INSPECTION OF MIXER EFFICIENCIES AT CENTRAL CONCRETE MIXING PLANTS BY MEANS OF GAMMA RAYS

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Synopsis

A nuclear method has been employed in a study of the efficiency of concrete mixers of 1 cu ft, 3 cu yd, and 8 cu yd capacity. The method consists of passing a collimated beam of gamma rays through the mixer and interpreting the extent of absorption as a function of the mixing process. The method is nondestructive.

A period of mechanical clumping has been discovered and its significance is discussed. It is concluded that the method is practical and that a reappraisal of present requirements for mixing time for central plant mix concrete is justifiable.

In March 1961, the Michigan State Highway Department established Research Project 61 H-7 to develop a method of determining concrete mixer efficiencies using nuclear techniques. The study was undertaken as a joint project of the Research Laboratory Division and the Department of Chemical Engineering of Michigan State University. C. A. Zapata, a full-time employee of the Division, was assigned to work on the project under supervision of both agencies in connection with his graduate program leading to the degree of Master of Science in chemical engineering. He was asked to concentrate primarily on the laboratory phases of the investigation.

Coincident with initiation of this research, the Highway Department also undertook a project to study the mixing times of large stationary concrete mixers, in cooperation with the U. S. Bureau of Public Roads. This study was conducted under the supervision of the Testing Laboratory Division, on the 8-cu yd capacity stationary mixer at the plant of the C. F. Replogle Co. of Centerville, Ohio, during construction operations on M 78 (Project 76-23, C2RN) near Morrice, Michigan.

As a result of some success in the laboratory phases of the joint MSHD-MSU project, the MSHD Office of Testing and Research requested the Research Laboratory Division to apply the nuclear technique at Morrice. Attempts to do this during the period of the Bureau of Public Roads study failed to produce satisfactory results because of technical difficulties, and it was only after additional laboratory experiments that these difficulties were overcome. Consequently, full-scale field tests of the nuclear method at Morrice were conducted only after the Bureau study had been completed, between July 14 and 18, 1961.

Later, between September 19 and 28, through the cooperation of the Eisenhour Construction Co. of East Lansing, the Division was enabled to observe the effectiveness of the nuclear technique in monitoring a 3.4-cu yd stationary mixer during construction operations on I75 (Project 16091, C9) near Indian River.

Meanwhile, during and after the Indian River tests, additional experiments were conducted in the laboratory, using a 1.3-cu ft mixer. The experiments included not only the gamma-ray monitoring method, but also such conventional tests as compressive strength, air content, slump, sodium chloride dispersion, sand and gravel distribution, and visual appearance. Many of these laboratory tests formed a basis for Zapata's thesis, which MSU accepted on December 13, 1961.

The field and laboratory tests enumerated for these three mixers, as well as subsequent additional laboratory tests on the smallest one, are analyzed and compared in this report.

Theoretical Basis

Preliminary laboratory investigation in connection with the project showed that a collimated beam of gamma rays, if made to pass through a concrete mixer in such a manner that it can be detected after passage by a sensitive pickup such as a scintillation device, can furnish considerable information concerning the mixer's efficiency.

When the detected pulses are suitably amplified and fed into a recording system, a trace is obtained which provides a permanent record of the times involved in the various stages of the mixing process, together with an indication of the thoroughness of mixing and of relative changes in density that may be related to air entrainment or other factors.

Although laboratory tests using a 1.3-cu ft mixer resulted in production of satisfactory traces with as little as 5 mc of cesium 137, pilot tests for the 8-cu yd mixer showed that this amount of radioactivity would be insufficient. Moreover, satisfactory penetration of gamma rays through concrete--or through any other material, for that matter--is governed not only by the amount of gamma rays available, but also by their energy. The energy of gamma rays from cesium 137 is 0.662 mev (million electron volts) from its barium 137 daughter; that from cobalt 60 is 1.17 mev and 1.33 mev for the pair of gamma rays which it produces; and gamma ray energies for radium 226 are 0.007, 0.047, 0.053, 0.08, 0.188, 0.351, 0.426, 0.5, 0.584, 0.803. 1.438, 1.9, and 2.420 mev. It is obvious, therefore, that with equal source strengths (amount of radioactivity), gamma rays from radium 226 will penetrate farther than those from cobalt 60, and that those from cobalt 60 will penetrate farther than those from cesium 137.*

The Research Laboratory Division was fortunate in having sealed sources of radium 226, in the form of radium 226-beryllium totaling 45 mc (millicuries), which were available for producing a collimated beam of gamma rays of considerable intensity.

Collimation and Equipment

Collimation was accomplished by inserting the source capsules as far as possible into a hole drilled axially in a 4-in. OD by 6-in. lead cylinder to within 2 in. of the bottom, holding the capsules near the bottom of the hole by stuffing in paper, corking the hole, and maintaining the cork in position with friction tape. A cone of gamma rays rather than parallel gamma rays was thus produced, the intensity being very high along the axis in front of the cork, and falling off rapidly at increasing angles from the axis.

Similarly, it was found desirable to collimate the solid angle of acceptance of the scintillation detector from its normal 2π steradians to as narrow a cone as possible. This was done by wrapping five thicknesses of 1/8-in. lead sheet around the tube, projecting approximately 4.5 in. beyond the crystal. Impulses picked up by the scintillation detector were fed into a rate meter, and from there to a recorder.

The scintillation detector used was Nuclear-Chicago Corp.'s Model DS-5 equipped with a sodium-iodide, thallium-activated crystal. The rate meter was a Nuclear-Chicago Model 1620B. The Brush recorder was Model BL-202 used in conjunction with a Brush Model BL-310 amplifier.

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* The National Bureau of Standards (1), for example, has shown that if a given amount of cesium 137 will penetrate 34 in. of 147-pcf concrete with an emergent intensity, x, the same amount of cobalt 60 will penetrate 44 in., whereas radium will penetrate 47 in.--all three to the same intensity, x.

THE 8-CUBIC YARD MIXER

Installation of Equipment

Installation of the nuclear instruments at the Morrice plant presented many difficulties, and it was only through generous cooperation of the contractor's personnel that the source holder and scintillation detector were finally secured in position.

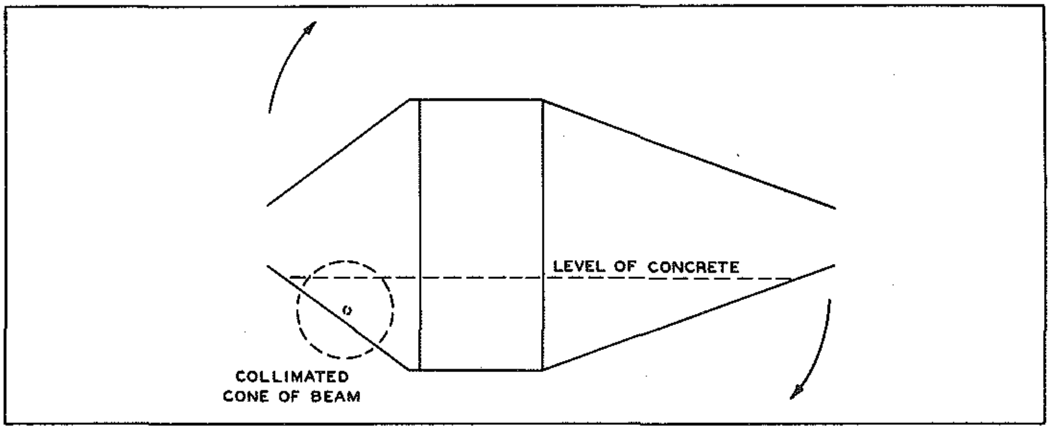
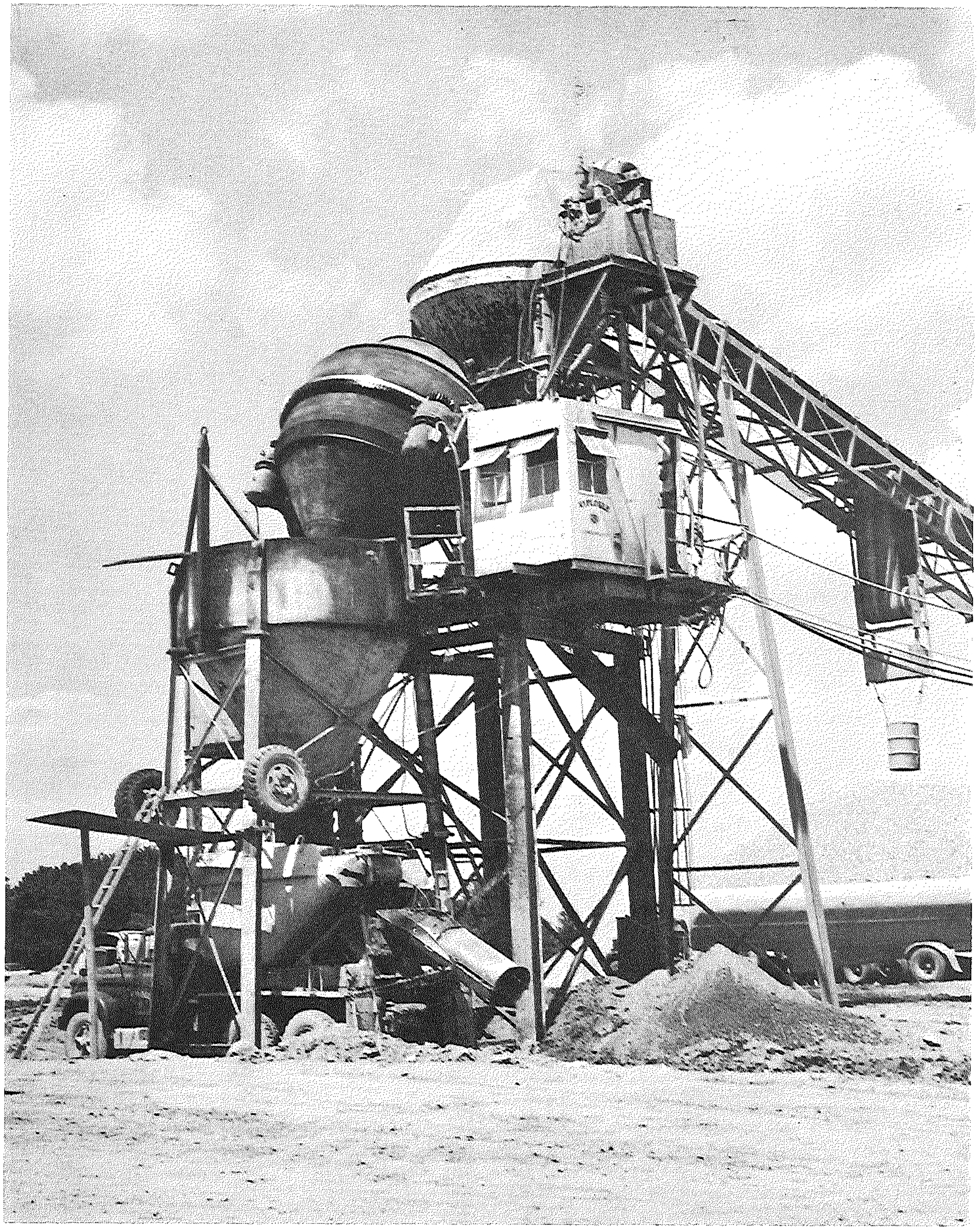


Figure 1. Schematic drawing showing location of collimated beam of gamma radiation.

Consultation with the contractor's superintendent and master mechanic disclosed that there was only one location where it would be possible to weld brackets to support the instruments without penetrating more than about 28 in. of concrete and 3 in. of steel (the maximum useful penetration estimated for the beam), and without interfering with normal operation of the mixer. This location was such that with the mixer in a horizontal position, the source holder would be on one side of the mixer and the scintillation detector on the other, with line-of-sight between the two being about 2 in. above the inside bottom of the mixer and about 2 ft from the charging orifice. Due to the expanding cone of gamma rays, however, and to Compton scattering within the mixer, concrete considerably higher than 2 in. above the bottom would be in a position to influence the amount of pickup. Fig. 1 shows the approximate location of the beam, the mixer being free to tip into and out of the cone of radiation, which remained fixed. Figs. 2 and 3 show the mixer in horizontal and vertical positions, respectively.



