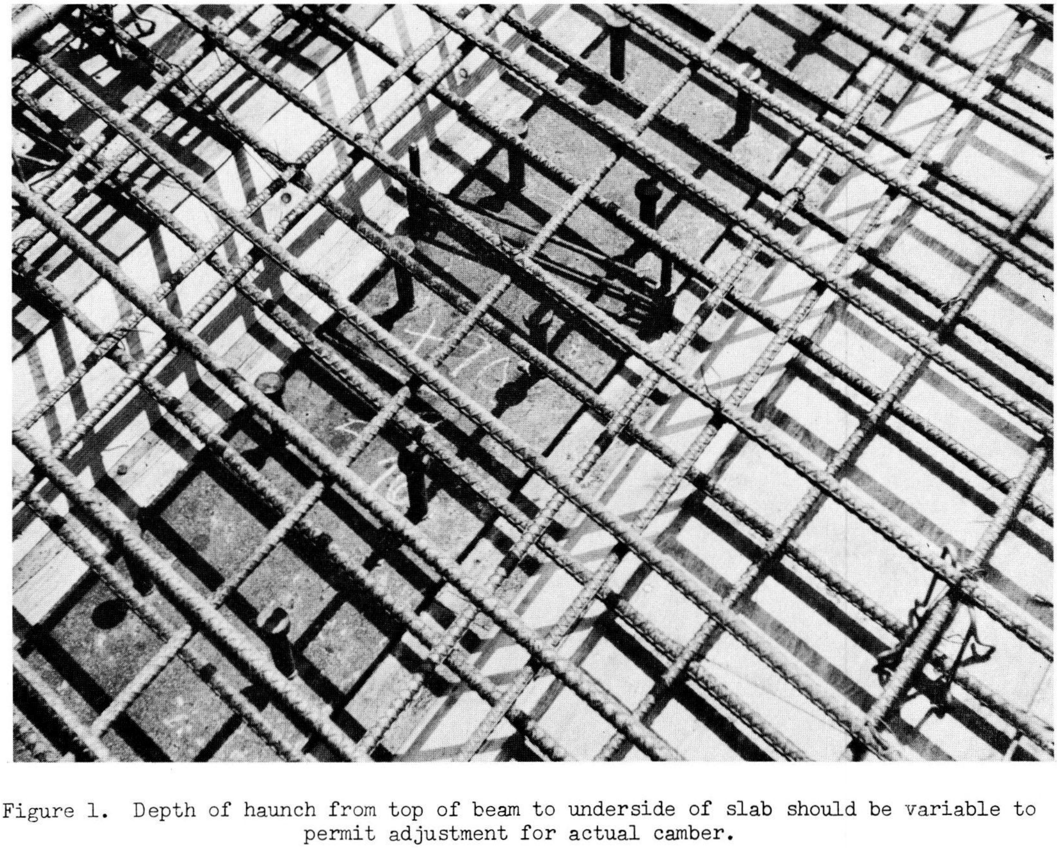


Figure 1. Depth of haunch from top of beam to underside of slab should be variable to permit adjustment for actual camber.

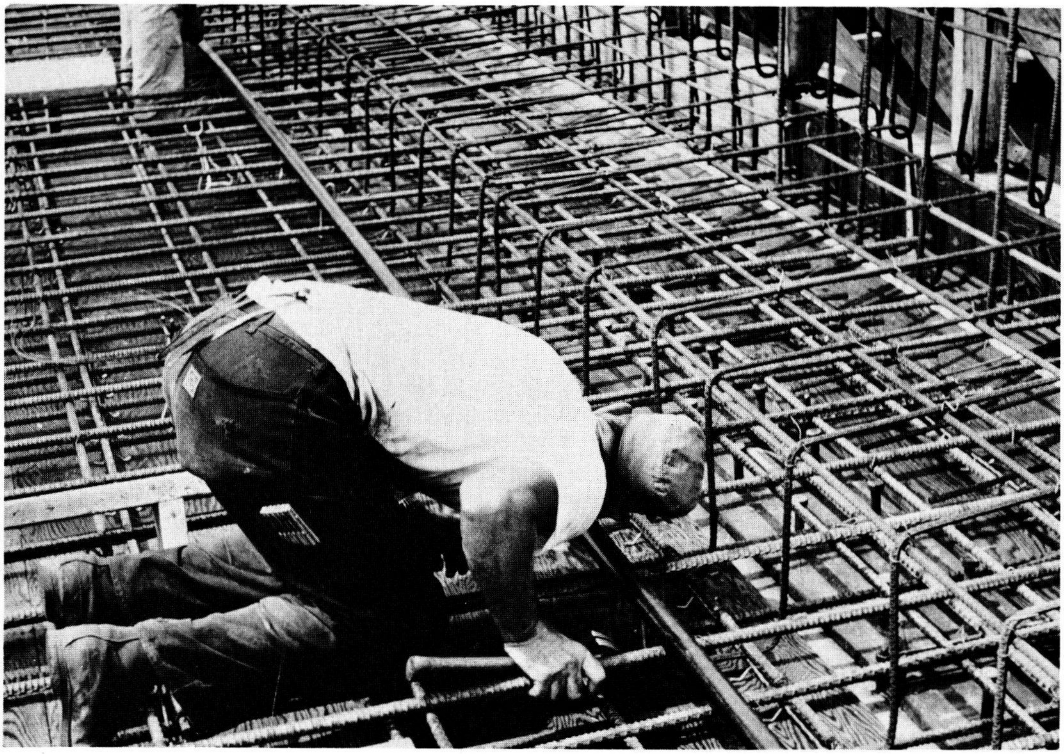


Figure 2. Screed guides and rails should be "sighted-in" after being set to calculated elevations.

Bridge structures vary widely in details of design and erection problems. Frequently considerable ingenuity is required to finally produce the desired structure. This discussion is concerned with the fundamental principles previously stated and which must be applied to each structure to produce a smooth-riding bridge deck.

Two principal causes for rough-riding bridge decks can be observed:

1. Long waves and abrupt dips in the longitudinal profile caused by failure to properly adjust the elevation of screed guides and end dams to compensate for the combined effect of actual camber in main structural members and deflections due to dead loads; and
2. Rough or uneven surfaces caused by inadequate concrete placing and finishing methods.

DESIGN CONSIDERATIONS

Often the designer can incorporate features which facilitate paving construction and thus contribute to a better riding surface.

When possible a stringer, or main beam, should be located under screed guides or rails. When built-in metal curbs, gutters or grade angles may be used as screed guides, the detail should include provision for vertical adjustment. End dams should be adjustable to final elevation in the field. Stringer profiles should be checked against the plan elevation of the deck surface to insure full design slab depth. Depth of haunch, or corbel, from top of beam to underside of slab should be a variable dimension (Fig. 1). The plans should show the loading sequence and calculated deflections due to slab dead loads. On multi-lane pavements consideration should be given to longitudinal joints. When used, these joints should be in line with a roadway lane edge.

SCREED GUIDES AND SCREEDS

Initial surfacing control and final longitudinal profile are determined by the screed guides. Screed guides must be accurately set to calculated elevations so that after deflection from all dead loads they conform to a true and smooth grade line. Elevation of screed guides should be checked by instrument and final minor adjustments made by "eyeing in" to a smooth line (Fig. 2).

Calculated elevations for top of deck forms and screed guides must be determined from consideration of (a) elevations on tops of all supporting beams or girders after erection, (b) anticipated deflections from dead loads and (c) cross slope on the finished surface. Because the screed guides are positioned after the deck forms and reinforcing steel are in place, the dead load deflection to be accommodated will be only that due to the weight of the deck concrete.

End dams and intermediate bulkheads must be set accurately to the final grade line as established in the field. Approach pavements on grade should be constructed after the bridge deck is in place, when they can be adjusted to meet the bridge deck profile.

Depending on bridge length and construction economics, the screeding equipment may be a fully powered finishing machine with oscillating screed, a vibrating screed, or a heavy hand-operated screed. Use of the hand-operated screed should be confined to small areas.

Finishing machines will be operated on bridge elements such as curb angles, or on temporary rails. Adequate supports must be provided to carry the heavy machine without deflection of the rails. Supports should be on structural beams at about 5-ft inter-

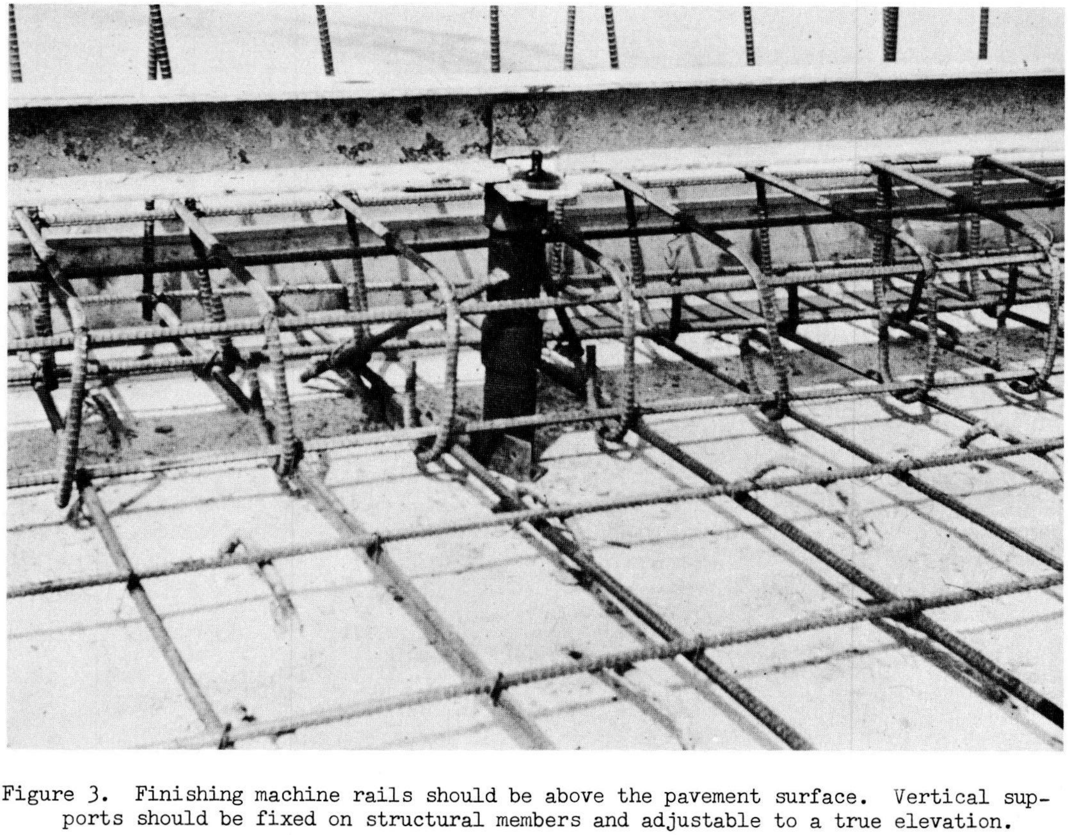


Figure 3. Finishing machine rails should be above the pavement surface. Vertical supports should be fixed on structural members and adjustable to a true elevation.

Figure 4. Concrete should be workable and have a 2- to 4-in. slump. Concrete should be placed against concrete and as near its final position as possible.

vals, with the spacings staggered on opposite sides of the roadway. Finishing machine wheels should be carried above the pavement surface to allow for hand finishing outside the roadway area (Fig. 3). Vertical supports must be fixed, but vertically adjustable to true elevation. Temporary rails and supports must be removable with minimum disturbance of the screeded concrete.

Vibrating screeds may be carried on bridge elements and/or pipe screed guides. Fixed supports must be adjustable and spaced close enough to prevent deflection of the screed guides. Screed guides should be supported on structural members and not on deck forming. Temporary guides must be removable with minimum distrubance to the screeded concrete.

Attention to proper positioning and support of screed guides should eliminate that part of rough riding due to an irregular grade line made up of a series of curves. This is only part of the story, however. Much rough-riding pavement is due to improper methods of handling, placing and finishing concrete. Improperly performed, these operations can produce a rough, uneven pavement even though it may conform generally to a true grade line.

CONCRETE MIX

A prerequisite for construction of a smooth-riding pavement is production of a concrete mix uniform in composition, workability, and consistency. The mix characteristics must be geared to the job. Because considerable reinforcing steel must be incorporated in a bridge deck slab, the maximum size of coarse aggregate will be $\frac{3}{4}$ in. to 1 in. for the usual slab depths. To be readily workable, concrete with this size of coarse aggregate will require a sand aggregate ratio of 38 to 40 percent or higher.

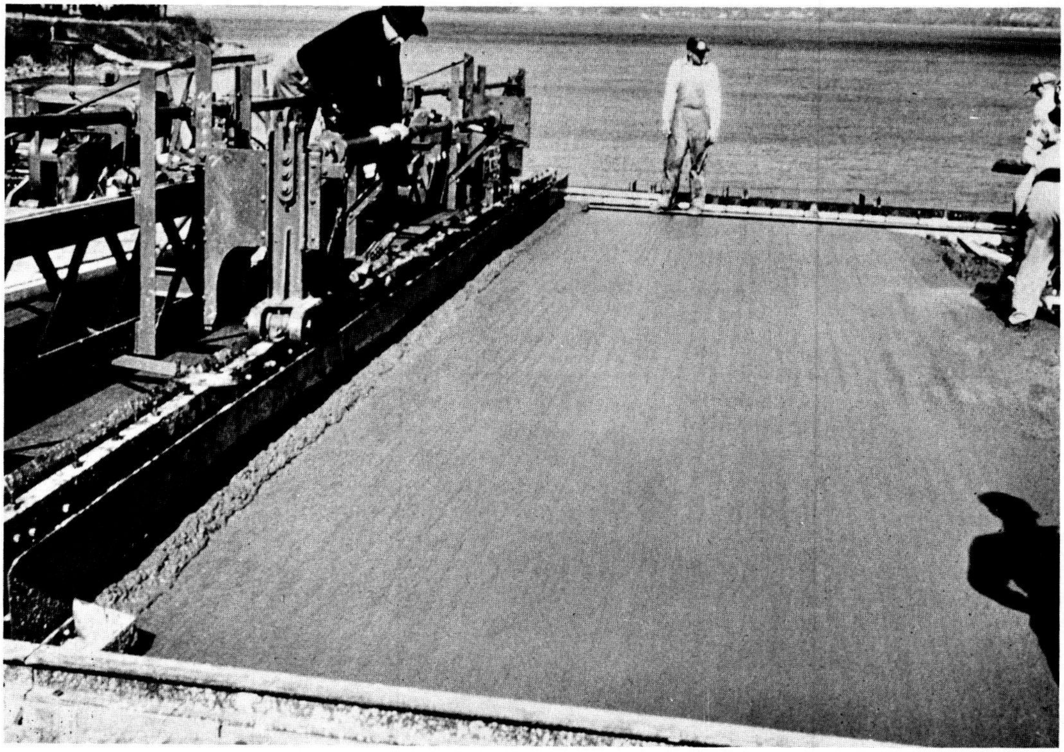


Figure 5. Finishing machines or vibrating screeds should move at a uniform rate and strike off the full paving width in one operation.

When the deck will be subjected to severe exposure conditions, the water-cement ratio should be not more than about 5 ¼ gallons of water per sack of cement. The consistency or slump of the mix should be between 2 and 4 in. With the foregoing factors established, it will be found that the cement factor for air-entrained concrete will be about 6 ½ to 7 sacks per cubic yard. This cement factor is slightly higher than for normal pavement mixes, due to increased slump and smaller maximum size of coarse aggregate.

Air entrainment increases durability and provides resistance to scale produced by de-icing chemicals. For the type of mix being discussed, the air content of the fresh concrete should be 6 percent, plus or minus 1 percent. Regardless of durability requirements, air entrainment is recommended for all pavement concrete because of improvement in workability.

HANDLING AND PLACING CONCRETE

Usually the mixed concrete will be placed in the forms from bottom dump buckets or concrete buggies. The handling and transporting method must be controlled to avoid segregation. Buggies should work on movable platforms or bridges. Concrete should be dumped against concrete previously placed, and as near its final position as possible (Fig. 4). Deep, widely spaced piles of concrete should be avoided, because the density of the concrete at the bottom of the pile will differ from that of the concrete shoveled into the spaces between piles. Spud vibrators will usually be needed to consolidate the concrete around the reinforcing. Vibrators should not be used to move concrete. The concrete should be spread by shoveling to approximate grade before screeding. Walking in the concrete should be kept to a minimum.

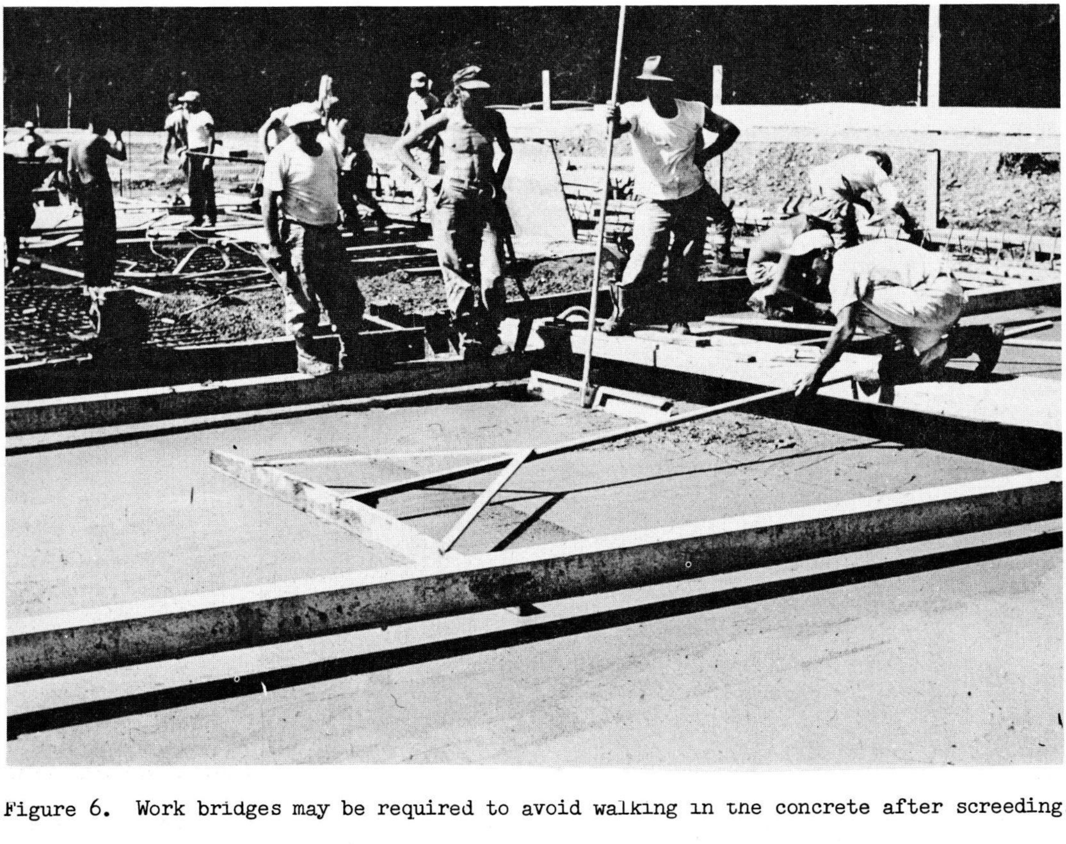


Figure 6. Work bridges may be required to avoid walking in the concrete after screeding.

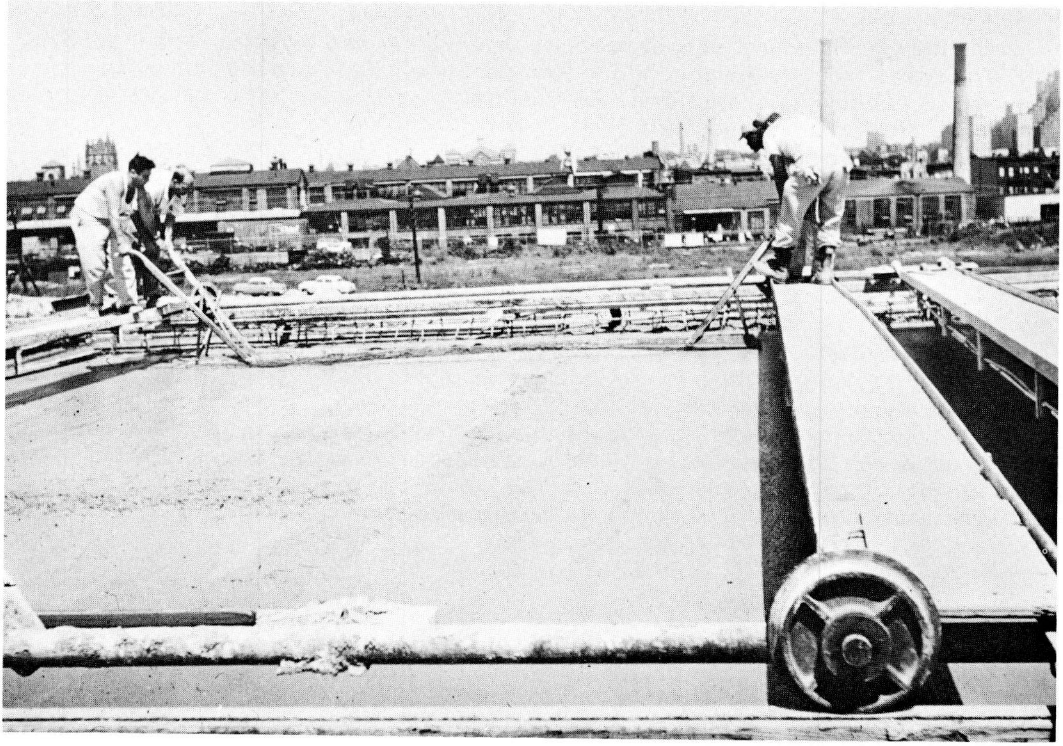


Figure 7. The longitudinal float removes slight waves left by the screed.

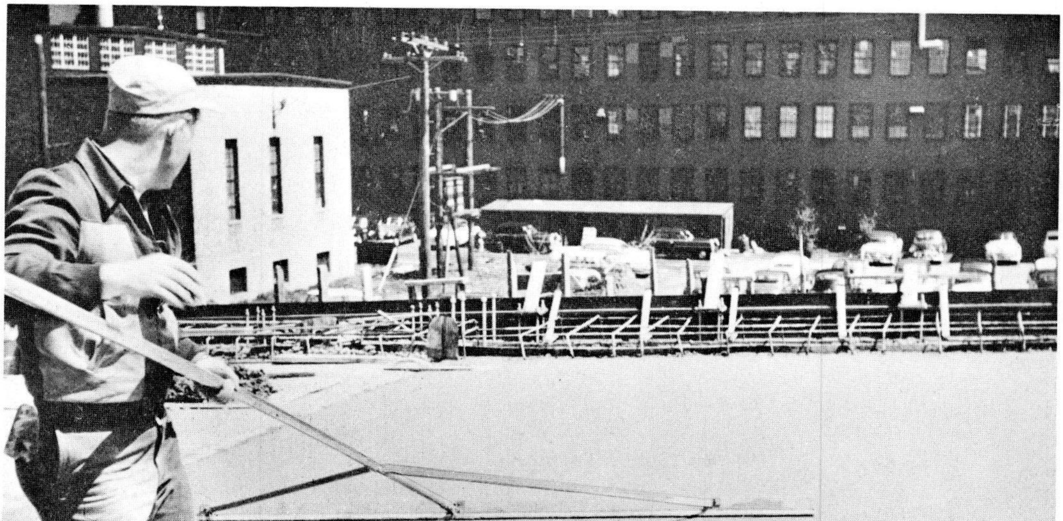


Figure 8. The 10-ft straightedge is required for a smooth-riding surface.