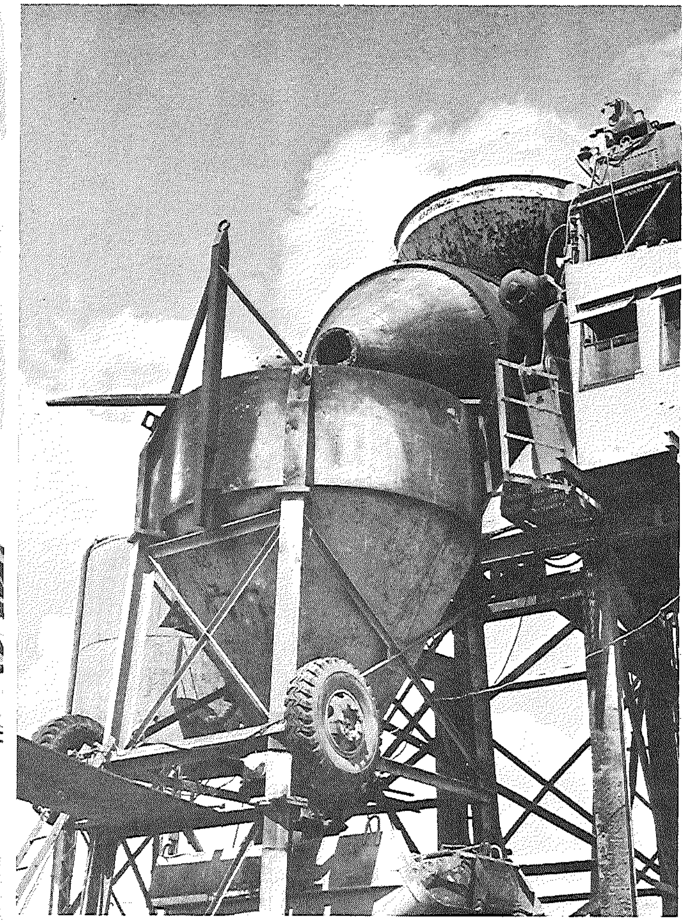


Figure 2. Mixer in horizontal position for mixing cycle (above).

Figure 3. Mixer tilted for discharge into hopper (left).

An additional complication arose from the fact that there was no suitable location for the rate meter, recorder, and other electronic gear. This problem was solved by placing these instruments in the trunk of a car and running a 100-ft cable to the scintillation detector. Although the detector was amply protected from water, cement particles, and other debris by wrapping it with tar paper, the car had to be washed daily to remove mortar flecks from the finish.

Experimental Results

All the equipment was installed and in operating condition by the afternoon of Friday, July 14, 1961. Between that time and the afternoon of the following Tuesday, a total of 106 cycles was recorded, of which 97 were technically acceptable in all respects, the remaining nine in most respects. It was then decided to attempt to make use of the fast neutrons which were also emitted by the radium-beryllium source, in order to secure information on water distribution during the mixing cycles. Time did not permit successful development of a method for satisfactory transmission of slow neutron pulses to the recording system over the 100-ft cable, however, so that no additional data were secured.

Analysis of the trace data indicated that eight distinct points of inflection, or transitions in the mixing process, could be identified. A typical gamma-ray trace of an average mixing cycle is represented schematically in Fig. 4, and Fig. 5 is a photographic reduction of an original trace (cycle 7, tape 2), whose measurements may be found in the Appendix.

Point 1. At point 1 on this trace, the mixer has been in the horizontal position for a few seconds, and charging has progressed sufficiently that enough materials are now intercepting the beam to reduce its intensity to the extent that the recording needle has returned to the trace paper from some position above it. The upper line of the recording paper corresponds to approximately 10,000 counts per minute, and point 1 represents a return of the needle after having been subjected to a shock dosage of several million counts per minute during the time the mixer was discharging in a vertical position and nothing was intercepting the beam. The base line represents zero counts per minute.

Point 2. Since the charging cycle was geared to 41 sec exactly, this interval has elapsed by the time point 2 is reached, if one makes the logical assumption that this inflection of the curve (because it is a low point and therefore means a low count rate or a high density) indicates that all the materials have now been introduced into the mixer. The curve goes no lower at this juncture simply because no more materials are coming in to lower it. As a matter of fact, the curve starts to rise again, as if in preparation for the marked rise which takes place a few seconds later at point 3.

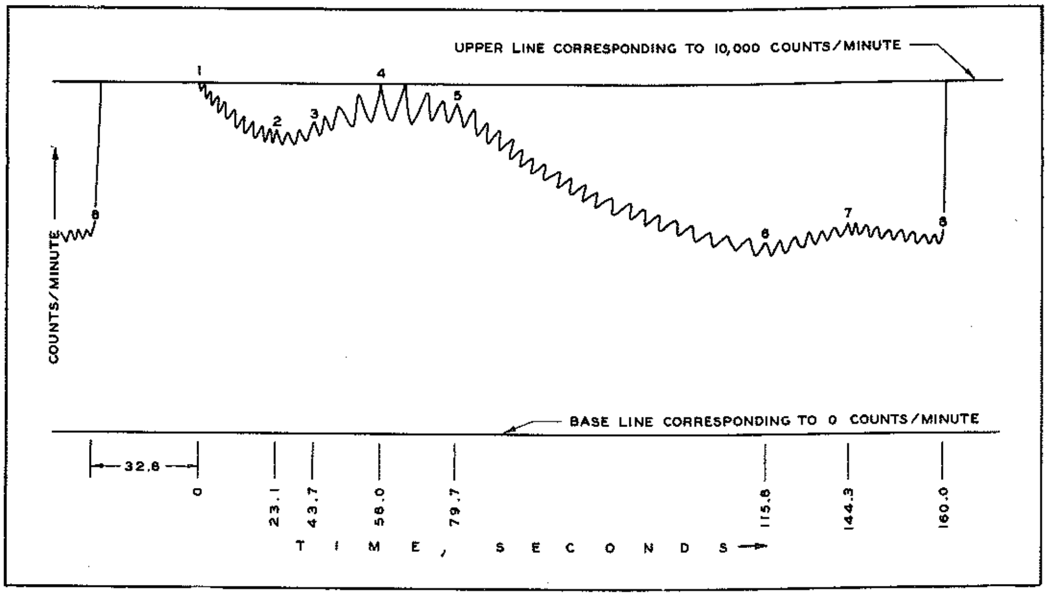


Figure 4. Schematic drawing of a typical gamma-ray trace from the 8-cu yd mixer.

Points 3 through 8. At point 3, the curve not only rises markedly, but the amplitude of the needle swings increases tremendously, both reaching a maximum at point 4. At point 5, count rate and amplitude have both returned to about what they were at point 3. Point 4 is invariably closer to point 3 than to point 5, a phenomenon which has not been explained, but which is thought to be associated with water absorption. Now the amplitude continues to decrease gradually and steadily until the end of the mixing cycle. This is not quite true of the height of the curve, however. The curve reaches a minimum at point 6, the lowest point of the entire trace, rises slightly until point 7 is reached, then falls very slightly to point 8. At point 8 the mixer is raised to a vertical position for discharging, and the recording needle again leaves the graph.

Interpretation of Data from the 8-cu yd Mixer

The field data are summarized in tabular form in Appendix Table 2, which lists the time intervals between major points of the curves, and their elevations above the base line (relative penetration of gamma rays).

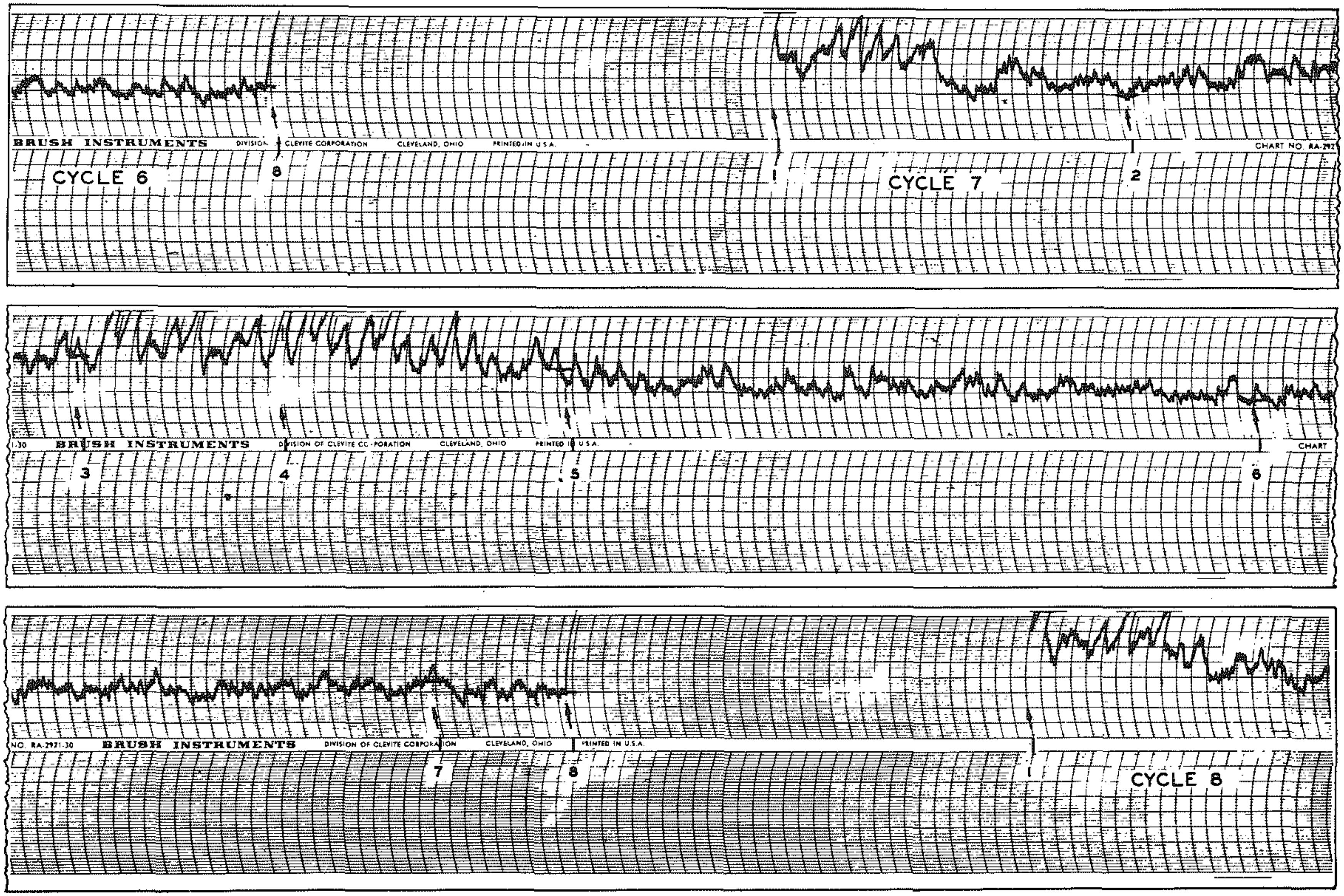


Figure 5. Photographic reduction of an original trace from the 8-cu yd mixer.

The data are arranged in five groups, A through E, corresponding to the five tapes employed during five different periods of observation.

Perhaps the most characteristic feature of the 106 traces recorded is the remarkable manner in which they reproduce each other almost exactly. They all follow the same pattern, and they are all very close to the same duration. Differences in height above the base line can be attributed to differences in background radiation, in amounts of sludge falling on the tar paper wrapping enclosing the scintillation detector or on the source holder; to differences in the mix ingredients or in their quantities; in the residual amounts of concrete left after discharge, which may coat the inside of the mixer; or to statistical variations in geometry from batch to batch. Any of these factors may have been responsible for the abrupt change which occurred after cycle 25, tape 2, in Table 2. It will be noted that this change persisted and was progressive during the balance of tape 2 and throughout tape 3 (the rest of the day), that the traces were back to "normal" at the beginning of tape 4, and that they remained normal thereafter.

A second characteristic feature of all the traces is the temporary rise in count rate and trace amplitude between points 3 and 5. This has been ascribed to a period of mechanical clumping before the mix water has been thoroughly distributed, resulting in pockets of lesser density being interposed between discrete "clods" of somewhat higher density. Obviously, if before mixing is complete large volumes containing more than their designed amounts of water or air should pass through the beam, their effect would be to allow increased transmission of gamma rays, which would be a measure of lesser average bulk density. This is apparently what happens during the period of mechanical clumping.

Since such a process would involve many variables, it is reasonable that neither the duration nor the effect of this period should be precisely the same from cycle to cycle. This indeed is the case, the extent of the rise in transmission varying from moderate to very marked. By "very marked" is meant a rise of several thousand counts per minute, enough to carry the recording needle off the paper in some instances. The duration of the period of mechanical clumping ranged from 16 to 57 sec, with a mean of 36 sec.

At point 5, marking the end of the period of mechanical clumping, the concrete has more of the properties of a plastic fluid, for the trace now assumes relative uniformity. The wide sweeps of the recording needle, indicating clumping, have disappeared and all subsequent changes are very gradual and relatively moderate in amount.

At least two of these subsequent changes deserve particular attention. First, the sweep amplitude continues to decrease both gradually and uniformly right up to the moment of discharge, when it is about half of what it was at point 5. This is interpreted to indicate a gradual and steady increase in the uniformity and plasticity of the mix. Second, a point of minimum count rate occurring at point 6 must represent a point of maximum density. The air content at point 6 is not zero; it is minimum. Between point 6 and point 8 the count rate gradually increases in a stepwise manner (density decreases). This period is interpreted to comprise the period of useful air entrainment.

Point 7 illustrates the stepwise nature of the gradual increase in count rate. This may be the result of a rhythmic forward and backward longitudinal surging of the batch in the direction of the axis of the mixer. Extrapolation of the trace suggests that if mixing had continued for two or three additional minutes, points 6 and 7 might be repeated at higher and higher count rates to some point of maximum air entrainment, after which they would be expected to occur at decreasing count rates as long as air was forced out of the batch and as long as surging continued. In the event that surging should cease, points 6 and 7 would cease to be repetitive, and the zigzag pattern of the trace would disappear, although a new point (9) indicating maximum air entrainment would probably appear. It is hoped that this extrapolation, as well as the exact air content at point 6, may be investigated experimentally.