SCREEDING CONCRETE

Finishing machines or vibrating screeds should be moved slowly and at a uniform rate along rails or screed guides which have been accurately set and securely supported (Fig. 5). A uniform amount of concrete should be kept in front of the screed at all times, and for the full width of the screed.

Finishing machines should strike off the full width of pavement in one operation. When vibrating screeds are used, two or more may be operated across the width being placed. The screeds should be moved forward closely together to prevent possibility of a "cold joint."

As mentioned previously, screed guides or rail supports must be arranged to be removable with minimum disturbance to the screeded concrete. Voids left after removal should be filled with concrete — not mortar.

It should be emphasized that walking in the concrete must be prohibited after the screeding operation. Walking in the concrete pushes coarse aggregate aside and leaves a pocket of mortar. This pocket will be of different composition and density than the adjacent concrete and can be expected to subside at a different rate.

Substantial work bridges will frequently be needed for all operations following screeding (Fig. 6). Work bridges should be planned and fabricated well in advance of concreting. Preparations should include means to support and move work bridges.

FINISHING CONCRETE

Final finishing of concrete in a bridge deck is subject to the same basic requirements

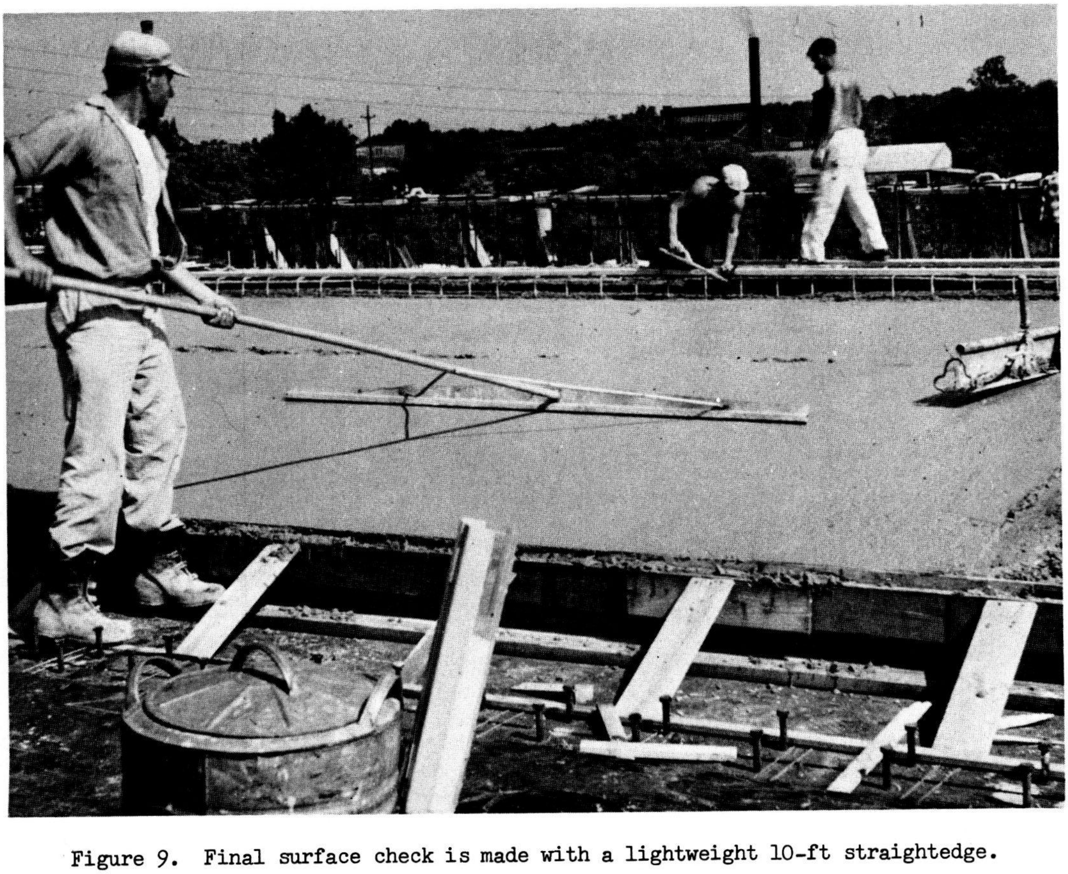


Figure 9. Final surface check is made with a lightweight 10-ft straightedge.

Figure 10. When wet burlap is used for curing it must be kept saturated.

as concrete in a pavement on grade. The only difference is that the work must frequently be done from work bridges above the concrete surface. Finishing operations should be delayed as long as possible so that the concrete will have had time for subsidence. "Finishing concrete" in this discussion includes the operations of using a longitudinal float, a scraping straightedge and application of surface texture.

The first of these operations is the use of a hand-operated longitudinal float, 16 ft in length, equipped with plow handles and worked from a pair of bridges spanning the full width of the roadway (Fig. 7). This is standard equipment, and usually of a metal channel section. The longitudinal float is operated transversely across the surface with a sawing motion, returned in the same path, and then moved ahead one-half length. The operation is then repeated.

Final surfacing is obtained by use of a long-handled 10-ft scraping straightedge (Fig. 8). This piece of equipment must be used by an experienced pavement finisher. It may be of wood or aluminum, and for best results should weigh in the range of 30 to 45 lb. The straightedge should be operated across the full working width in one operation. When necessary, it must be handled from work bridges spanning the pavement.

The straightedge is operated by placing it on the near edge of the pavement, sliding it across the surface with the handle about 10 in. above the pavement, and returning along the same path with the handle at shoulder height. It is then moved ahead one-half length and the operation repeated. The scraping straightedge should be used as late as possible so as to benefit by the final slumping of the concrete.

The pavement surface at all joints should be carefully straightedged while the concrete is being finished. Any necessary transitions to meet such joints should be carried out on long lines with no abrupt change, so that a smooth-riding joint is secured.

A light checking straightedge should be used while the concrete can still be worked (Fig. 9). Any irregularities observed should be corrected and the needed steps taken to prevent a recurrence of such defects.

Smoothing lutes are sometimes used to float down high spots, fill surface voids, or to work up mortar for final texturing. They are about 4 in. wide, and 4 to 6 ft in length. Use of the smoothing lutes usually produces short waves or hollows in the surface. Following use of a smoothing lute, the surface should be carefully checked with a 10-ft straightedge.

The final surface texture will usually be produced with a burlap drag. The burlap should be a seamless strip, longer than the paving width and wide enough to that at least a 24-in. width is in contact with the surface. It should be kept wet and free from hardened concrete. In some cases a light broom finish is used; but the burlap drag finish is considered to produce the most even surface and the smoothest ride.

BULKHEADS

Deck placing will usually start and end at a transverse joint. However, where it is necessary to set an intermediate bulkhead it should be installed with the greatest of care, so that the exact pavement cross-section is maintained along this line. Vertical dimensions should be set and checked from piano wire measurements to eliminate sag. A key-way strip should usually be installed in these construction joints. Tooling of the joint edge is unnecessary and undesirable.

CURING

Curing should be placed as soon as possible without marking the fresh concrete. If a double layer of wet burlap is used, it must be kept saturated (Fig. 10). White pigmented membrane has been used successfully with spray applications.

CONSTRUCTION CONTROL

Construction control that produces satisfactory work is a compound of experience and application of adequate specifications. An adequate specification insures that differences of opinion which may affect the quality of the construction will be resolved on the basis of engineering experience. It also provides a legally binding agreement as a basis for the engineer to establish those construction controls which he knows from experience are necessary to produce a satisfactory structure.

Most highway bridges are built by agencies which have established Standard Highway Specifications. Where more detailed bridge deck specifications are needed, they probably would be incorporated as a supplement to, or a revised section in, the Standard Specifications. In either case, the form and wording should conform to local practice. For this reason, the suggested specification provisions which follow are presented in outline form.

SUGGESTED SPECIFICATION PROVISIONS FOR PLACING AND FINISHING CONCRETE BRIDGE DECKS

General

Conform to Standard Specifications requirements, except as supplemented or modified herein.

Conform to plan dimensions and elevations, except as modifications are approved by the engineer.

Place deck concrete in the sequence shown on the plans.

Construct curbs, sidewalks, and parapets after curing of deck concrete is completed.

Surface smoothness tolerance the same as for pavements on grade, but not more than ⅛ in. in 10 ft.

Finishing procedure and equipment the same as for pavement on grade, except:

1. Single, suspended screed, power driven finishing machine is permitted for strike-off and screeding; or
2. Vibrating screeds are permitted for strike-off and screeding;
3. Hand finishing methods permitted outside of mechanically screeded areas, and to a bulkhead in case of equipment breakdown;
4. Longitudinal float may be hand operated.

Preconstruction conference of engineer and contractor to review proposed construction procedures and requirements.

Materials

Conform to Standard Specification requirements.

Composition of Concrete

Maximum water cement ratio: not more than 5 ¼ gallons per sack.

Fine aggregate portion of total aggregate: 35 to 45 percent.

Consistency: 2 to 4-in. slump.

Air entrainement: 6 percent plus or minus 1 percent for ¾-in. and 1-in. maximum size coarse aggregate.

Minimum cement factor: not less than 6 sacks per cubic yard.

(Where severe exposure is not a consideration, the water and cement requirements can be modified to suit local conditions.)

Construction Methods

Finishing machine wheels to be supported above pavement surface on temporary rails or other horizontal structural device.

Vibrating screeds to be supported on temporary pipe guides, grade angles, etc., at surface elevation.

Vertical supports for screed guides or finishing machine rails to be fixed, but vertically adjustable; spaced to limit deflection under the screed or finishing machine to not more than ⅛ in. in 10 ft; erected on structural members, unless permitted otherwise by the engineer; removable to at least 2 in. below the surface, with minimum disturbance of the concrete.

Screed guides, or rails, to be set to elevations determined from the profile grade line, and adjusted for calculated deflections and surface cross slopes (the relative difference in elevation between the top flanges of structural beams as erected and the surface grade must be determined to insure required slab thickness and cover over reinforcement).

Screed guides, or rails, to be surfaced before placing concrete; final surfacing, after elevations have been checked by instrument, by minor vertical adjustments to the supports while "eyeing in" to obtain a smooth surface.

Concrete to be delivered at uniform, adequate rate by buggy or bucket ahead of finishing machine or screeds.

Concrete to be placed without segregation, spread to approximate grade, and consolidated around reinforcing before screeding.

Finishing machine to be power driven for oscillating screed and machine movement.

Vibrating screed to be power vibrated and moved with positive means, such as by cranking or by winch and cables; pulling by hand lines may be approved by the engineer when he has determined that the method will produce satisfactory results.

Screeds adequate to cover not less than the projected width of approach pavement, and preferably the full width of deck being placed.

Screeding to progress forward at a slow and uniform rate.

All operations following screeding to be performed without walking in the concrete; from work bridges if necessary.

Voids left after removal of screed guides and supports to be filled with concrete — not mortar.

Sixteen-foot longitudinal float worked parellel to pavement centerline with a sawing motion across the width of surface and back, before moving ahead one-half length.

Ten-foot long-handled finishing straightedge to be used by experienced pavement finisher; straightedging to be delayed as long as possible to allow for subsidence.

Ten-foot testing straightedge to be used while concrete is still workable and irregularities can be corrected.

Surface texture to be the same as on approach pavement.

Curing by continuously saturated burlap, paper or white pigmented curing compound, to be applied as soon as possible without marking the fresh concrete.

At least 15 days before starting concrete placement, the contractor to submit for the engineer's approval a plan for concrete placing and finishing operations, material supply, equipment and men to be used.