THE 3.4-CUBIC YARD MIXER

With the cooperation of the Eisenhour Construction Co., the Research Laboratory Division studied applicability of the gamma-ray monitoring method to a 3.4-cu yd stationary concrete mixer near Indian River during operations between September 19 and 28, 1961. Figs. 6 through 13 show the installation at this site and the associated nuclear instruments and recording equipment.

Traces covering a total of 768 batches were obtained during this period. Of these, 349 were entirely experimental, procured for adjustment or calibration purposes only. The remaining 419 traces were useful for interpreting various aspects of the mixing process.

The 419 Batch Traces

In all, some 419 complete mixing cycles were recorded for the 3.4-cu yd mixer. These were divided into five data groups for analysis. Group 1 contains 150 batches for which charge times were recorded on the trace and there were no dead times in the mixer. The duration and magnitude of the recorded trace inflection points from the "subgroups" within this data group are listed in Table 3.

Group 2 has 19 batches with charging times recorded, but with various dead times during the mixing cycle. Group 3 contains 20 batches with dead times in the mixer, but with charging times not hand-recorded. Group 4 lists 201 batches with no dead times and no charging times recorded. Group 5 includes 29 batches in which mechanical clumping persisted up to the moment of discharge.

Schematic representations of average traces for each of the five groups, and other traces of interest, are shown in Fig. 14. Details on cycle or batch duration and other factors in the mixing process for all five data groups and listed in Appendix Tables 4 through 8.

Group 1. Average mixing time for the 150 batches in group 1 was 79 sec, measured from the moment charging began. Measuring from the moment charging ended, average mix time was 52 sec. Although this figure of 52 sec is considerably less than the 105 sec Michigan specifies

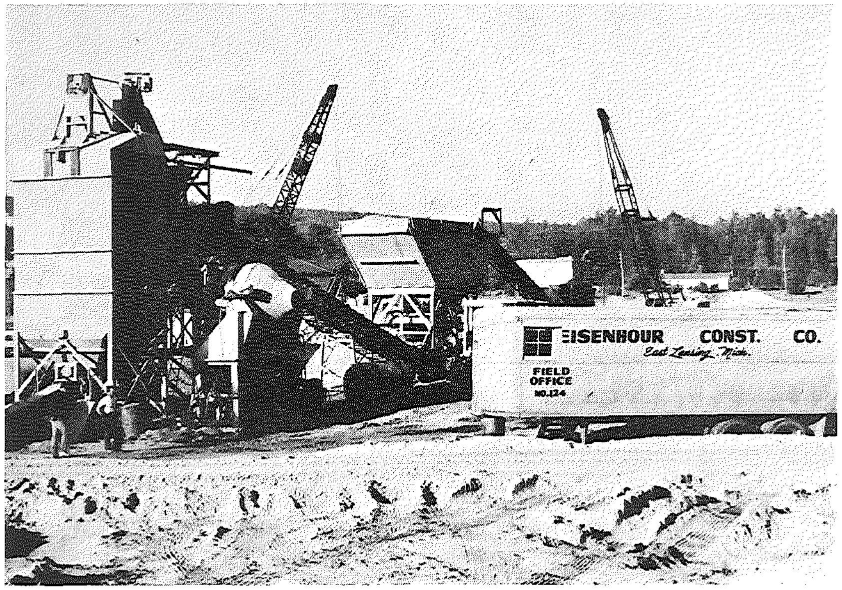


Figure 6. General view of Indian River site.

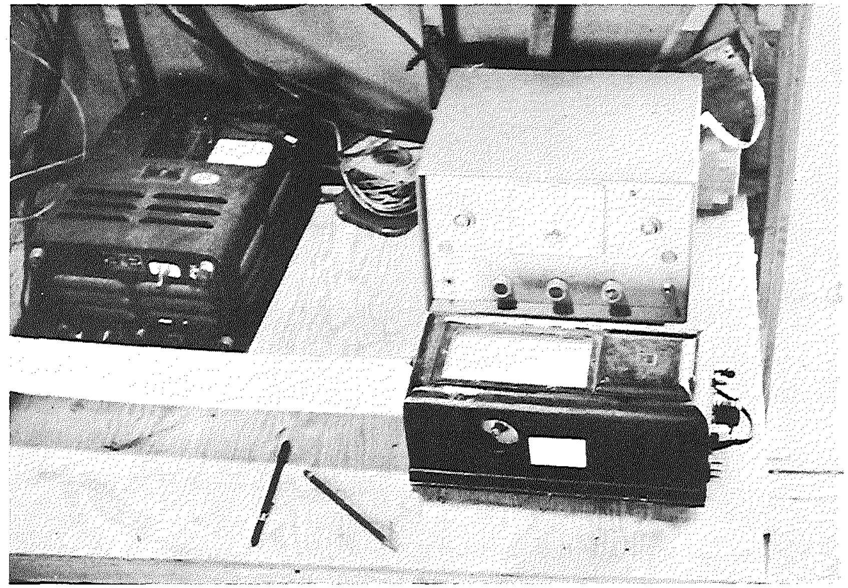


Figure 7. Instrumentation used at Indian River.

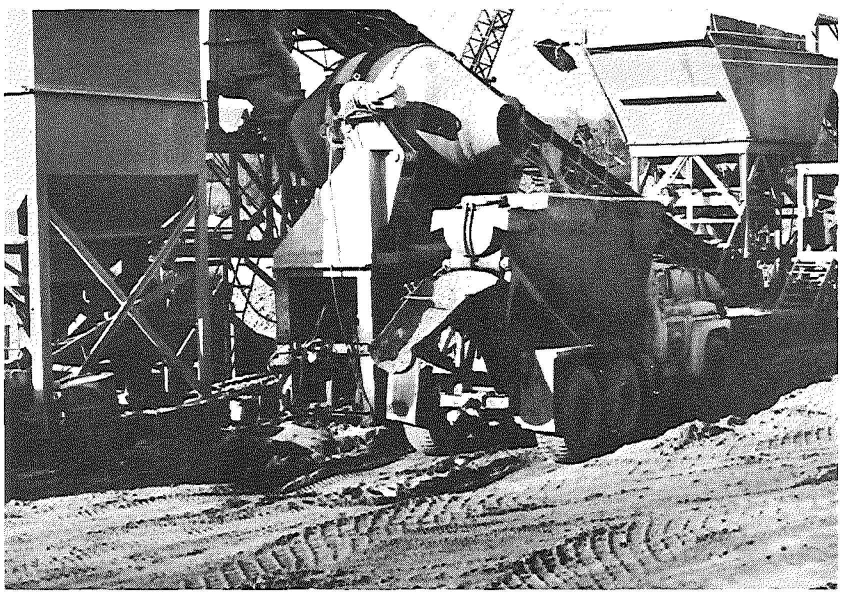


Figure 8. Mixer in horizontal position.

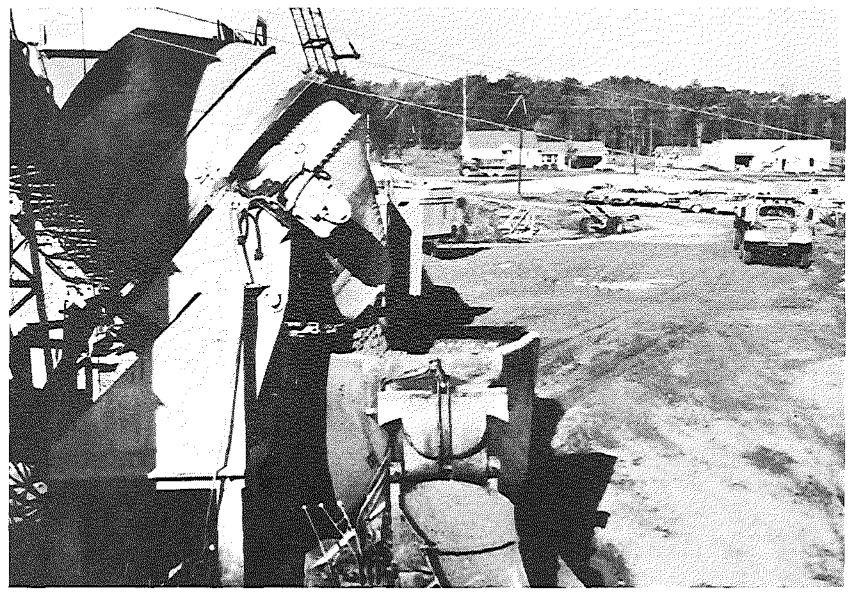


Figure 9. Mixer being dumped.

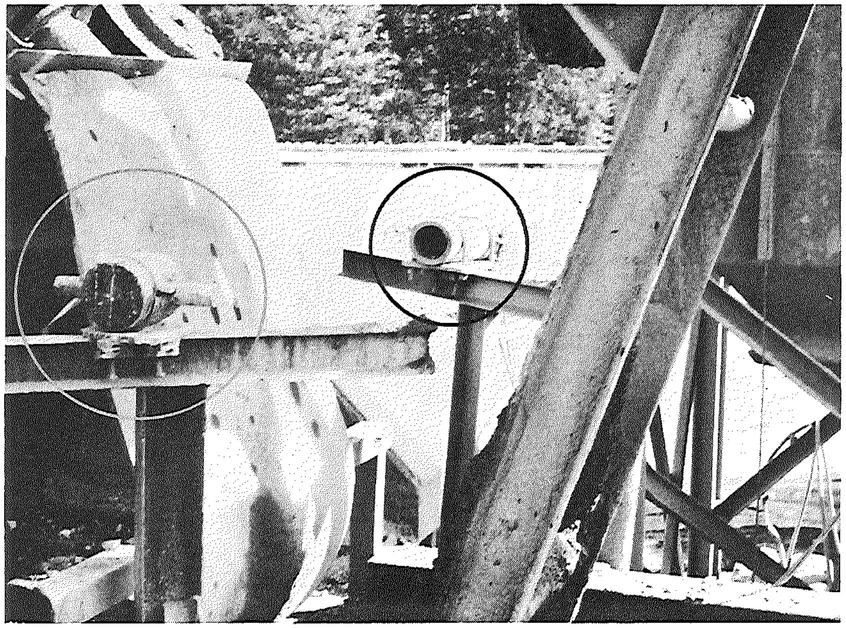


Figure 10. Mixer raised, with source at left and pickup tube at right.

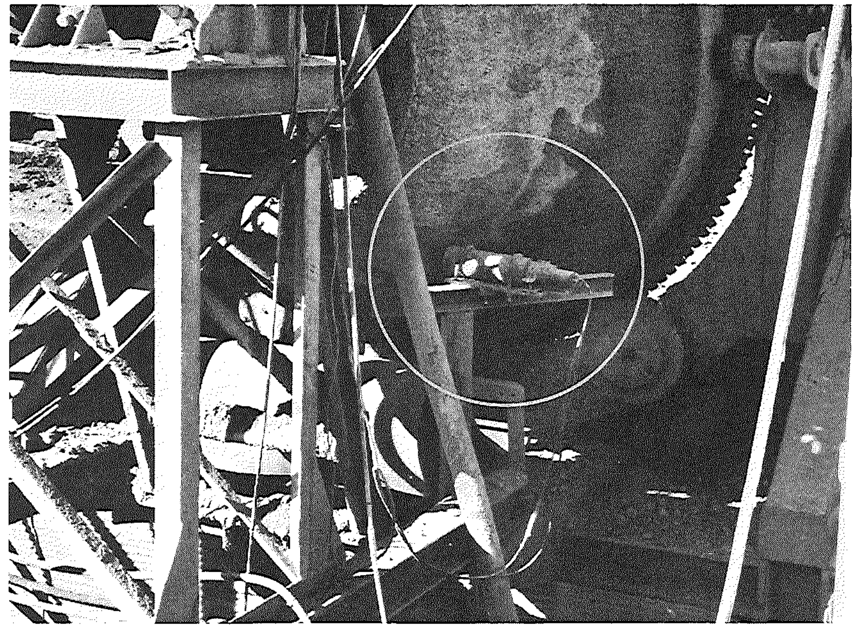


Figure 11. Rear view of pickup tube.

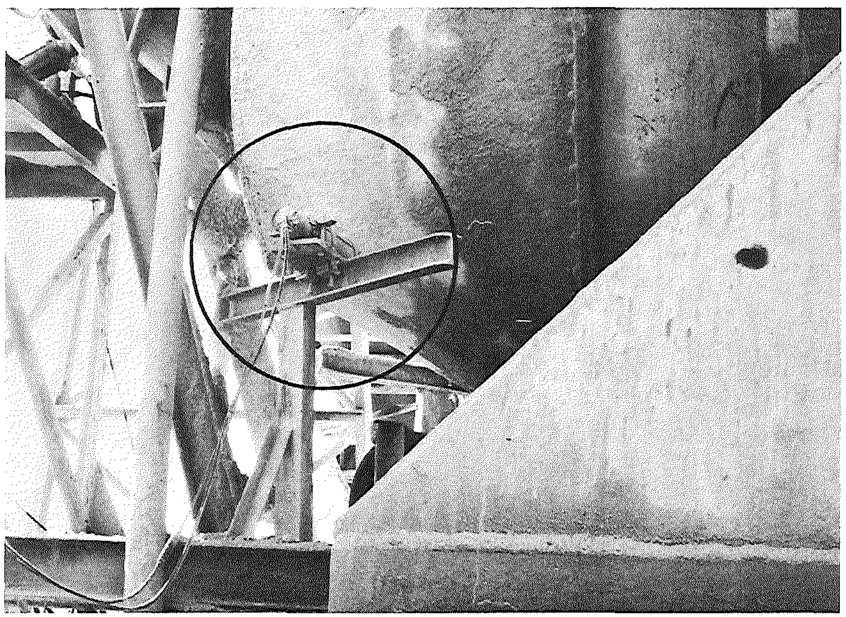


Figure 12. Side view of pickup tube.

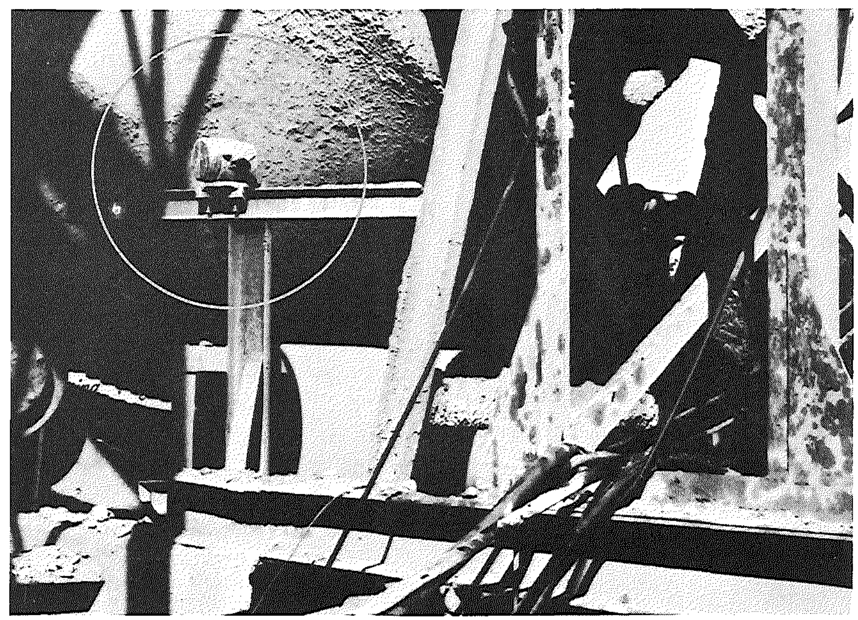


Figure 13. Radium-226 holder for 45-mc source.

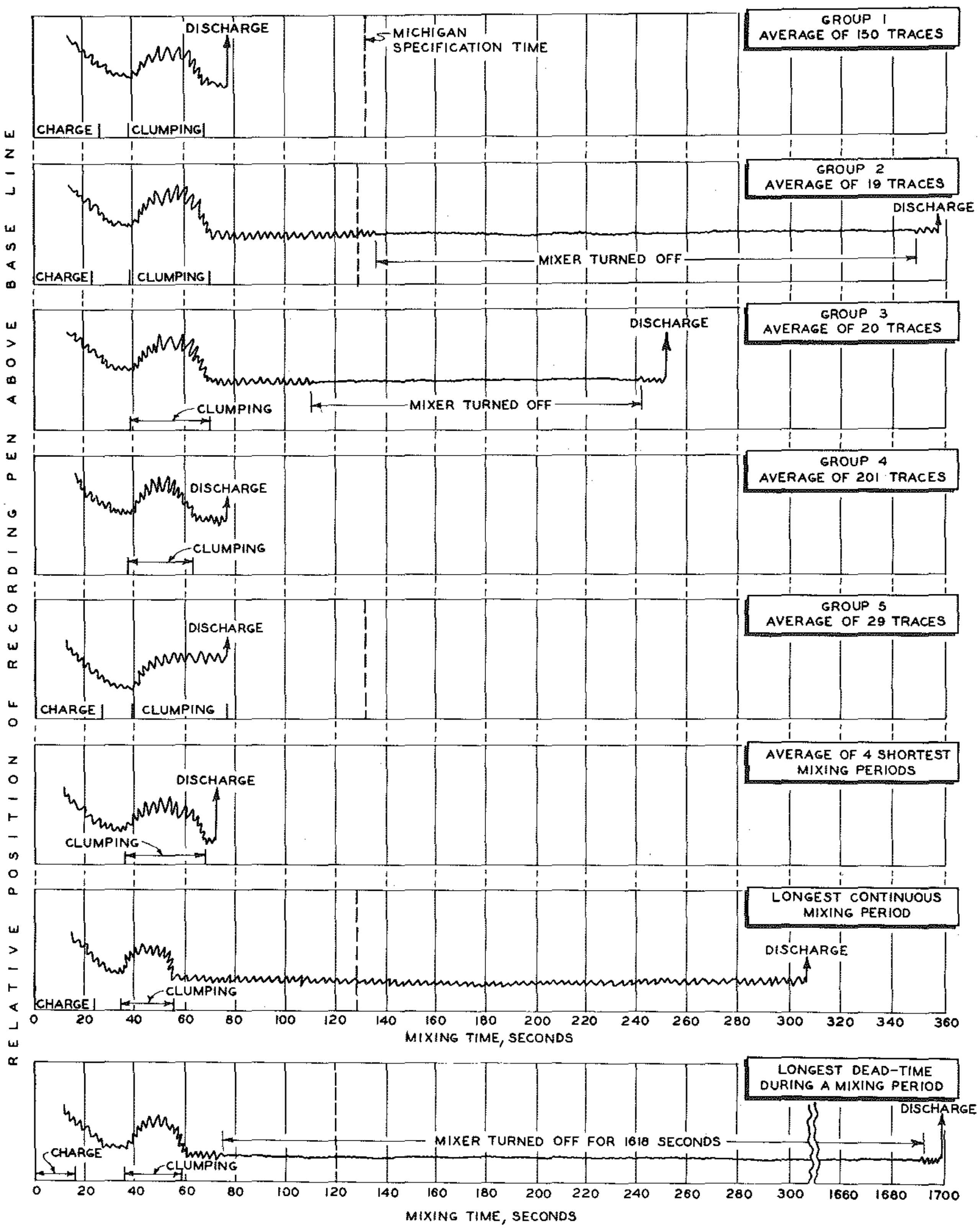


Figure 14. Average traces for the five data groups obtained using the 3.4-cu yd mixer, with three examples of unusual mixing period incidents.

(2), the curve shows that in this group the period of mechanical clumping had ended 10 sec before discharge. It is believed that this indicates fairly thorough mixing, since very little discernible change, if any, can be detected in the traces once the clumping period is over. A slight reduction in the amplitude of needle swings has been noted, presumably associated with increased workability; but changes in the mean elevation of the recording needle above the base line, which would indicate changes in density, are almost impossible to detect. Charging time averaged 27 sec, and mechanical clumping 29 sec in group 1.

Group 2. Average mixing time for the 19 batches in group 2 was 112 sec after conclusion of charging time, or 7 sec more than Michigan specifies. In addition to actual mixing, however, there was an average dead time of 224 sec during which the mixer was not turning. This was due to unavailability of trucks when they were needed. In these batches, the last 10 sec of mixing occurred after the dead time. Charging time averaged 23 sec, and mechanical clumping 32 sec in group 2.

Group 3. Group 3 differs from group 2 in that the end of the charging period was not hand-recorded. Both the beginning and the end of charging are accompanied by audible signals, but neither of these two points is associated with any feature of the trace; therefore, they must be noted by hand. This was done on all traces for the beginning of charge, but not in all cases for the end of charge. Average dead time for the 20 batches in group 3 was 131 sec. Mechanical clumping averaged 32 sec in duration. Mixing time averaged 121 sec from the moment charging began. If one accepts an average charging time of 26 sec for the 186 batches for which the end of the charging period was noted, this makes 95 sec the average mixing time for the batches in group 3.

Group 4. This group contains 201 batches without dead times, but for which the end of charging was not noted. Average time of discharge for these batches was 78 sec, which is also the average mixing time from the moment that charging began. On the basis of a 26-sec charging period, however, this becomes 52-sec average mixing time from the moment that charging was over. In this group, mechanical clumping ended, on the average, 12 sec before the moment of discharge. Clumping in group 4 averaged 27 sec in duration.

Group 5. This group contains 29 batches in which the period of mechanical clumping persisted up to the moment of discharge. Both the Research Laboratory Division representative, R. E. Hanna, and the plant inspector, Murray Follette, agreed that the materials for these batches appeared to be drier than normal. Mixing time averaged 77 sec from the moment charging began, and the clumping period averaged 37 sec in length. The moment that charging ended was hand-recorded for 17 of the 29 batches. This averaged 27 sec, and if accepted for the entire group the average mixing time would be 50 sec measured from the end of charging.

It is doubtful that one should say that the batches in group 5 were not well mixed. It is far more likely that the sand or aggregate was a little drier than usual, and that clumping persisted because of lower slump and much lower workability. It is probable that addition of very little water would have brought about a rapid end of clumping.

Among all the batches recorded in all five groups of data for the 3.4-cu yd mixer, the shortest mixing time measured from the beginning of charge was 73 sec. A schematic average of four batches of this duration are shown in Fig. 14.

The trace for the batch mixed for the longest continuous period without dead time, also presented schematically in Fig. 14, showed a low level of the recording needle occurring from 117 to 204 sec after charging ended, or 153 to 180 sec after charging began. The needle was slightly higher before this period and again after it, apparently indicating that maximum density occurred during the interval between these two points. The change in elevation of the needle is so slight, however, that it is difficult to detect, and the corresponding change in density is undoubtedly minimal.

Finally, a trace for the batch remaining in the mixer for the longest dead time is shown schematically in Fig. 14. Of 19 batches in group 2, this one was actually in the mixer for a dead time of 1618 sec, during a total mix time of 1768 sec from the moment the charge began--in all, just 32 sec less than one-half hour.

Day-to-Day Variations

The data for the 3.4-cu yd mixer shown in Tables 4 through 8 are arranged in five groups, and further subdivided by date in subgroups. Those data marked with an asterisk were excluded from the averages in accordance with Chauvenet's criterion.

It can be seen that the period of mechanical clumping ranged from 24 sec to 34 sec in Group 1 and from 25 sec to 32 sec in Group 2. It is perhaps significant that the longer periods occurred on the same day in both groups; the same is true of the shorter periods.

Mixing time measured from the end of the charging cycle varied from 35 sec to 61 sec in Group 1. With a single exception, mixing time became steadily shorter from September 19 to September 28. During the same period, however, the length of the charging time increased. Available data on which to base a correlation of these trends with moisture contents were inconclusive.

THE 1.3-CUBIC FOOT MIXER (Laboratory)

Certain laboratory tests conducted in connection with this research project formed the basis for the thesis submitted by Zapata in partial fulfillment of the requirements for the degree of Master of Science at MSU (3). A copy of this thesis is in the MSU library. Additional tests were performed with the assistance of personnel of the Concrete Unit, Materials Section, in order to confirm some of the preliminary findings reported in Zapata's thesis.

All laboratory tests were made on concrete mixed in a 1.3-cu ft drum-type batch mixer. Mix design was furnished by the Concrete Unit in accordance with the American Concrete Institute recommended mix design for 10A structural concrete. Air-entraining portland cement type IA was used in all batches except those for the photographic tests.

Visual Appearance (photographic tests)

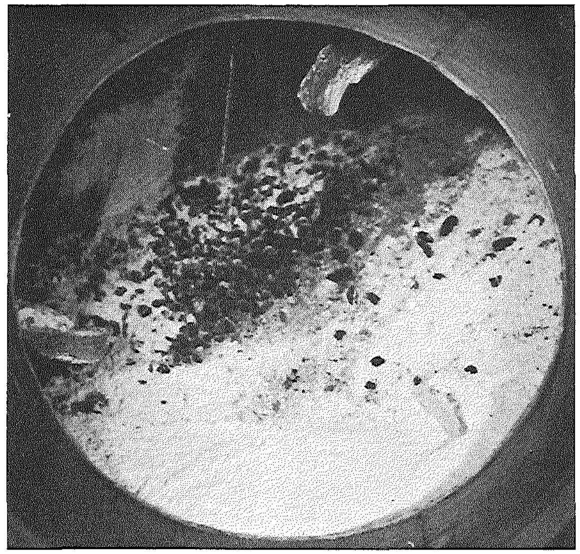
Preliminary tests showed that photographs taken at frequent intervals during the mixing of normal concrete failed to differentiate the mixing pattern because of a lack of contrast among the various ingredients. When the gravel was sprayed with black enamel, however, and when white cement was used, it was found that the mixing process could be followed visually.

Fig. 15 shows six photographs taken at various intervals up to 60 sec after the start of mixing. These views disclose no apparent visible improvement in the thoroughness of mixing after 45 sec.