CONCLUSION

The essential requirements discussed herein have been found for many years to be good practice in securing smooth-riding surfaces on bridges and highway pavements. The suspended nature of a bridge and the limited working space usually create conditions requiring careful planning and some ingenuity if basic requirements are to be met. Where pavements have not been satisfactory from a smooth-riding standpoint, it has been observed that one or more of the requirements discussed herein has been omitted. Surprising as it may seem, much important bridge deck paving has been observed where many of the procedures mentioned here were omitted, and only the barest screeding tools were used. Simply screeding off the fresh concrete and applying a surface texture is not adequate to finish a pavement expected to have a smooth-riding surface. It is important that adequate design and specifications be provided, and that the engineer and contractor review the matter of essential equipment and procedure for paving.

Portland Cement Concrete Paving with Central-Mixed Concrete

W.P. Yamarick, Chief Engineer, C.F. Replogle Co., Circleville, Ohio

The increased volume of highway construction during the past decade has challenged the ingenuity of designer, contractor and equipment manufacturer. Greater need for intricate interchanges, urban construction and other complicated pavement arrangements promoted the consideration of more efficient construction methods. Central-mixed concrete offered the necessary characteristics of high-capacity automation, versatility and portability. Through the cooperative efforts of owner and contractor this method has now proved its merit by performance and ranks as an outstanding development of the highway industry. This paper represents the experience of a contractor employing central plant procedures on varied highway projects for the State of Ohio.

●FOR THE PAST two decades, "paver on the grade" has been the universally accepted technique for producing high volume, quality concrete for large highway paving projects. With the continuing impetus of progress and competition, standards were established by industry that influenced the consideration of other methods. High production, versatility, and rigid quality control were all met by central-plant installations. Equipment improvement, advent of air-entraining concrete and modification of restrictive specifications made practical the application of this technique to highway construction. In general, central-plant installations include the following basic approaches:

1. Transit mix — the proportioning of material at a central location and mixed in a transit-mix truck either en route or at the work site.
2. Shrink mix — the proportioning and partial mixing at a central plant and delivered to the work site in transit-mix trucks.
3. Central-plant mix — the proportioning and complete mixing of materials at the plant and delivery to the work site in agitator or non-agitator trucks.

This report is devoted to central-plant mixing and hauling with non-agitating trucks. Numerous comparisons to pavers are made throughout because of the almost universal familiarity with this type of operation.

CENTRAL-PLANT INSTALLATION

The components of a central plant are basically similar to a conventional dry batch installation with the addition of a mixing unit. Aggregates are weighed and delivered to a rotating drum, cement is measured conventionally, delivered with the aggregate or fed directly to the mixer where water is added and the resultant mixture discharged into a hauling unit or an accumulating hopper.

The modern plant is usually fully automatic with interlocked batching and mixing controls so as to minimize human errors. The operation of the plant is electric, powered by portable generators or commercial current. A master control panel is normally located at the mixer with auxiliary controls at each operation to permit manual operation should the automatic mechanism fail.

A typical cycle of a central plant is as follows: the cycle can be considered to begin when the drum returns from its discharging tilt. The drum returned to its mixing position actuates a relay that opens the discharge valve of the water weighing hopper and the proportioned water is fed to the drum. A few seconds later the drum is charged with aggregate followed by cement. After the specified mixing time has elapsed the concrete is discharged and hauled to the placement site. During the mixing operation, cement and aggregates are automatically proportioned and stored, either on a conveyor belt that directly charges the mixer or in a holding hopper located above the mixer, and then charged by gravity.

The concrete is hauled to the placement site in trucks equipped with specially designed non-agitating bodies. Capacity of these vehicles varies from 4 to 6 cu yd. The concrete is gravity discharged by raising the beds and spotted accurately by chutes that are hydraulically actuated. At the pouring site the concrete is placed in a self-powered box-type spreader. This spreader is equipped with a hopper which travels across the grade from one form to the other depositing concrete evenly to the correct depth. When depositing bottom course concrete, this spreader has a capacity of approximately 150 to 180 cu yd per hour. For half-width paving, concrete is usually discharged directly on the grade and spread with a conventional screw spreader. However, it is desirable, if not necessary, on full-width paving to place the mix inside the forms by other means. As yet, auger and paddle spreaders are not available to efficiently transfer concrete 18 to 20 ft at the rate necessary to handle the production of a large central plant. In the event only auger spreaders are available when paving full width, hauling units would have to pour from both sides of the pavement or travel inside the forms on the subgrade. After placement of the mesh, the top lift can be placed by a second box spreader or by backing the first spreader that deposited the bottom lift. Because most specifications permit a heavier first lift, many contractors find it possible to use a conventional auger spreader on the top lift without diminishing production. The remaining operations of finishing and curing are identical to the other paving methods and are not discussed herein.

INVESTMENT CONSIDERATIONS

A contractor purchasing a new paving spread will base a major portion of his decision on initial investment and operating costs. It is reasonable to assume that the finishing equipment is comparable in cost regardless of the paving method employed. Therefore hauling units and plant are the two remaining requirements to be considered.

Hauling Units

In general a fewer number of slightly more expensive hauling units is required for central-mix paving operation. The additional initial cost results from the use of specially designed, single-purpose bodies. The fewer number results from reducing the waiting time at the plant for loading and reducing the time at the grade for discharge. For example, the average total time to load and discharge a 6-cu yd hauling unit is between 1½ to 1¾ min. This is about equivalent to the time necessary for a single 1⅓ dry batch to be weighed at the plant and dumped into the skip of a paver. The travel time for either vehicle being equal. Simply stated — improved equipment usage is realized in a wet-batch haul through the reduction of waiting time at the batch plant and grade for an equivalent yardage.

From an investment viewpoint, however, the contractor considering central plant is confronted with the additional expenditure for hauling units, whereas in a paver operation, hauling units are universally available on an hourly rental or a per batch basis. This possibly represents the major difference in basic initial cost in the two techniques. At an average cost of $15,000 each for ten to fifteen hauling units, an investment of this magnitude must be justified on the basis of:

1. Availability of capital.
2. Continuity of work that would permit the distribution of the fixed costs of depreciation and interest.
3. Available projects consisting of hauls sufficiently comparable so that a base number can be acquired to handle the plant production efficiently. Occasionally the

capacity of the plant is not fully used on extreme hauls of a job because it would be too costly to own hauling units for the few days necessary to pour out the long-haul yardage. A dry-batch hauler, however, has the versatility of more readily adding trucks on the long haul to satisfy the demand of pavers.

Plant Facilities

The production available from a paver or a central plant is largely dependent on the required mixing time. Extensive tests conducted during the past few years verify that time required for proper mixing is not a factor of drum size or batch size. Therefore, for comparative purposes, an 8-cu yd mixer operating on a 2-min cycle (total time to produce and discharge one batch) yields the equivalent of 2 and a fraction dual-drum pavers when operating on a 60-sec mixing time. It appears that the initial investment per cu yd for this phase would be ½ to ⅓ less for central mix. This however does not follow in the case where commercial power is not available and portable generators must be employed to operate the electric drives of a central plant. In this type of installation the initial cost would roughly be equal.

The batching equipment, namely the bins and weighing facilities, are of comparable cost. An appreciable saving occurs in a central-plant installation where municipal or suitable stream water is available and can be piped directly to the mixer. This arrangement is rarely feasible in a paver operation and results in the elimination of two or more water trucks per paver.

The equipment investment requirement resolves itself to (1) the individual contractor's operational program and (2) the specific location of paving projects that may or may not have available commercial water and power supply. No convenient formula applies to all situations. The economics of investment must be reviewed, therefore, on an individual basis.

The author's Company made the following comparative analysis for its own requirements in 1958:

Central-Mix Plant

Fully automatic, portable, 8-cu yd plant.
Production: 240 cu yd per hour when operating on a 1-min 30-sec mixing cycle.
Estimated Cost:

1. 8-cu yd mixer drum complete with base and holding hopper	$ 40,000.00
2. 36-in. conveyor complete	20,000.00
3. Automatic batch bins, cement silos, etc.	60,000.00
4. 300 KW generator and accessories — assembled by the company	30,000.00
	$150,000.00

34E Dual-Drum Paver Plant

Production: Maximum production of two 34E pavers when operating at 100 percent efficiency and a 1-min mixing cycle is 240 cu yd per hour. Probably production is less than 200 cu yd per hour.

1. Two 34E dual-drum pavers	$100,000.00
2. Batch plant — 3 stop	55,000.00
3. 2 water trucks	15,000.00
	$170,000.00

The addition of one water truck to the central plant cost would make its investment close to that of the paver plant. It is pertinent to recognize, however, that the production of 240 cu yd per hour or 200 cu yd per hour fór the pavers may be optimistic where theoretical output of a central plant is not uncommon, and with proper plant design, can be expected. In addition to initial investment, the C. F. Replogle Co. believed that the obsolescence factor as well as maintenance costs were far more favorable to central plant than pavers.

FIELD CONSIDERATIONS

Plant

Approximately four acres are required for aggregate stock piles and plant. A sloping terrain or a side hill arrangement provides drainage and more important, a difference in elevation between the mixer and the batch bins. The mixer drum must be set high enough to discharge into trucks or higher if into a holding hopper (Fig. 1). Conveyors are used to take the aggregate from the weigh batchers to the mixer drum. At an average incline of 18 to 20 deg to prevent aggregate rolling on a belt, the length of the conveyor is proportionate to the difference in elevation between the weigh batcher and drum.

Many installations place both the cement and aggregate on a conveyor belt. This offers the desirable advantage of pre-blending all materials, except water, by ribboning the cement on the belt with the aggregates. The batch enters the drum in a proportioned mixture that greatly improves the uniformity of the concrete. Repeated field tests have verified the desirability of this operation. The loss of cement from the belt is negligible and is considered less than that experienced in a paver operation. This pre-blending operation can also be accomplished by storing the aggregate and cement in a holding hopper prior to charging the mixer. The effectiveness of both techniques has prompted certain authorities to consider this as a factor in reducing the mixing time required by their specifications.

The central-mix plant presents a different maintenance task to a contractor because practically all drives and controls are electrical. Sealed explosion-proof motors, control panels enclosed in dustproof housings, etc., have resulted in availability of 95 percent or better. This degree of performance can be insured only through the training of competent mechanics and electricians. An effective preventive maintenance program is vital. Any breakdown of the plant results in complete stoppage of production, whereas in a multiple-paver spread the failure of one mixer reduces output but doesn't completely terminate operations.

A mobile radio installation is almost mandatory to permit close contact between the plant and pouring site. A breakdown of a key machine on the forms might occur when upwards of 100 cu yd is mixed and must be either placed in the forms or wasted. A 5- or 10-min delay in notifying the plant might add another 25 to 50 cu yd to handle. This surge of mixed concrete, however, offers an advantage in the event of a plant breakdown because there is usually sufficient concrete on the way to the grade to pour to a bulkhead.

Grade

After the concrete is placed in the forms, the finishing of central-mixed concrete is performed by conventional methods. The placing of concrete within the forms by a box-type spreader has proved satisfactory and efficient. The box or hopper has an open discharge gate so the concrete flows directly on the grade and is large enough to receive the full yardage of a hauling unit. Because the combined weight of the machine and concrete is appreciable, the spreader is so designed to transfer its weight to two forms by use of four wheels and two walking beams on each side. Nevertheless it is advisable to use heavy-duty forms to minimize deflection during operation. Particular care must be exhibited in superelevated sections to insure sufficient penetration by form pins into the subgrade to resist the overturning of forms by the spreader. The use of a box-type spreader presents other operational considerations because of its size, 24 ft by 28 ft. Lifting on and off forms must be closely supervised to avoid any racking which would interfere with subsequent mechanical operation. In addition, transferring from one site to another requires the dismantling of this spreader to permit hauling over highways.

When operations approach a bridge that must be crossed, light mine rail are laid and the equipment traveled to the other side under their own power. No time is lost, because mixed concrete can be placed directly on the grade ahead by the hauling units, while the finishing equipment is crossing the structure.