Sodium Chloride Dispersal

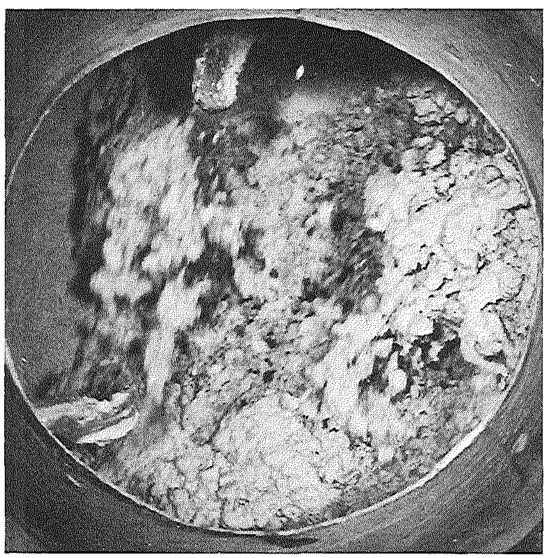
To test these conclusions more objectively, 200-g quantities of dry, pulverized, commercial grade sodium chloride were added to the dry materials in each of three batches prior to addition of the mix water. The rate of hardening was retarded by addition of 50 g of sugar to the mix water for each batch. Starting from the moment mixing began, samples of approximately 1100 to 1200 g were taken at frequent intervals up to discharge at 210 seconds. These were diluted with distilled water, filtered, aliquots taken, and the aliquots titrated with 0.098 N silver

Sand, black gravel, and white cement ready to be mixed.

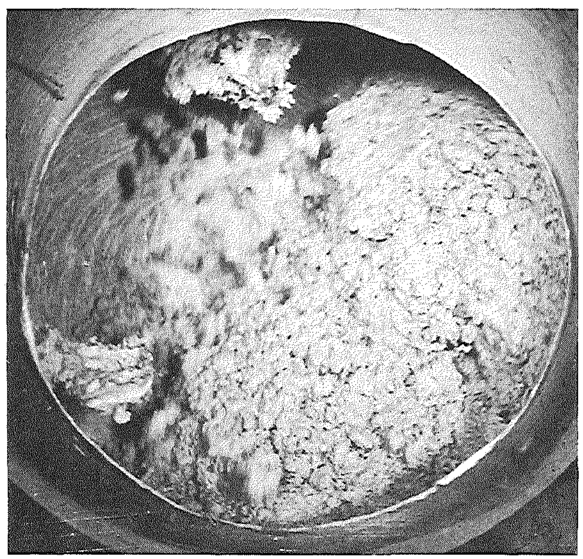


After rotating 5 sec, before adding weighed amount of water.

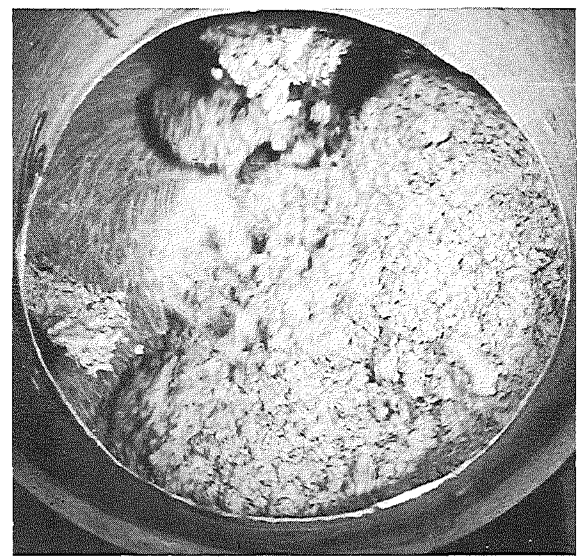
Appearance after 15 sec of mixing operation.



Appearance after 30 sec of mixing operation.



Appearance after 45 sec of mixing operation.



Appearance after 60 sec of mixing operation.

Figure 15. The batch-type drum mixer of 1.3-cu ft capacity at six stages in the mixing process.

nitrate. The numbers of milliliters of silver nitrate used in the titration per 1000 g of fresh concrete were then plotted against seconds elapsed from the start of mixing, as shown in Fig. 16.

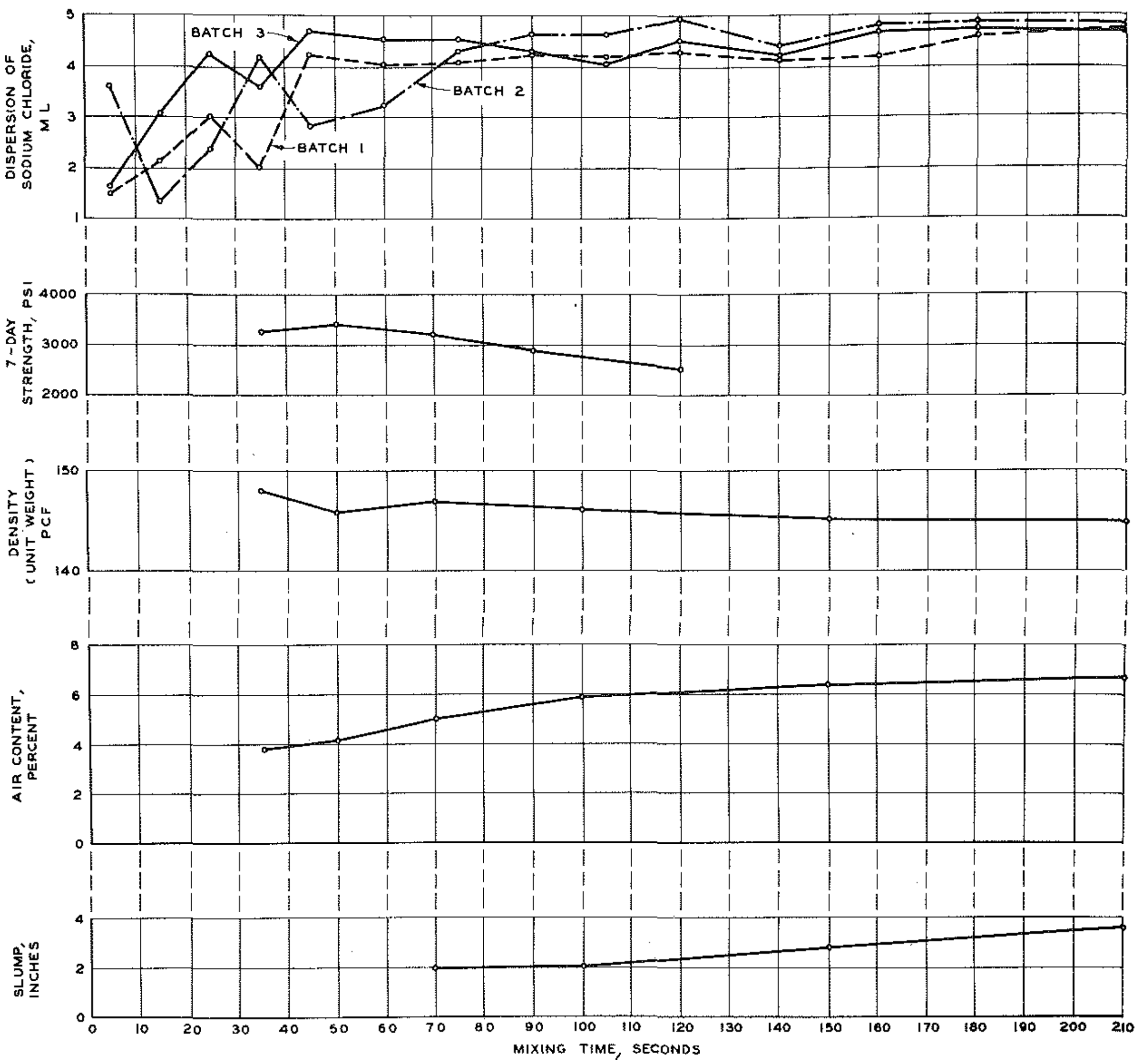


Figure 16. Effects of mix time on concrete properties using 1.3-cu ft mixer.

As far as batches 1 and 3 are concerned, Fig. 16 shows that the thoroughness of mixing remained fairly constant from 45 to 210 sec. Batch 2 was as thoroughly mixed at 75 sec as the other two batches at 45 sec, but then followed them in uniformity. In general, there appeared to be a slight improvement in thoroughness of mixing up to 210 sec, but this could have resulted from experimental error. If one accepts the best two out of three results, it would be fair to state that the mixes appeared to be quite uniform after 45 sec, with any subsequent changes being insignificant.

Conventional Tests

Conventional tests included slump, air content, unit weight or density, and 7-day compressive strength. The test results are plotted in Fig. 16 against mixing time up to 210 sec. In all cases, both slump and air content increased progressively with duration of mixing. The greatest density occurred about 37 sec after mixing began, followed by another peak at 70 sec, after which the unit weight dropped as duration of mixing increased. The compressive strength at seven days showed a marked rise at 50 sec of mixing, with a rapid decrease in strength as mixing time lengthened.

Additional Tests

Inasmuch as the results of these conventional tests, which were reported in Zapata's thesis (3), were based on a small number of batches, it was considered advisable to conduct some additional laboratory tests to confirm the earlier results. Accordingly, 15 separate batches were mixed, monitored by the gamma-ray method, and determinations of air content, slump, density, and 7-day compressive strength made at intervals up to 423 sec of mixing.

Although measurement of the uniformity of dispersion of sand and gravel was attempted during this test series, the results of this particular phase were inconclusive, probably because the sampling technique and screening procedure were not of sufficient precision for the small total batch size of 1.3 cu ft.

The results, listed in Table 1 by increasing duration of mixing time, confirm the results of the first tests almost exactly. Air content reached a maximum at 210 sec, then dropped slightly. Slump generally tended to increase with mixing time. Density remained high between 30 and 90 sec, then dropped slightly. The greatest compressive strength occurred at 55 sec, then dropped markedly as the concrete was mixed for longer periods.

During the course of this series, it was found that the rate at which mix water was added had some effect on the duration and degree of mechanical clumping, as shown in Fig. 17. It was determined, however, that clumping ended at 55 sec when the rate of water addition was adjusted to the same rate as in the first tests (20 sec to add the mix water).

TABLE 1
PROPERTIES OF CONCRETE FOR LATER TESTS USING THE 1.3-CUBIC FOOT MIXER

Batch No.	Total Mixing Time, seconds*	Air Content, percent	Sample Composition**				Slump, in.	Density (Unit Weight), pcf	7-Day Compressive Strength, psi***
			Sand, percent	Gravel, percent	Water, lb	Water in Sand, percent			
11	12	---	----	----	7	4.0	----	-----	-----
9	17	3.6	35.7	42.7	7	3.3	5 1/2	134.8	2,507
15	25	3.9	35.3	44.2	8	5.2	5 1/4	145.6	3,137
6	30	3.6	35.8	44.4	10	3.6	1 3/4	149.0	3,053
7	30	3.9	35.3	43.2	10	3.4	4 1/2	148.0	2,814
5	35	3.8	37.1	42.9	15	4.9	1 1/4	149.0	3,221
13	35	3.8	36.5	42.0	7	4.2	1 1/8	148.5	2,972
4	44	4.3	35.8	43.7	19	2.8	3 1/4	148.0	2,828
3	53	4.1	37.1	41.1	19	2.8	1/2	149.0	3,178
1	55	4.4	36.8	43.3	19	3.6	1 5/8	148.0	3,284
12	60	4.1	36.4	42.3	7	4.0	1 1/4	148.5	3,227
8	90	4.7	34.5	44.7	10	3.4	4	148.0	2,930
2	210	7.2	38.0	41.7	--	4.0	6	142.6	2,780
10	360	6.2	32.4	45.7	7	6.1	8	143.6	2,324
14	423	6.2	35.3	41.9	6 1/2	4.1	3 1/4	145.6	1,999

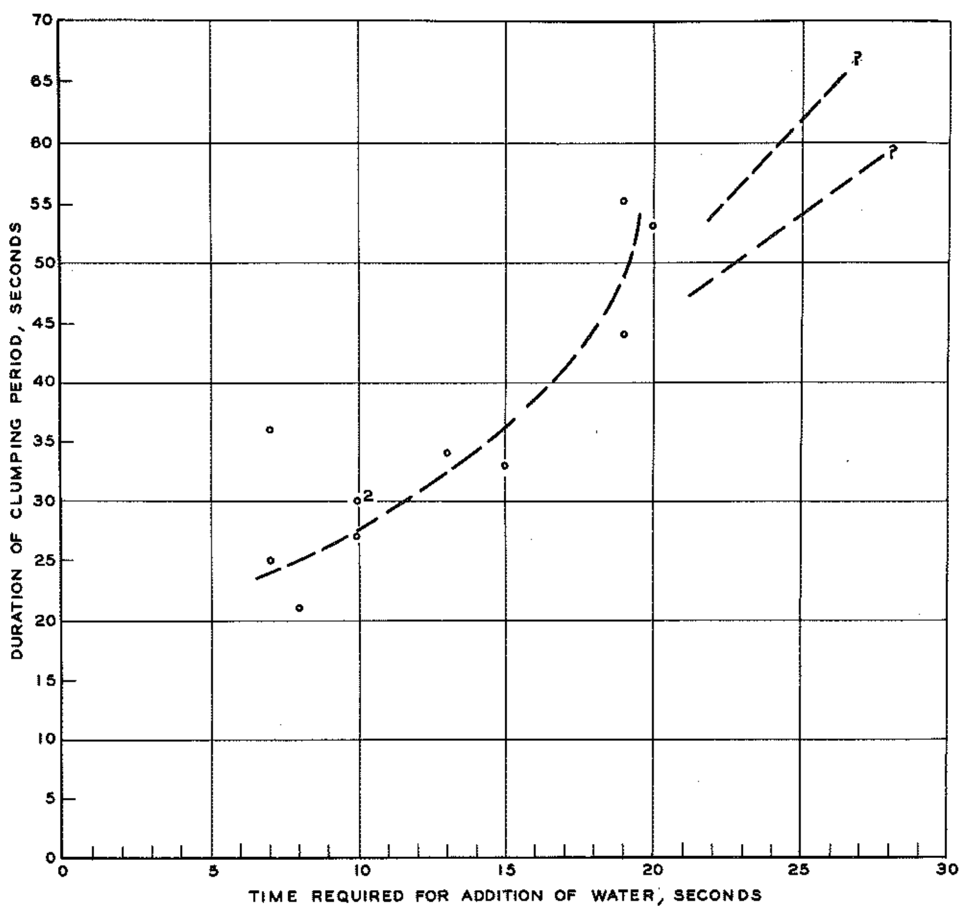


Figure 17. Effect of rate of addition of mix water on duration of the clumping period in experiments using the 1.3-cu ft mixer, with possible extrapolations at upper right.

COMPARISON OF THE THREE MIXERS

Relative performances of the three mixers are shown graphically in Figs. 18, 19, and 20. Here gamma ray penetration is plotted against time for the significant inflection points, with photographic reductions of original traces superimposed on the same time scale. Discharge times prescribed by the formula for stationary concrete mixers in the 1960 Standard Specifications (2) are indicated on the graphs.

The 1.3-cu ft Mixer

The clumping period ended in the case of the small laboratory mixer about 55 sec after mixing started. Maximum 7-day compressive strength was reached by samples extracted between 50 and 55 sec, suggesting that the end of the clumping period would be a good time to stop mixing. Air content was about 4.4 percent, with slump a little under 2 in., and density was high.

One can increase air content by mixing a few seconds longer, but compressive strength starts to decrease noticeably in about 10 sec. One solution might be stopping the mixer about 5 to 10 sec after clumping ends, which would be between 60 and 65 sec after mixing begins.

The 3.4-cu yd Mixer

Considering the laboratory results, one could reasonably suggest discharge of mixers of this capacity about 10 sec after clumping ends. Since clumping ended 70 sec from the moment the charge began, and since charging time averaged 26 sec, this would mean a change in specifications to permit discharge at 54 sec when measuring from the moment that charging ended. A safety factor of an additional 10 sec might be considered, in which case discharge might be permitted at 64 sec after the end of charging. In any case, 64 sec would be a minimum, without regard to possible further improvement in uniformity.

The 8-cu yd Mixer

With this mixer, which was rated at 7.78 cu yd, clumping ended 80 sec after the trace first returned to the recording chart. If one assumes that charging ended at the lowest point on the trace before clumping began,

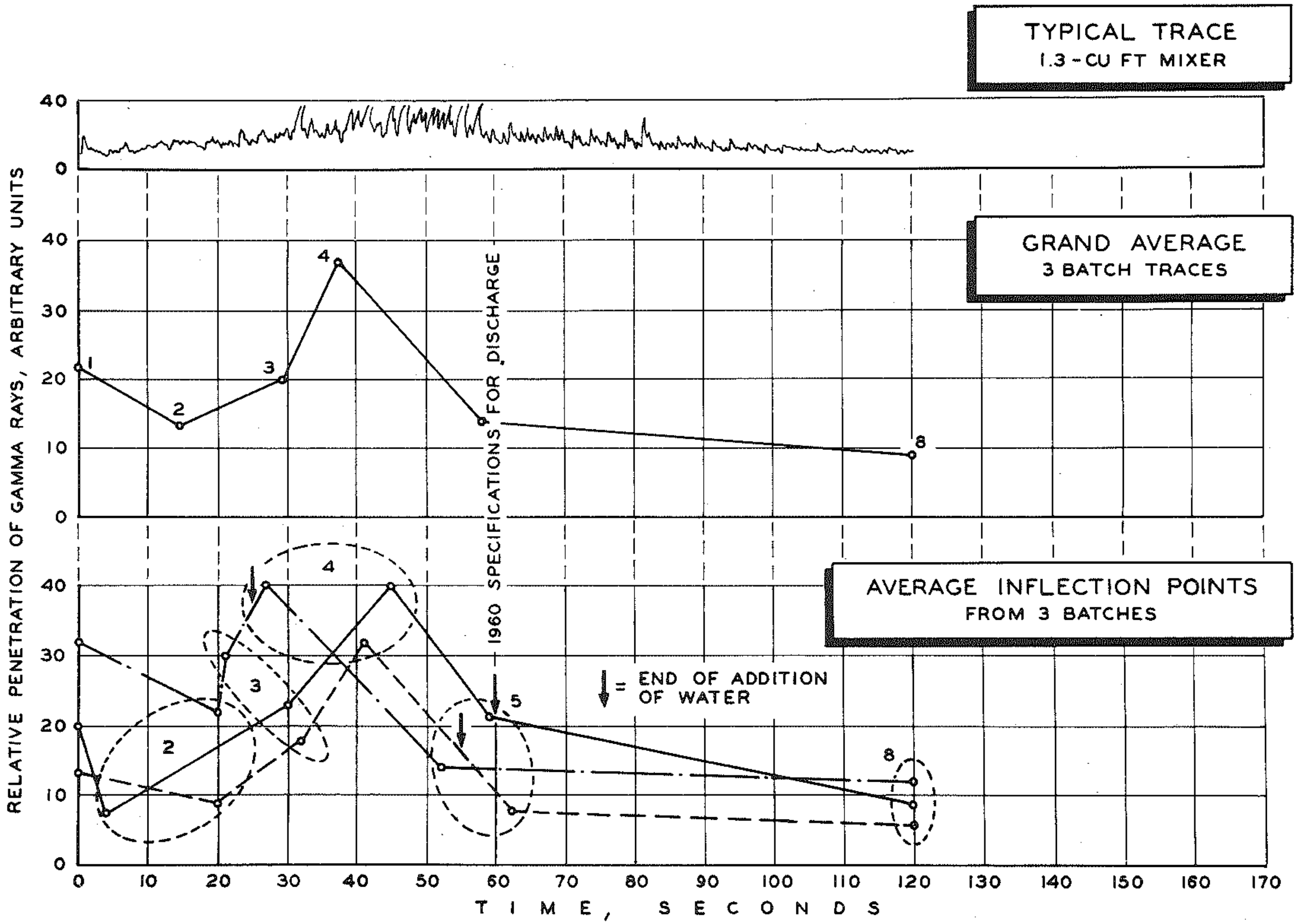


Figure 18. Graphic summary of data obtained with the 1.3-cu yd mixer.

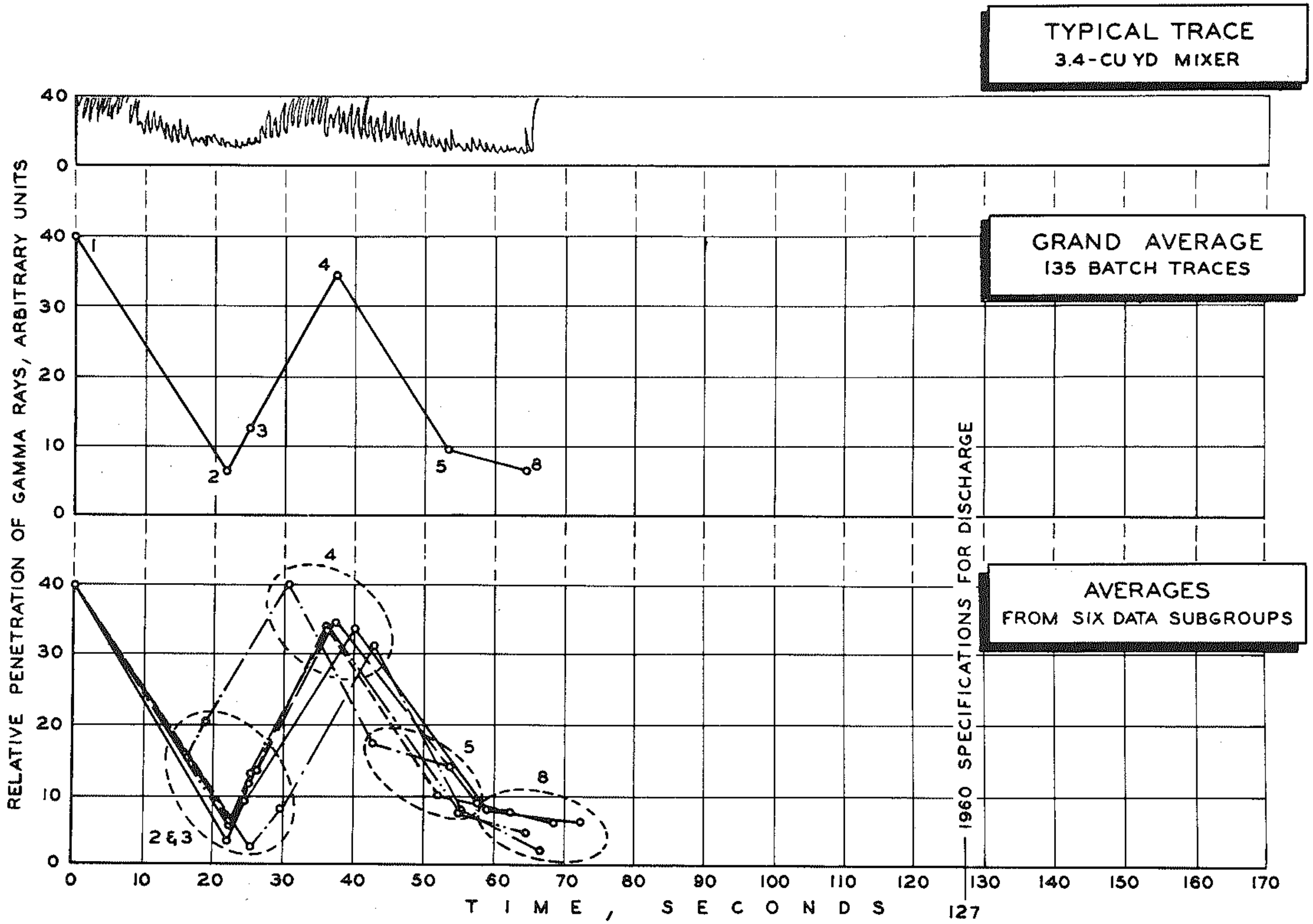


Figure 19. Graphic summary of data obtained with the 3.4-cu yd mixer (Appendix Table 3).

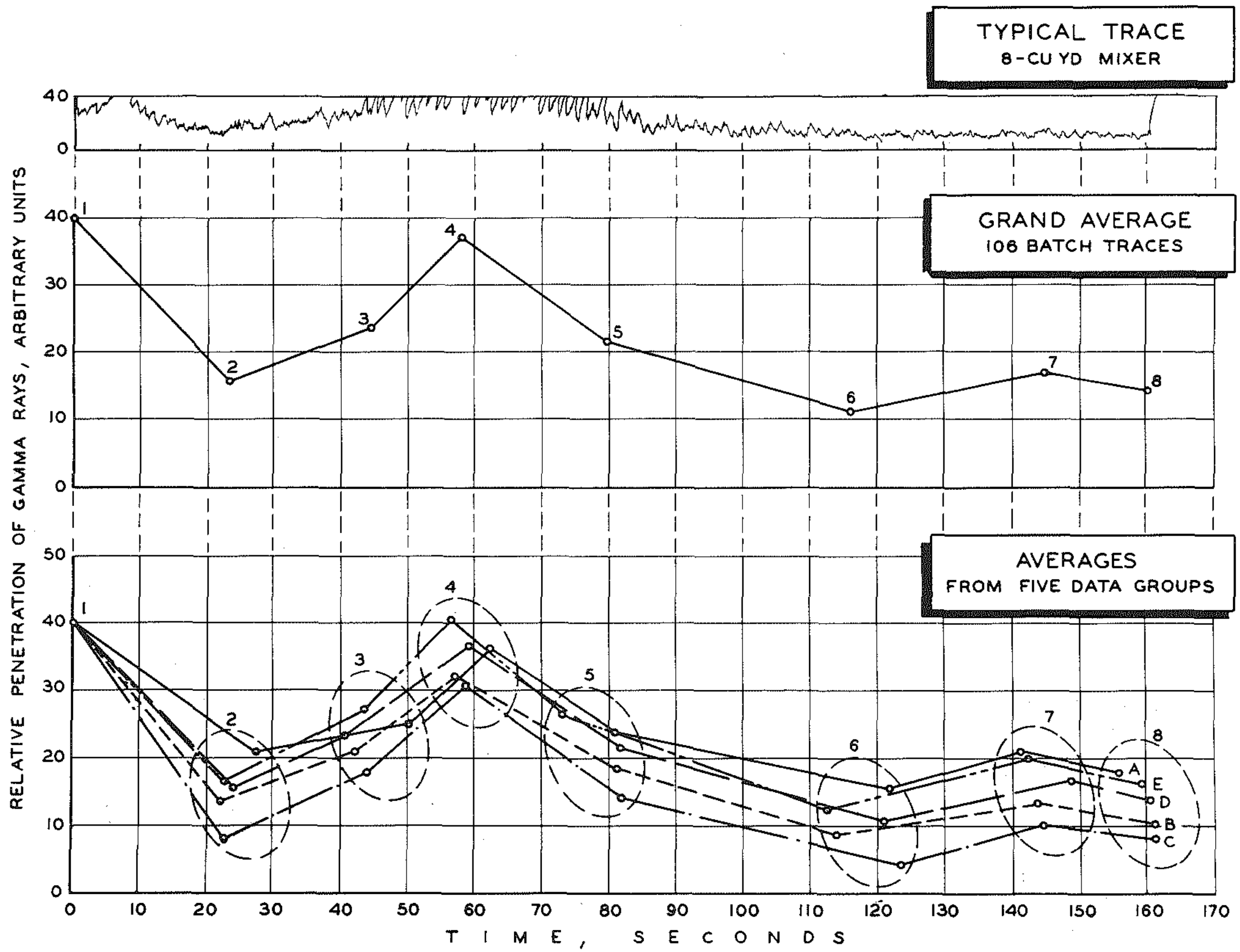


Figure 20. Graphic summary of data obtained with the 8-cu yd mixer (Appendix Table 2), for which 1960 Specifications would require discharge at approximately 189 sec.