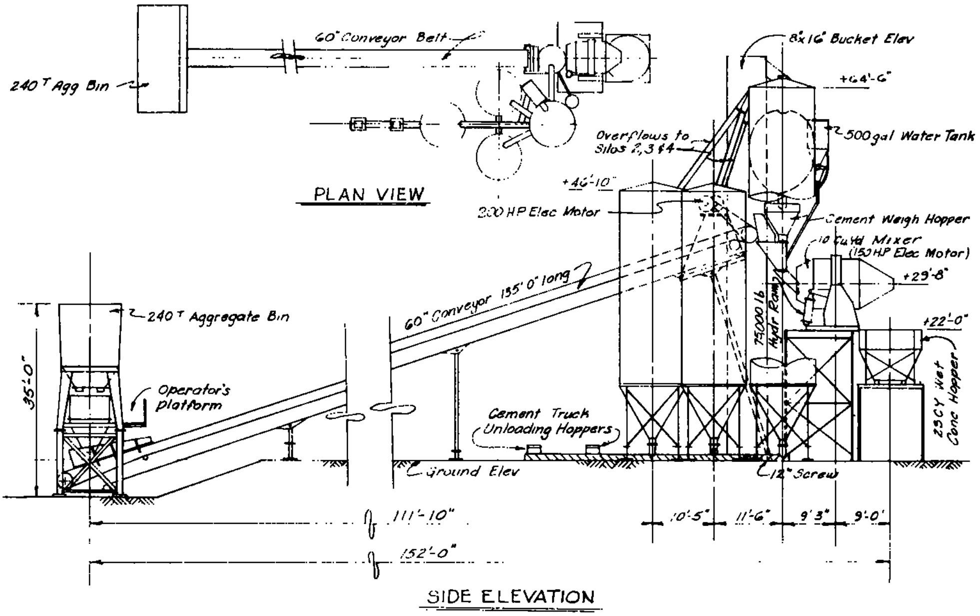


Figure 1. Batch plant arrangement 10 cu yd mixer.

Usually concrete is poured at more than one location at one time. This is accomplished by the organizing of a crew for main line and a crew for approaches and miscellaneous work. Properly scheduled completion of the main line is concurrent with the completion of all other paving. The full plant capacity is therefore used at all times from beginning to end of a paving project.

Hauling

Central-mixed concrete is transported in specially designed bodies of either the agitating or non-agitating variety. The choice largely depends on the specific requirements of the contractor. Agitation is looked on with favor by many commercial consumers of ready-mix concrete who favor concrete being mixed as it is discharged. Certain urban hauls lend themselves to agitated hauls, particularly those of extended travel time. However, these considerations may be academic in choosing the type of hauling units for the majority of highway pavement construction. Extensive tests confirm the acceptability of both methods, each having its own particular characteristics that may be desired to meet a given requirement. Many contractors have gone to non-agitated hauling units because of lesser initial and operating costs.

No detrimental effects have been experienced in transporting concrete in non-agitating units on paving projects in the State of Ohio. Hauls in excess of 5 miles are uncommon; however, 10- and 12-mi distances have been completed acceptably. Factors other than distance should be considered, such as haul road, atmospheric conditions, air content, and slump. It is usually possible to pour away from the central plant and use this pavement to travel on after the curing period, thereby increasing travel speed and reducing time of delivery. Smooth, properly maintained haul roads also reduce the disturbance of the mix that might promote segregation during haul. It is very important that the air content be kept at the upper limits permitted by specifications. A mix of five to seven percent air is desirable, which after hauling extended distances, places and works well. No significant loss of air is realized even on the most extended hauls. Such efforts can insure the delivery of concrete with no detrimental characteristics.

Vibrators are installed on dump bodies to insure rapid and thorough discharge. Bodies require thorough cleaning at the end of each shift. Dirty beds promote further buildup of the following shift and add unnecessary weight to the hauling unit. The trucks must possess a great degree of dependability because of the risk of concrete setting up in the body during a breakdown. Exceptionally well-maintained haul roads are necessary to minimize mechanical failure of trucks. The high center of gravity of rear dump hauling units require that berms be bladed level particularly in superelevated sections to avoid overturning. Pouring operations are usually scheduled to permit discharging the vehicles on the driver's side. This allows faster spotting and more important, a safer operation because the driver can gage his movements personally and, therefore, more accurately.

CHARACTERISTICS THAT WILL PROMOTE MORE EXTENSIVE USE IN FUTURE

Versatility

To properly handle modern traffic, pavements have become increasingly intricate in design. Complicated interchanges and the intersections require extensive variable width lanes, tapered sections, dog legs, approaches, and like work. This is generally low production work involving extensive hand labor to pour and finish. The use of pavers results in the use of only a small portion of its capacity thereby greatly increasing the cost of this operation. Central mix offers the flexibility to perform this work efficiently. The plant production can be fully realized by pouring in multiple locations at one time. It is common practice to pour at ten or fifteen locations in one day in addition to maintaining production on the main line pavement. Further, the delay in production when moving a paver from one location to another is all but eliminated because of the maneuverability of truck hauling units.

Central mix offers particular adaptability when operating in inaccessible or restricted areas. The congestion of pavers, batch trucks and water trucks is eliminated and replaced by a delivery spread. When only narrow berms are available for working area, it is often necessary to operate the paver inside the forms while backing the batch trucks a considerable distance down the subgrade. The rutting of the subgrade, tracking of foreign material by the batch trucks, and placing of joint assemblies close to the placement of concrete may be undesirable. These objections can be minimized or entirely eliminated in a central-mix operation when sufficient berm is available for the travel of trucks.

Paving with central mix is particularly adaptable to areas congested by restricted working room and necessity of maintaining public traffic. Very often this category of work cannot feasibly be performed by pavers because of the amount of equipment necessary at the pour. Under such conditions, a contractor may choose to construct such pavement by purchasing commercial ready-mix concrete. The cost of this pavement is increased and the yardage of pavement poured by the plant is decreased over which the fixed cost of move-in and set up are distributed.

Automation

The construction industry is following the trend of time toward reduction of labor and improvement of product through automation. Locating the facilities of batching and mixing at one site greatly implements the conditions under which automation can be economically applied. Labor reduction may in reality be a secondary benefit. Each variable controlling quality, such as moisture in aggregate, air content and slump, can be reflected accurately and quickly without the delay of manual performance. Additional benefits are realized by the owner because fewer qualified inspectors are required to administer a centrally located, automatized operation.

Many contractors have experienced considerable operational difficulties when automatizing a paver-batch plant. A batch plant serving three pavers on a 1-min mix must produce approximately 240 batches per hour. Measuring cement, water, and 3 aggregates would require 1,200 operations per hour. A 12-cu yd central plant on a 1- to 1½-min mixing cycle can reasonably be assumed to approach the output of three pavers. At 30 batches per hour only 150 measurements are required. The sheer number of additional cycles necessary to produce an equivalent amount of concrete greatly increases the exposure of mechanical failure.

Capacity

The quantity of concrete that can be economically produced by a central plant is virtually unlimited. Additional mixer drums at the plant would yield as much concrete as could be hauled by the available units. Because the congestion at the site of pour is greatly diminished, only the imagination of the contractor in building a plant and the engineer in designing the project would control the ultimate capacity of the installation.

DEVELOPMENTS AND INNOVATIONS

The technique of central-mix concrete paving is of comparatively recent origin. Research and developments will produce improvements that will surpass accepted standards of today. Fully automatic batching from a central station will soon be common. Electrical controls will conduct every phase of a batching operation. The quality and uniformity will be confined within minute tolerance by instruments that will compensate for moisture variations in aggregate for each batch. The effort being directed to not only eliminating human error but also to reflect more quickly the variances in materials that control the quality of concrete.

The importance of water-cement ratio has been recognized as an all important factor to quality concrete. Significant progress has been made in the development of side discharge dump bodies that will handle concrete of minimum slump that would still be workable. They are a non-agitating body design that rotate as a unit about a center shaft parallel to the chassis. The discharge is not restricted by collecting chutes and the full length of the body permits the rapid flow of concrete into a box-type spreader.

The turbin mixer being developed and tested at present offers interesting advantages desired by central plant manufacturers. The compactness of a turbine mixer would lower plant height making construction more economical and improve the over-all portability of the plant. In addition, the reduced mixing time offers high production desired by industry.

Innovations and improvements such as these are unlimited — the challenge of which will be continually met by the contractor and the engineer. The highway industry needs an atmosphere of assistance and cooperation such as prevalent in Ohio. Specifications must permit and stimulate new techniques to be developed and tested. Pavements of higher quality and reduced costs will be the result. Eventual savings will be shared by owner and contractor — the final beneficiary will be the public who will travel on more high-type pavements.

Effect of Mixing Time and Overload on Concrete Produced by Stationary Mixers

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

This paper covers tests made in conjunction with the Bureau of Public Roads on two concrete paving projects to determine the minimum time of mixing required by stationary mixers, used to mix concrete for agitating or non-agitating delivery, to prepare well-mixed and uniform concrete, and to determine the amount of overload that can be permitted.

Two mixers were used in the tests, one a 210 S, the other a 254 S. Mixing times were 150, 120, 90, 75 and 60 seconds, with no overload and with a 10 percent overload.

Tests were made to determine compressive and flexural strength, consistency, air content, unit weight and percentage of mortar in the mix (using washout).

Based on the results obtained, the Ohio Department of Highways has changed its specifications for central-mix concrete to $1\frac{1}{2}$-min mixing time with an allowable 10 percent overload.

● **IN THE SUMMER** of 1958, the Ohio Department of Highways participated in a mixing time study of 34-E dual-drum pavers. This study, suggested by the Bureau of Public Roads and participated in by several highway departments was to determine the most desirable mixing time and the permissable overload, if any. As a result of Ohio participation in the paver study, considerable interest in optimum mixing times, not only for pavers, but also for stationary mixers used with central-mixed concrete paving operation was generated in the state.

Generally, a minimum mixing time of one minute for the first cu yd plus 15 sec for

Figure 1.

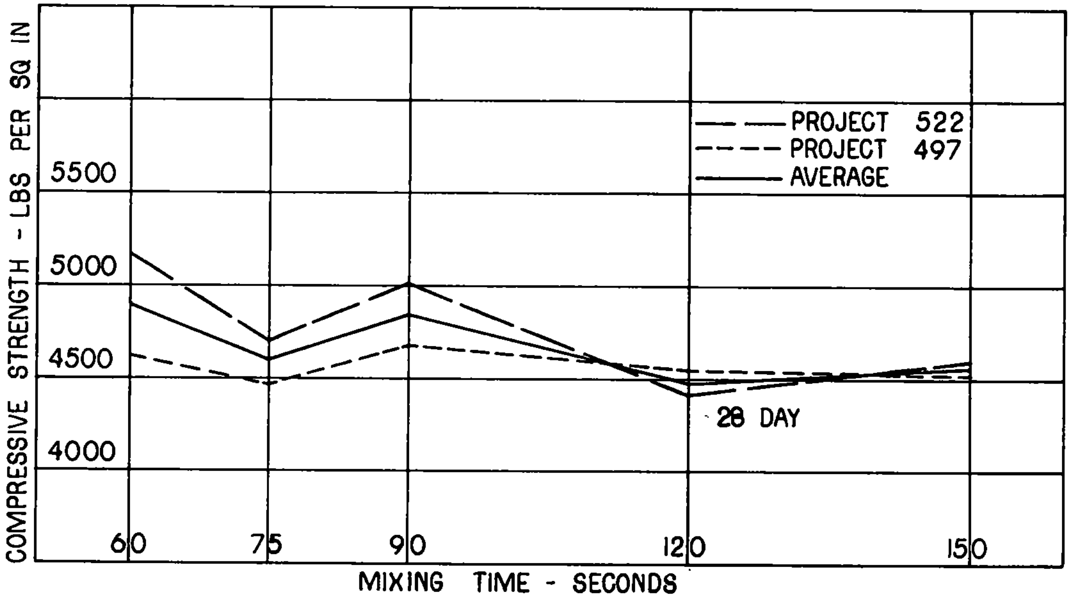
each additional yard or fraction thereof was specified for concrete completely mixed in a stationary mixer. Some concrete users, however, were of the opinion that the length of mixing time required was not dependent on the size of the mixer, but that any properly designed mixer, regardless of size, would mix concrete in approximately the same time.

Figure 2.

Figure 3.

The Ohio Department of Highways specifications required a minimum mixing time of two minutes for stationary mixers.

The possibility of including stationary mixers in the paver study was reviewed with the Bureau of Public Roads and it was decided a more practical approach would be to conduct a separate study.



EFFECT OF MIXING TIME ON COMPRESSIVE STRENGTH
AVERAGE OF BOTH LOADINGS

Figure 4.

TABLE 1

MIXING TIME VERSUS COMPRESSIVE STRENGTH

Mixing Time (sec)	Overload (%)	Compressive Strength (psi) 250S Smith Project 522 (1958) Max	 Min	 Avg^{a}	 210S Burmeister Project 497 (1958) Max	 Min	 Avg^{a}	 Composite of 2 Projects Max	 Min	 Avg
		28-Day Break								
150	0	5180	3860	4614	5320	4600	5077	5320	3860	4846
150	10	5080	4140	4568	4570	3460	3973	5080	3460	4271
120	0	4950	3880	4510	4740	4140	4435	4950	3880	4473
120	10	4640	3930	4326	5020	4100	4663	5020	3930	4495
90	0	6030	4740	5306	5080	4170	4629	6030	4170	4968
90	10	5300	4030	4713	5230	4240	4730	5300	4030	4722
75	0	5530	3740	4619	5110	4210	4747	5530	3740	4683
75	10	5430	4300	4803	4850	3820	4210	5430	3820	4507
60	0	5620	4450	5022	5440	4100	4748	5620	4100	4885
60	10	5960	4710	5323	5060	3360	4511	5960	3360	4917

[a] Each average compressive strength represents 27 samples taken from 3 batches.

Accordingly, arrangements were made to make such a study on two Ohio highway projects in the summer of 1959.

A proposed program for the study was prepared and submitted to the Bureau of Public Roads for approval. Variables provided for in the program were mixing times of 150, 120, 90, 75 and 60 seconds, with 0 and 10 percent overloads. The tests were to be essentially the same as those used in the paver study which was reported by D. O. Woolf of the Bureau of Public Roads at the 1960 Highway Research Board meeting. Samples for tests were taken from each tenth batch of 90 consecutive batches. Three samples were taken from each batch sampled. Specimens were made for compression and flexure tests on certain batches. Tests were made for air content, slump and unit weight. Washout tests to determine percent of coarse aggregate were also made. Some modifications in the planned procedure were made as will be explained later.

Two projects were selected for the study. On one project, located on US 33, about 20 miles southeast of Columbus, designation Project 522(1958), Fairfield and Franklin Counties, the concrete was mixed in a 254-S (9.3 cu yd) Smith Mixer (Fig. 1). The weighted aggregates were fed to the mixer by belt, the charging times for a 10 percent overload being 23 sec. For the same size batch, charging time for the water was 26½ sec, and discharge time for the mixed concrete 15 sec. Inasmuch as the plant was completely interlocked only the mixing time was changed, the charging and discharge times remaining unchanged. This gave an additional mixing time of about 2 sec to all batches

TABLE 2

MIXING TIME VERSUS TRANSVERSE STRENGTH

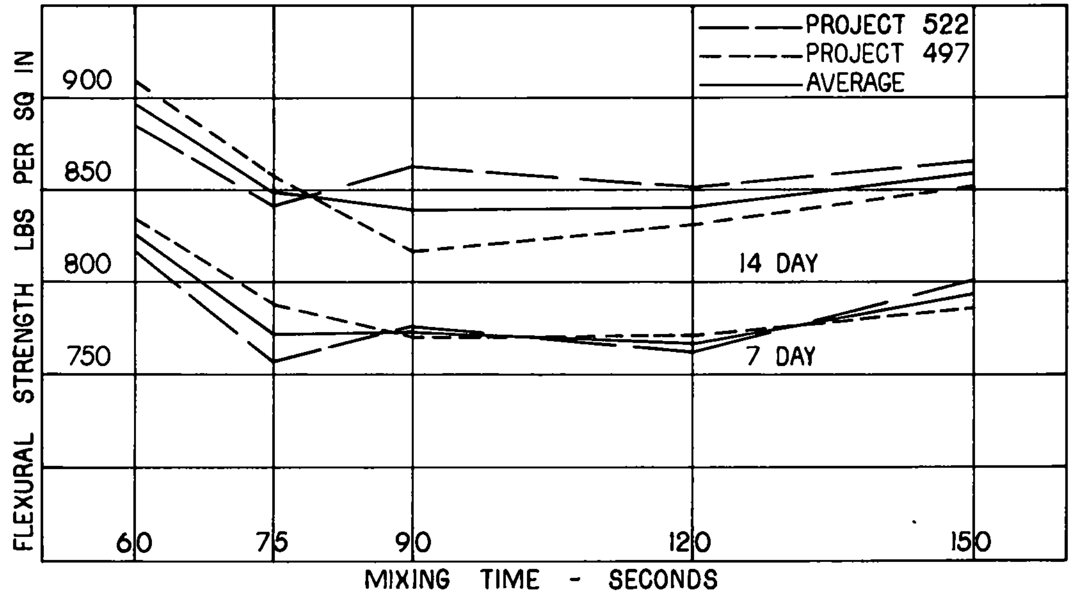
Mixing Time (sec)	Overload (%)	Transverse Strength (psi)								
		254S Smith Project 522 (1958)			210S Burmeister Project 497 (1958)			Composite of 2 Projects		
		Max	Min	Avg[a]	Max	Min	Avg[a]	Max	Min	Avg
					7-Day Break					
150	0	940	720	807	950	660	811	950	660	809
150	10	920	670	796	900	680	761	920	670	779
120	0	880	590	758	950	700	799	950	590	779
120	10	870	650	766	880	650	744	880	650	755
90	0	880	670	778	910	580	796	910	580	787
90	10	890	650	775	920	660	747	920	650	761
75	0	890	680	774	940	710	813	940	680	793
75	10	880	640	739	840	650	764	880	640	752
60	0	930	720	804	920	780	831	930	720	818
60	10	900	760	832	920	650	837	920	650	834
					14-Day Break					
150	0	980	780	872[b]	950	780	861[b]	980	780	867
150	10	980	780	861	990	750	843	990	750	852
120	0	940	740	847	960	760	835	960	740	841
120	10	900	800	856	980	670	826	980	670	841
90	0	950	830	883	910	680	831	950	680	857
90	10	950	760	842	870	720	800	950	720	821
75	0	970	780	861	920	810	861	970	780	861
75	10	870	750	820	940	780	853	940	750	837
60	0	1050	780	904	980	830	904	1050	780	904
60	10	930	730	865	970	850	914	970	730	890

[a] Each average flexural strength represents 18 breaks of 9 beams from 3 batches.
[b] Each average flexural strength represents 9 breaks of 9 beams from 3 batches.

of zero percent overload. Batches of 0 and 10 percent overload with all five mixing times, as planned, were processed through this plant.

A 210-S Burmeister Mixer (Fig. 2) was used on the second project, which was located on US 35 about 15 miles southeast of Chillicothe, designation Project Number 497(1958), Jackson County. With this plant the weighted aggregates and cement were fed by a belt into a collecting hopper, from which they were discharged into the mixer. At this plant, also completely interlocked, the charging time for the aggregates was 44 sec, discharge time 25 sec and charging time for the water 52 sec. In this case, as in Project 522, only the mixing times were changed, so that the smaller batches had slightly longer mixing than did the overload batches. Because the capacity of the cement scales was only 5,000 lb, the complete 10 percent overload could not be used. The actual overload was 9.2 percent. Due to a misunderstanding the 0 overload was not 0 but 2.8 percent. For tabulation of test results and analysis these overloads are considered to be 0 and 10 percent, not 2.8 and 9.2 percent as they actually were.

As the study was originally planned it was intended to take a 100-lb sample from the first third, second third, and last third of the test batch as discharged from the mixer.



EFFECT OF MIXING TIME ON FLEXURAL STRENGTH - AVERAGE OF BOTH LOADINGS

Figure 5.

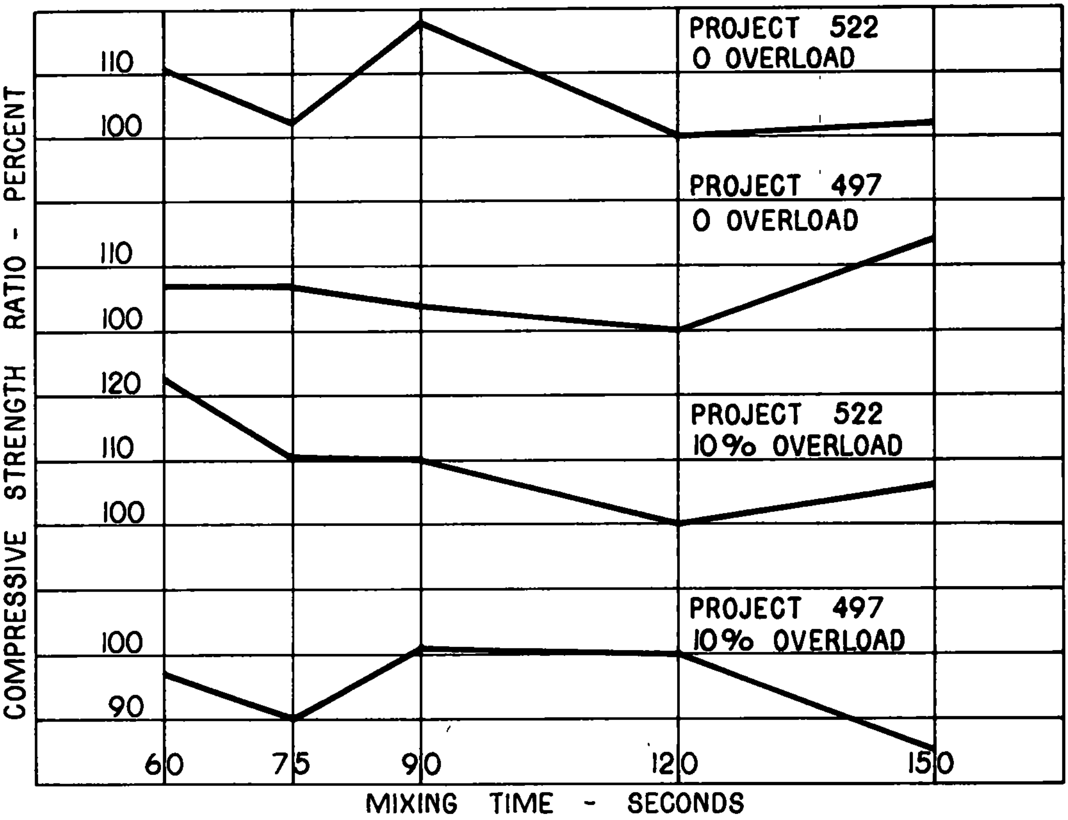
TABLE 3

EFFECT OF MIXING TIME AND OVERLOAD ON COMPRESSIVE STRENGTH AT 28 DAYS

		Unit Compressive Strength (psi)					Ratio to Strength for 120-Sec Mixing Time (%)				
		Mixing Time									
Project No	Overload (%)	60 Sec	75 Sec	90 Sec	120 Sec	150 Sec	60 Sec.	75 Sec.	90 Sec	120 Sec	150 Sec
522(58)	0	5022	4619	5306	4510	4614	111	102	118	100	102
497(58)	0	4748	4747	4629	4435	5077	107	107	104	100	114
522(58)	10	5323	4803	4713	4326	4568	123	111	109	100	106
497(58)	10	4511	4210	4730	4663	3973	97	90	101	100	85
Average		4901	4595	4844	4484	4558	109	102	108	100	102

However, on closer analysis this seemed to be hazardous as well as impractical. Because each plant was equipped with a holding hopper, it was then decided to divide the batches into thirds as they were discharged from the holding hopper. The procedure used was as follows:

1. Immediately prior to discharge of a test batch all concrete in the holding hopper was withdrawn.
2. The test batch was then discharged into the holding hopper.
3. The test batch was then discharged by thirds into three dumpcrete trucks and transported to the casting and testing area.