this would mean that clumping ended 57 sec after charging ended. An additional 20 sec of mixing would bring the total mixing time to 77 sec, which might be considered as a minimum mixing time for this mixer, after which relatively minor increases in uniformity would be achieved by additional mixing.

A relatively minor improvement in uniformity, however, may be important. A clue to the extent of such improvement is given by the changes in density of the materials passing through the gamma-ray beam.

If one accepts point 2 in the traces as being the instant that charging ended, an assumption which seems very plausible, it is seen that the point of maximum density occurred 93 sec later, with minimum density 121 sec after charging ended. On the average, the batches were mixed 16 sec longer than this.

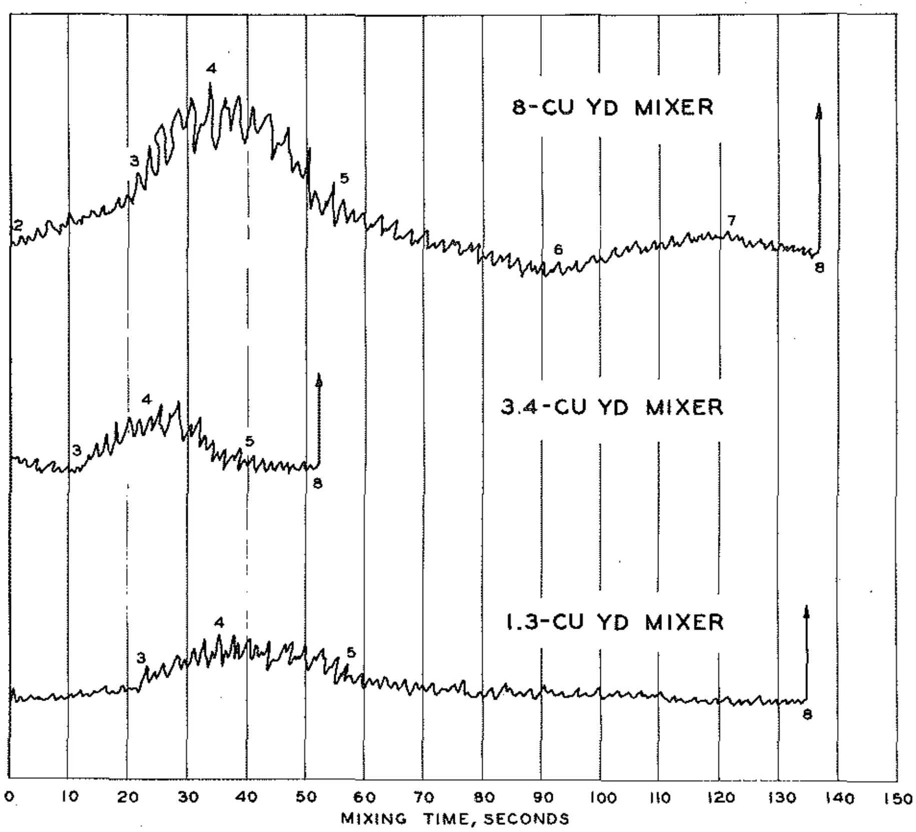


Figure 21. Schematic drawings of gamma-ray traces from the three mixers.

Fig. 21 shows schematic drawings of gamma-ray traces from the three mixers, and Figs. 22, 23, and 24 give photographic reductions of typical original gamma-ray traces. Fig. 25 provides a comparison between the nuclear technique applied to the 8-cu yd mixer, and results obtained by Cortright, Legg, and Vogler (4) for the same mixer. The gamma trace point 7, at 121 sec after completion of the charging period, appears to coincide with these authors' "third point" (120 sec). The gamma trace point 6, at 93 sec, evidently coincides with their "second point" (90 sec).

CONCLUSIONS

The gamma-ray monitoring technique offers a method of continuously recording certain features of the concrete mixing process nondestructively while mixing is in progress. Once agreement has been reached on the significance of the phenomena being recorded, the method appears useful for calibrating a mixer to produce the desired degree of uniformity under the conditions imposed.

A well-defined period of mechanical clumping was discovered, which generally must be completed before mixing can be considered thorough and the mixture uniform throughout.

Variations in density, plasticity, and air content appear to be reflected in the traces. The physical property of strength does not appear in the traces, but this may be determined indirectly by calibration against known factors which do appear.

The results of the study indicate that a reappraisal of present requirements for mixing times for central plant mix concrete is justifiable.

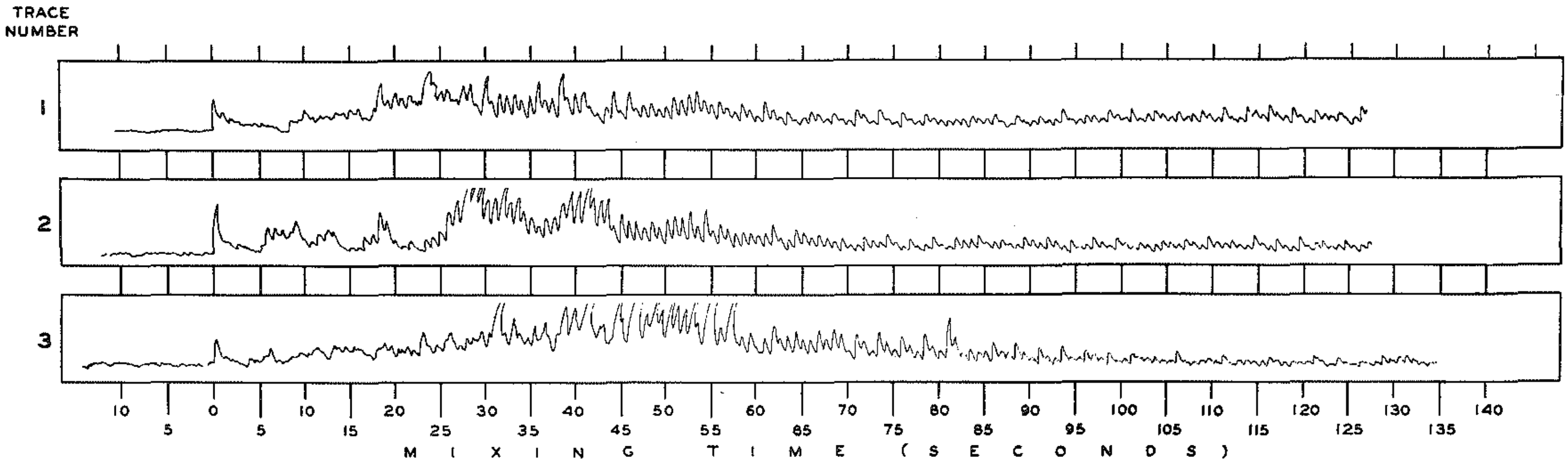


Figure 22. Photographic reductions of typical original traces from the 1.3-cu ft mixer.

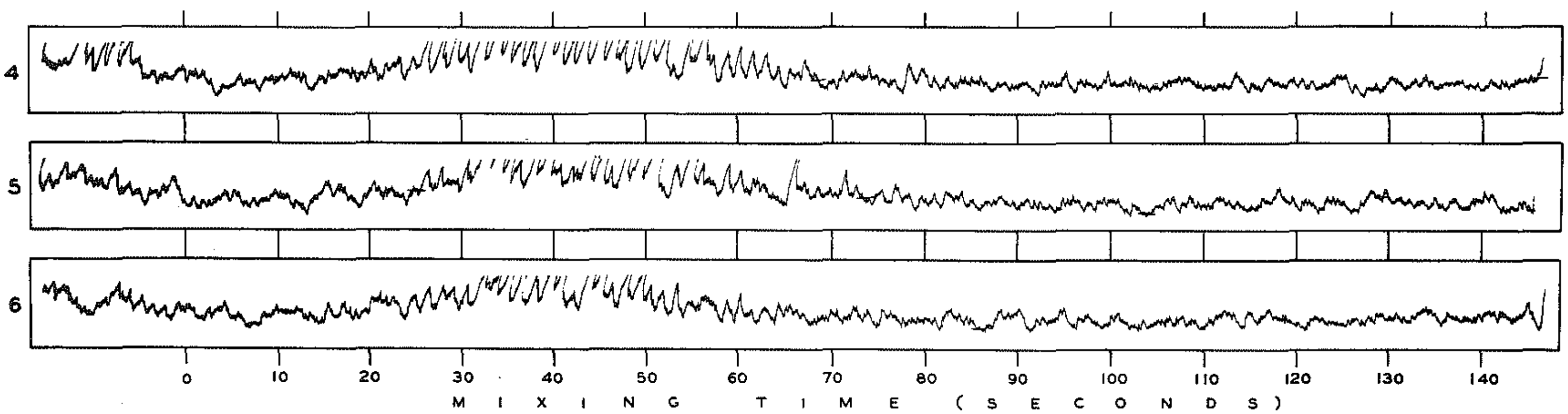


Figure 23. Photographic reductions of typical original traces from the 8-cu yd mixer.

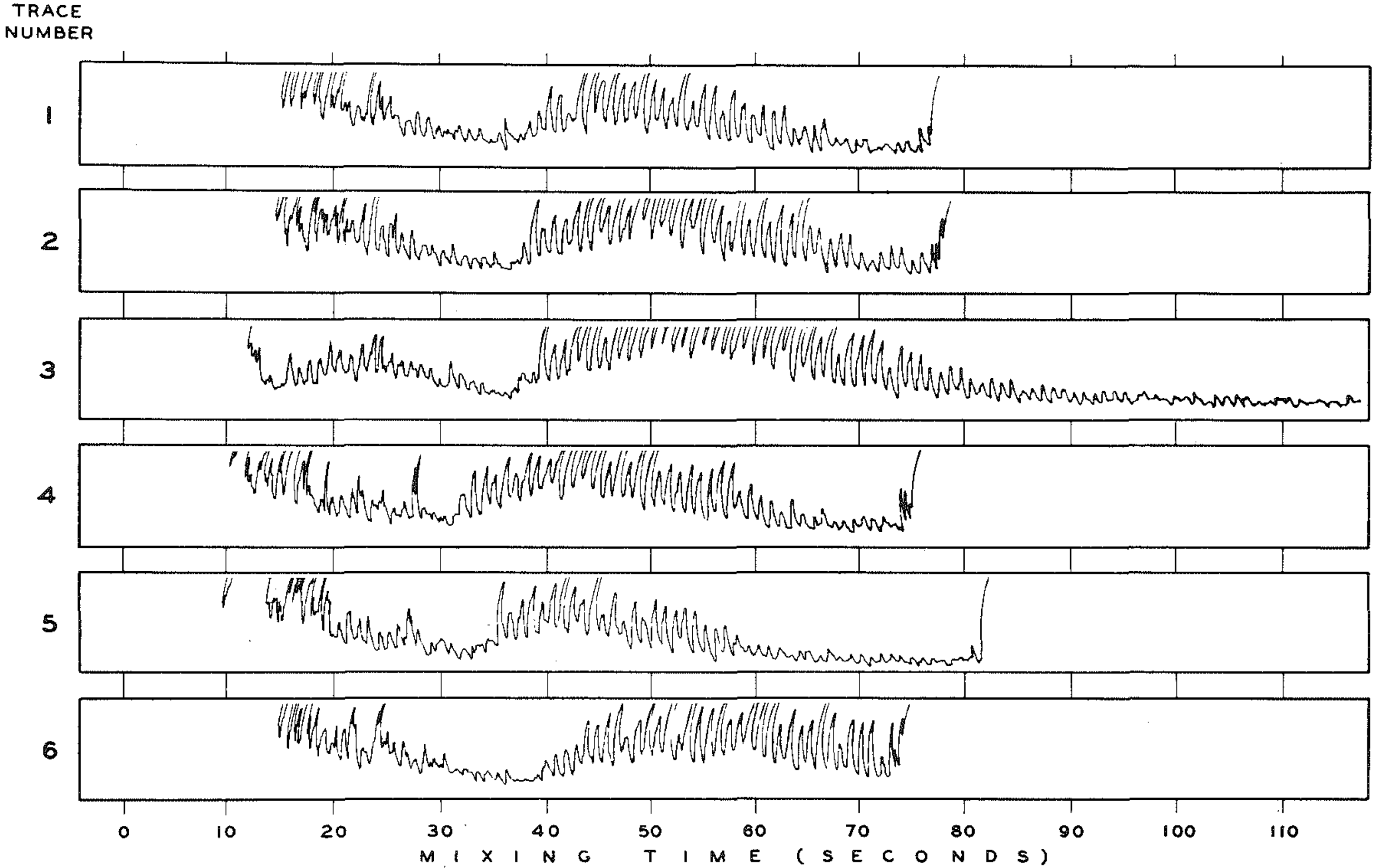


Figure 24. Photographic reductions of typical original traces from the 3.4-cu yd mixer.