EFFECT OF MIXING TIME ON COMPRESSIVE STRENGTH AGE 28 DAYS

Figure 6.

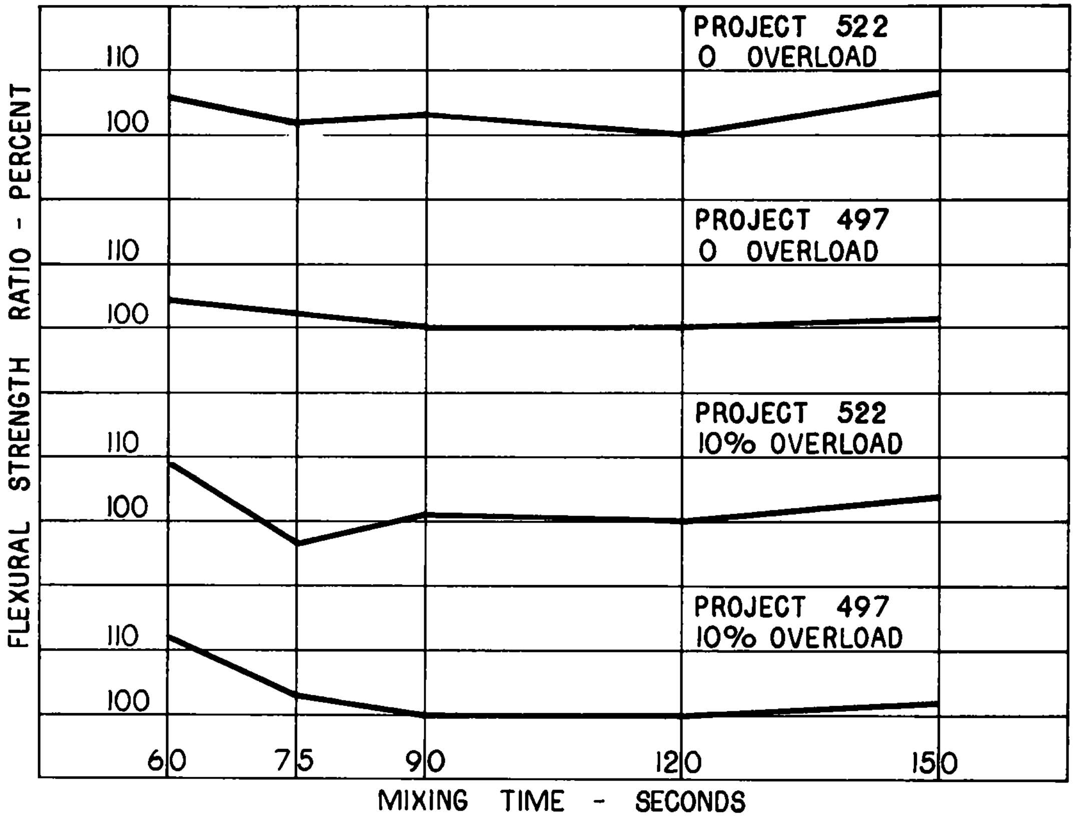
TABLE 4
EFFECT OF MIXING TIME AND OVERLOAD ON FLEXURAL STRENGTH AT 7 DAYS

		Unit Flexural Strength (psi)					Ratio to Strength for 120-Sec. Mixing Time (%)				
		Mixing Time									
Project No	Overload (%)	60 Sec.	75 Sec.	90 Sec	120 Sec.	150 Sec.	60 Sec.	75 Sec.	90 Sec.	120 Sec.	150 Sec.
522(58)	0	804	774	778	758	807	106	102	103	100	106
497(58)	0	831	813	796	799	811	104	102	100	100	101
522(58)	10	832	739	775	766	796	109	96	101	100	104
497(58)	10	837	764	747	744	761	112	103	100	100	102
Average		826	773	774	767	794	108	101	101	100	103

4. At the casting area a test sample of concrete was discharged from each truck into pans (Fig. 3) and designated First, Second and Third samples.

Three 6- by 12-in. cylinders were cast from each third sample of three test batches. These were cured overnight at the casting site and transported to the testing laboratory on the following day where they were stored in the moist room until tested at 28 days. The average results obtained from these tests are given in Table 1. A review of these data shows that the average compressive strength of the 10 percent overload concrete is approximately 4 percent less than that with no overload.

Similarly, 6- by 6- by 40-in. beams were cast for testing. These were handled in the same manner as the cylinders. The beams were tested at the laboratory in a center



EFFECT OF MIXING TIME ON FLEXURAL STRENGTH AGE 7 DAYS

Figure 7.

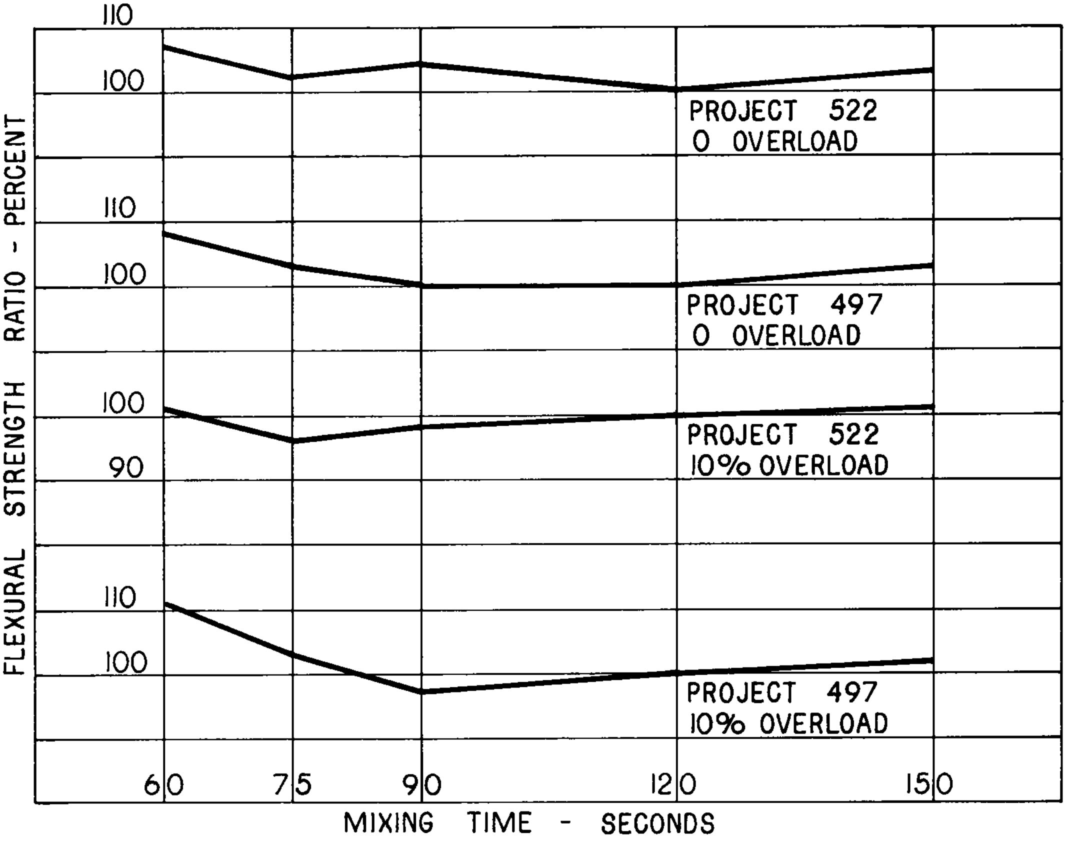
TABLE 5

EFFECT OF MIXING TIME AND OVERLOAD ON FLEXURAL STRENGTH AT 14 DAYS

		Unit Flexural Strength					Ratio to Strength for 120-Sec. Mixing Time (%)				
		Mixing Time									
Project No	Overload (%)	60 Sec	75 Sec	90 Sec	120 Sec.	150 Sec	60 Sec	75 Sec.	90 Sec	120 Sec.	150 Sec
522(58)	0	904	861	883	847	872	107	102	104	100	103
497(58)	0	904	861	831	835	861	108	103	100	100	103
522(58)	10	865	820	842	856	861	101	96	98	100	101
497(58)	10	914	853	800	826	843	111	103	97	100	102
Average		897	849	839	841	859	107	101	100	100	102

loading device, two breaks being made at seven days and one at 14 days from each specimen. The data obtained from these tests are given in Table 2. A review of these data shows that the concrete with no overload averaged 3 percent higher at seven days and 2 percent higher at 14 days than the concrete with the 10 percent overload.

Inasmuch as the overload had no significant effect on either the compressive or flexural strength it may be assumed that a 10 percent overload, at least so far as



EFFECT OF MIXING TIME ON FLEXURAL STRENGTH AGE 14 DAYS

Figure 8.

TABLE 6

AIR CONTENTS OF SELECTED SAMPLES

Specimen No.	Mixing Time (Sec.)	Average[a] Air Volume (%)	Average[a] Number Voids per Traverse (In.)	Average Air Volume Field Tests (%)	Average Slump Field Tests (In.)
10-2-2	60	4.41	7.41	4.2	2
8-5-2	75	4.84	7.46	4.2	2 ½
6-8-2	90	3.83	5.25	4.2	2 ¼
4-2-3	120	3.62	7.13	4.4	2 ¼
2-8-1	150	3.75	7.05	4.2	2 ¾

Note: — All specimens tested represent 10 percent overloads.

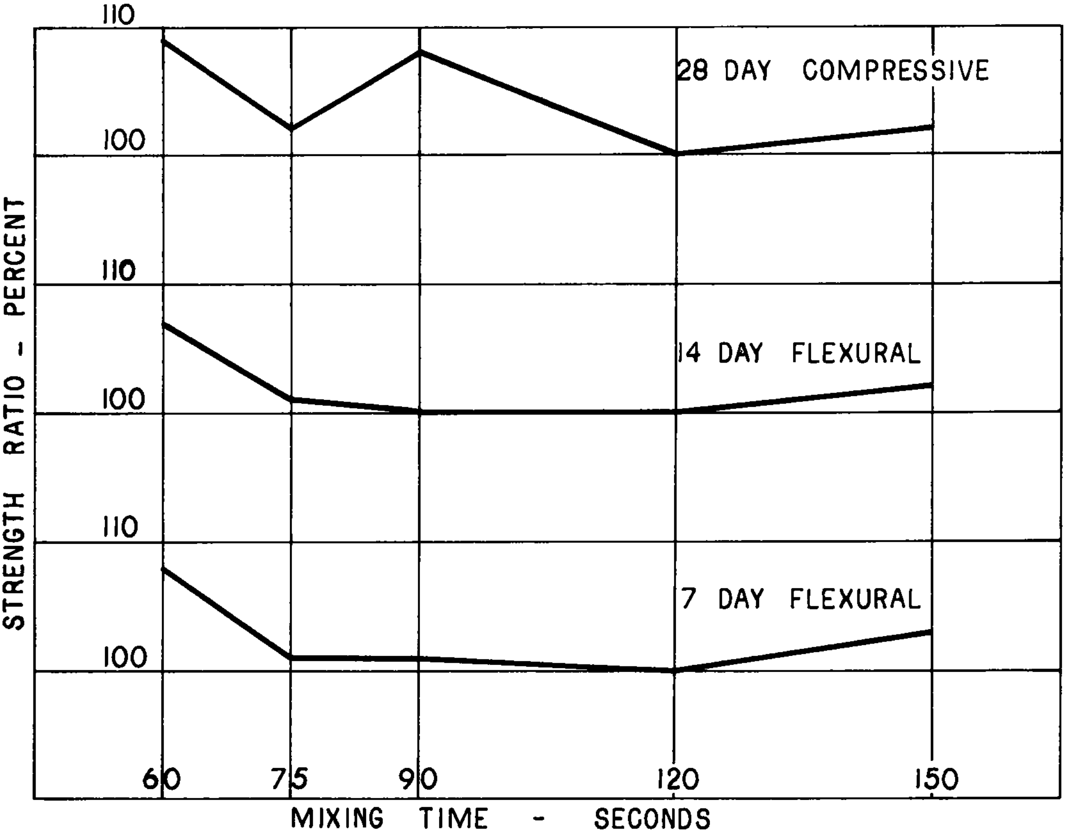
[a] Average of two sections cut from each beam.

strength is concerned, may be permitted because this will produce 10 percent more concrete of essentially the same strength.

The effect of mixing time on compressive and flexural strength using the average of both loadings for each project is shown in Figures 4 and 5. Comparisons were also made to show the effect in percent that variation of the mixing time had on both compression and flexural strength. In these comparisons, the strength obtained with 120 sec of mixing was considered to be 100 percent. Table 3 and Figure 6 give this information on 28-day compressive strength. The 7-day and 14-day flexural strengths are compared in Tables 4 and 5 and in Figures 7 and 8.

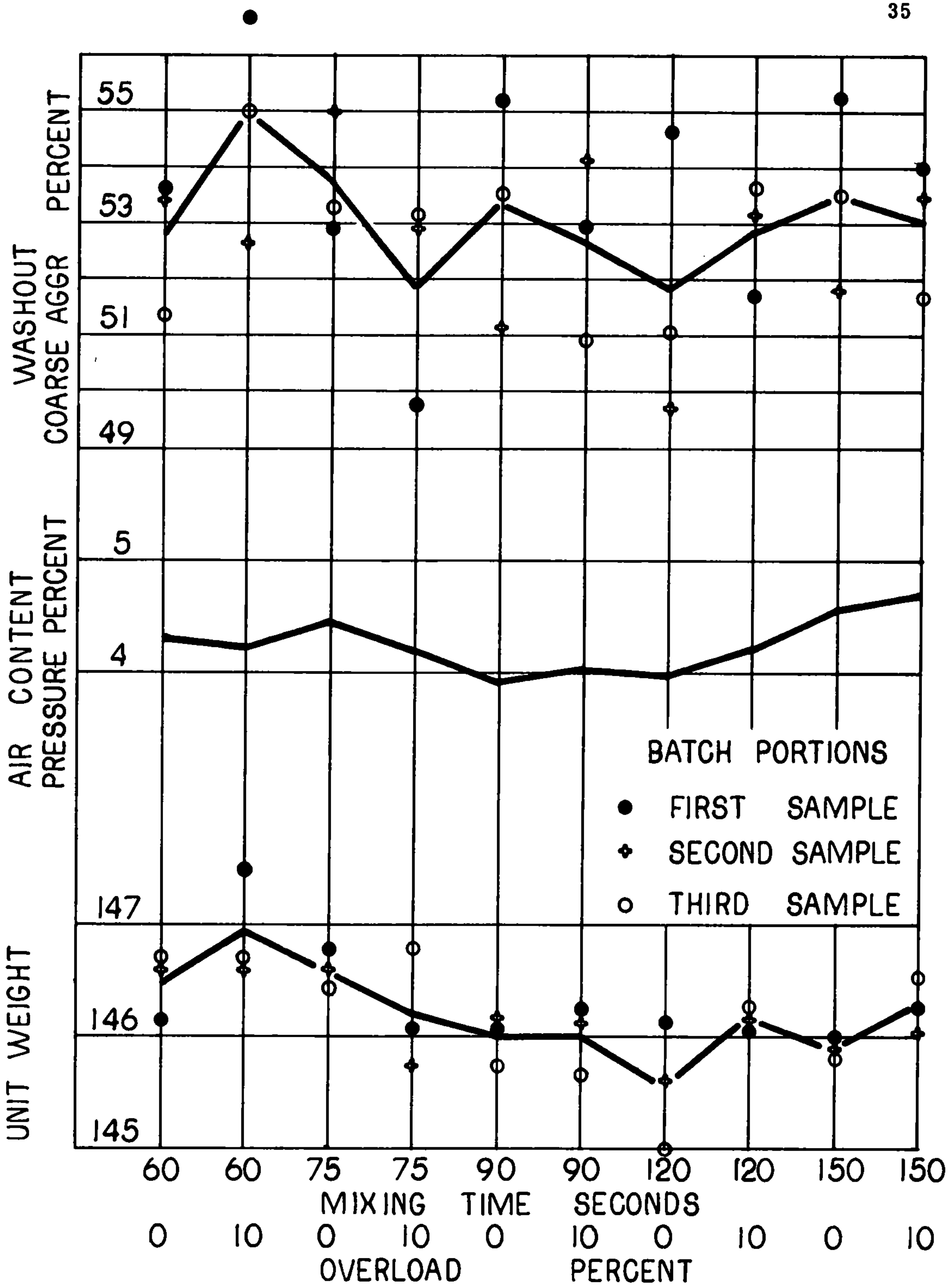
The composite effect of variation in mixing time is shown in Figure 9. Here 0 and 10 percent overload test results are combined using the 120-sec average as 100. A study of the data in Figure 9 shows that both compressive and flexural strengths are greatest with 60-sec mixing. The compressive strength, except for a peak at 90 sec, decreases slowly with additional mixing with some slight recovery at 150 sec. The flexural strength also decreases with more than 60 sec of mixing and here again some recovery is shown with 150 sec. In neither case do the data indicate that mixing more than 60 sec is conducive to higher strengths.

Unit weight determinations and washouts were made to determine uniformity within the batches. These were made on each third of three test batches of each combination of mixing time and overload on both projects. Because different aggregates were used in the two projects, no effort was made to combine the results obtained. The three test samples were combined for each batch and the air content determined using a pressure meter; slump tests and Kelly Ball tests were also made. In addition, air checks



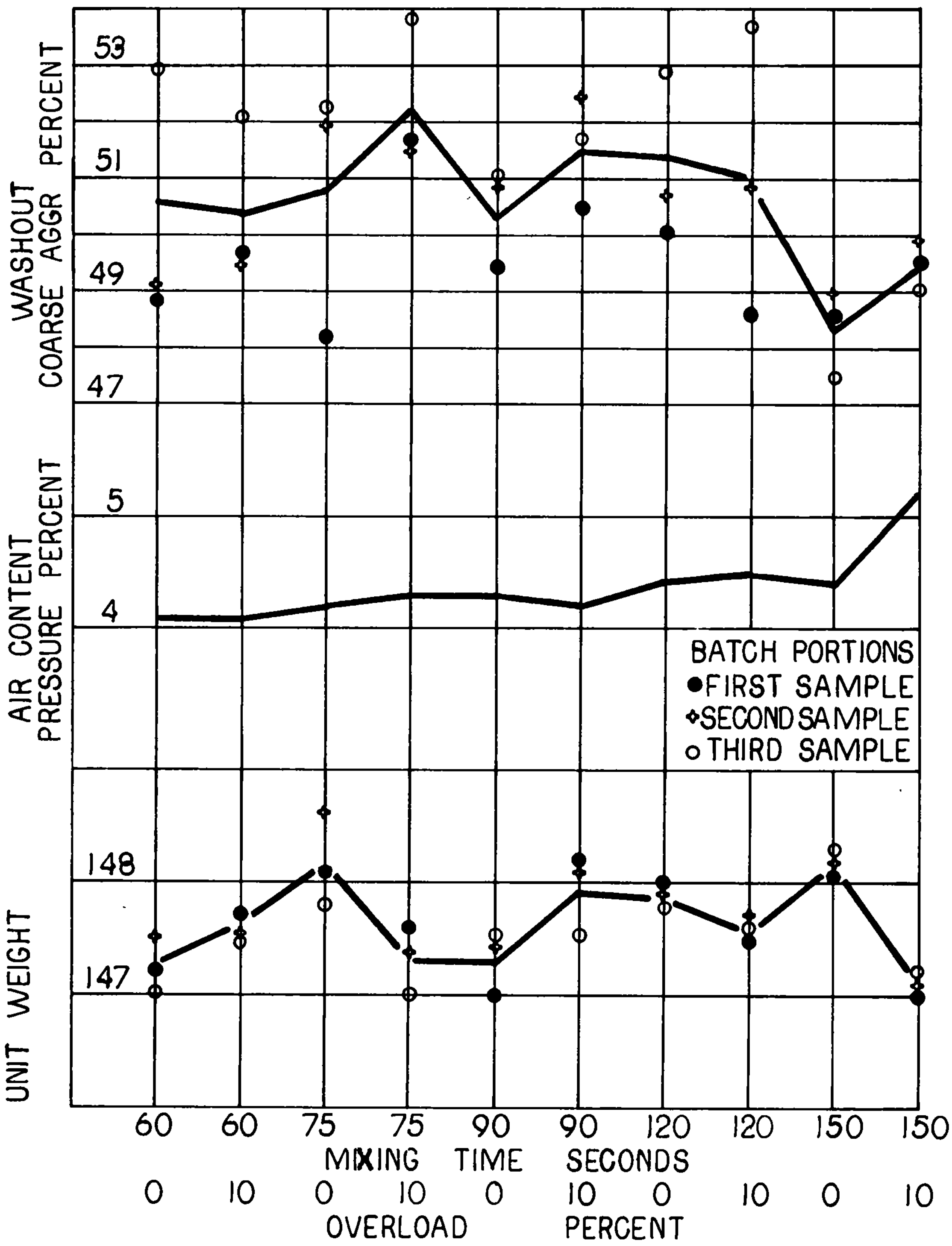
COMPOSITE EFFECT OF MIXING TIME ON STRENGTHS

Figure 9.



UNIFORMITY OF CONCRETE PROJECT 522

Figure 10.



UNIFORMITY OF CONCRETE PROJECT 497

Figure 11.

were made of the individual batch portions using the Chase Air Indicator. These varied considerably and were not used for comparison.

The results of the washout tests, expressed in percent of coarse aggregate and of the unit weights of the concrete for Project 522 (254-S Smith) are shown in Figure 10. No significant variation was obtained indicating that the concrete was mixed to essentially the same uniformity regardless of mixing time or overload used. Similar information for Project 497 (210-S Burmeister) is shown in Figure 11. Again no significant variation is found.

Based on a preliminary review of the data obtained in this study it was decided by the Ohio Department of Highways to reduce the specified mixing time for concrete mixed in stationary mixers from 2 to 1½ min. This mixing time has been permitted by proposal note since December 1959.

It was previously pointed out that the strengths obtained with the 60-sec mix were on the average higher than those obtained at any other mixing time (Fig. 9). This raised the question as to whether the air entrained at this mixing time was of the proper size and distribution. Through the courtesy of the Portland Cement Association, a limited number of air determinations were made (early in 1960) at their laboratory on sections of 5 test beams from Project 522, (254-S Smith). The results obtained by these determinations, together with related field data, are given in Table 6. This shows that based on the data available, the 60-sec mixed concrete had an air content comparable to or greater than that obtained at longer mixing periods.

It is the present intention to make further tests before reducing the required mixing time below the 1½-min minimum now specified. The charging times for aggregates used in this study, 23 and 44 sec, permit some mixing before the actual mixing period is started. This may have some bearing on the actual mixing time required.

ACKNOWLEDGMENTS

The author thanks D. O. Woolf of the Bureau of Public Roads for his guidance and counsel prior to and during the conduct of this study; and also acknowledges the cooperation of both state and contractor personnel involved in the work and points out that all necessary modifications in the contractor's operation were made at no additional cost to either the State or Federal Governments.

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