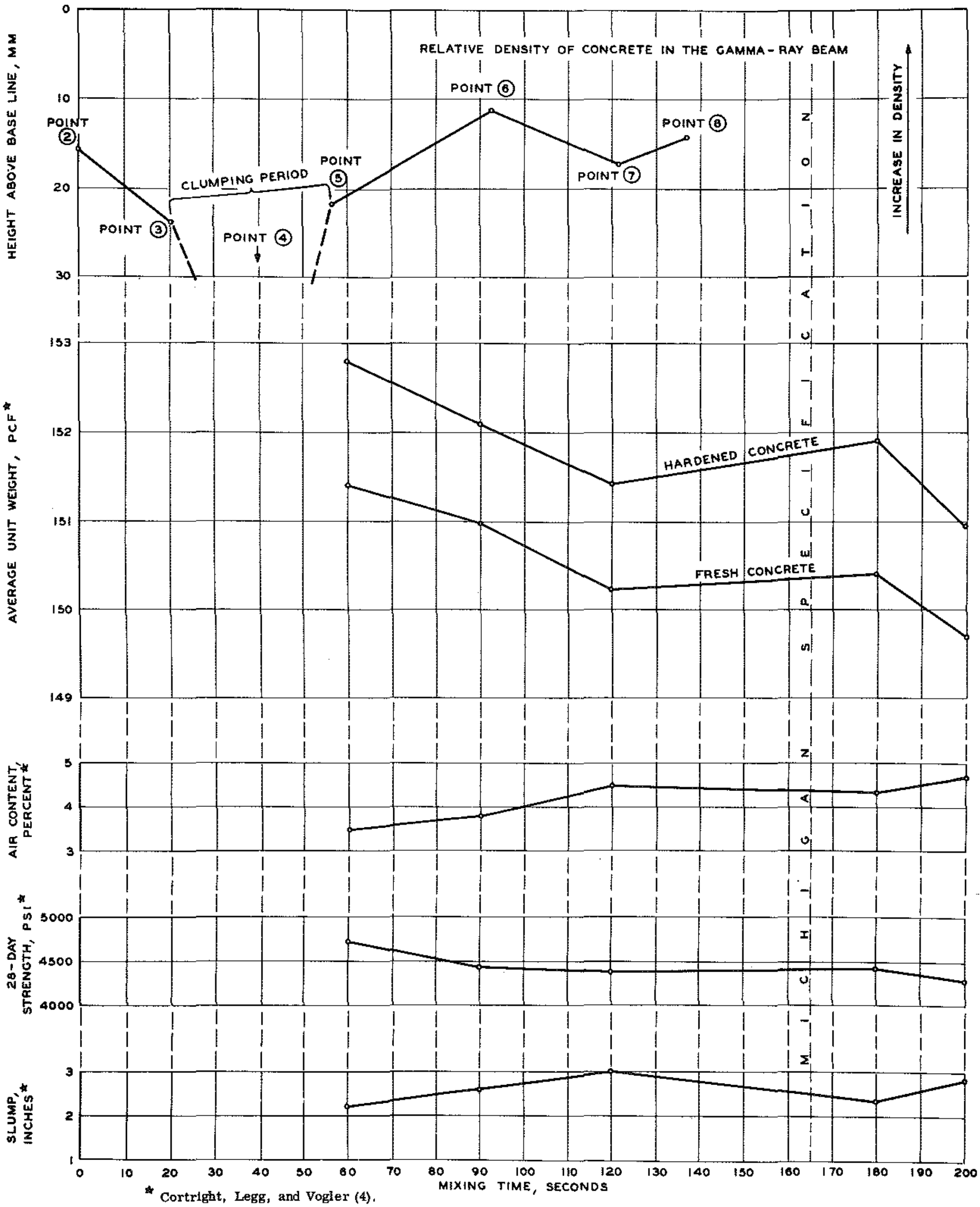


Figure 25. Effects of mix duration on concrete properties using the 8-cu yd mixer, comparing nuclear density data with data obtained through conventional testing.

FUTURE RESEARCH

If additional experiments of this type are authorized, it would be desirable to study the effect of varying the location of the beam of gamma rays, and to develop a reliable method of calibrating against true density. Such a calibration would necessitate first and foremost a precisely reproducible geometry, which implies improved collimation of the beam to as narrow a cone as possible and its passage through a sufficiently large bulk that surface effects are completely negligible. A single sealed source of approximately 200 mc of radium 226 would probably be ideal for mixers of 8-cu yd capacity. Sensitivity to air entrainment would be improved, since this affects density; but sensitivity to such phenomena as surging and mechanical clumping would probably be reduced.

Reproducible geometry also implies a means of preventing a steady buildup of sludge from forming on the source holder and scintillation detector, even though these are protected by tar paper. Such a buildup acts both as an absorber and as a scattering medium, whose effect is a function of its thickness. Although it may be impossible to eliminate sludge formation entirely, its buildup into layers should be kept at a distance from the holder and tube by means of a baffle or shelf on which the deposits may accumulate without detrimental effect.

In addition, it is hoped that a practical means will be found of transmitting slow neutron pulses through 100 ft of cable, so that water distribution may be followed during the mixing cycle by means of a fast neutron beam. Although experiences reported by Burley, Block, and Diamond (5, 6) indicated that 2 c of plutonium-beryllium were required to give "an accuracy of plus or minus 0.05 percent at the three percent level in less than one minute" in measurements of moisture in foundry sand, those authors had some difficulty in transmitting through 28 ft of cable, with a preamplifier located at the counter tube site. This is an area in which further progress depends largely on electronic developments.

REFERENCES

1. Fig. 6 (p. 51) in "Protection Against Radiations from Sealed Gamma Sources." Handbook 73, National Bureau of Standards, U. S. Dept. of Commerce (1960).

2. Paragraph 4.14.03(j) "Mixing" (pp. 237-38) in "1960 Standard Specifications for Road and Bridge Construction." Lansing: Michigan State Highway Department.

3. Zapata, C. A. "Concrete Mixing Studies by Gamma Ray Absorption." Michigan State Highway Department Research Report P87 (December 1961). M.S. Thesis submitted to MSU Dept. of Chemical Engineering.

4. Cortright, D. N., Legg, F. E., and Vogler, R. H. "Performance Tests on a Stationary Concrete Mixer at Various Mixing Times." Lansing: Office of Testing and Research, Mich. State Highway Department (1962).

5. Burley, H. A., and Diamond, M. J. "Neutron-Moderation Gages Water in Foundry Sand." Nucleonics, Vol. 19, No. 8 (August 1961), pp. 45-7.

6. Burley, H. A., Block, A. D., and Diamond, M. J. "A Nuclear Method for Measuring the Moisture Content of Foundry Sand." General Motors Engineering Journal, Vol. 8, No. 1 (Jan.-Feb.-Mar. 1961), pp. 2-6.

APPENDIX

Batch Tests for the 8-cu yd Mixer

Batch Tests for the 3.4-cu yd Mixer

TABLE 2
DURATIONS AND MAGNITUDES OF TRACE INFLECTIONS
8-cu yd Mixer

Group	Cycle	Intervals Between Points of Inflection Indicated, seconds								Heights of Points Indicated, mm							
		8 to 1	1 to 2	1 to 3	1 to 4	1 to 5	1 to 6	1 to 7	1 to 8	1	2	3	4	5	6	7	8
Group A: Tape 1 7-14-61, 1:20 to 3:35 PM	1	45.8	18.6	58.0	68.0	79.0	129.0	154.4	163.6	40.0	16.0	22.0	30.0	22.0	13.0	18.5	15.0
	2	34.0	21.0	53.0	64.0	82.0	141.0	147.0	158.0	40.0	17.0	21.5	28.0	18.0	14.0	16.5	15.0
	3	40.0	29.6	48.4	58.0	75.0	121.0	130.0	153.8	40.0	27.0	28.0	42.0	26.0	20.0	24.0	22.0
	4	35.6	20.0	47.0	62.0	77.4	103.0	143.4	155.6	40.0	24.5	27.0	35.0	23.0	18.0	25.0	23.0
	5	37.4	36.6	47.0	63.0	77.0	117.0	143.0	154.0	40.0	24.5	28.0	40.0	25.0	20.0	25.0	21.0
	6	33.0	40.0	53.0	71.2	94.6	124.6	140.4	159.4	40.0	14.0	15.0	28.0	18.0	10.0	14.0	10.0
	7	32.4	39.0	58.6	65.0	85.0	125.0	144.0	160.0	40.0	13.0	16.0	27.0	21.0	10.0	14.0	13.0
	8	45.0	14.6	41.0	57.0	74.0	104.4	125.6	147.6	40.0	22.0	28.0	45.0	28.0	15.0	25.0	21.0
	9	43.0	32.6	47.6	50.0	78.2	124.6	144.0	149.6	40.0	23.0	32.5	44.0	25.0	16.0	24.0	17.0
	10	38.8	19.0	45.0	66.0	83.0	120.0	141.2	154.0	40.0	25.5	32.0	45.0	32.0	19.0	24.0	21.0
	Average:	37.5	27.1	49.9	62.4	80.5	121.2	141.3	155.6	40.0	20.7	25.0	36.4	23.8	15.5	21.0	17.8
Group B: Tape 2 7-17-61, Start at 11 AM,	1	28.0	17.0	42.0	55.0	84.0	110.0	152.0	166.0	40.0	7.0	23.0	36.0	24.0	13.0	17.0	14.0
	2	36.0	20.0	40.0	52.0	72.0	102.0	152.0	156.0	40.0	16.5	24.0	37.0	25.0	12.5	18.5	11.0
	3	31.5	24.0	42.0	54.0	76.0	109.0	157.0	161.5	40.0	16.0	26.0	37.0	25.0	11.5	18.0	16.5
	4	30.8	17.5	47.0	61.5	90.0	114.5	134.5	162.0	40.0	16.0	27.0	37.0	18.5	13.0	19.0	15.0
	5	31.5	27.5	41.0	56.0	83.0	118.0	139.0	162.0	40.0	15.0	18.5	36.5	20.5	12.5	19.0	16.5
	6	32.0	26.5	34.0	51.5	83.0	118.0	142.5	161.0	40.0	15.5	22.0	35.0	21.5	11.5	18.0	17.0
	7	33.0	23.5	41.5	55.0	73.5	119.0	151.8	160.7	40.0	15.0	27.0	35.0	22.5	12.5	18.5	15.0
	8	30.3	23.7	41.5	56.5	84.5	105.5	136.0	162.5	40.0	18.5	27.0	37.0	21.0	13.0	20.0	17.5
	9	31.2	23.0	42.0	60.5	85.8	124.7	141.3	162.3	40.0	16.5	27.0	36.5	20.0	11.0	19.5	16.0
	10	30.4	22.0	42.2	54.0	88.8	117.6	132.5	161.3	40.0	15.0	29.5	37.0	20.0	12.0	20.5	18.0
	11	33.3	29.4	39.8	57.5	96.3	133.4	156.9	160.4	40.0	16.0	25.5	45.0	17.0	14.0	19.0	15.0
	12	30.3	26.0	45.0	65.8	102.2	124.3	144.8	162.3	40.0	19.0	24.0	34.0	20.0	13.5	19.0	16.5
	13	32.4	20.1	34.5	51.7	84.0	143.5	-----	161.3	40.0	17.5	24.5	37.0	20.0	14.0	----	20.0
	14	32.0	17.0	40.7	60.0	89.4	119.3	144.4	160.4	40.0	17.5	25.0	35.0	20.5	12.0	21.0	13.5
	15	31.4	22.8	39.2	54.4	77.0	101.7	130.3	160.4	40.0	16.0	23.5	37.0	21.0	13.0	20.0	16.5
	16	30.0	24.0	41.4	55.9	84.3	114.0	145.7	162.0	40.0	18.0	24.5	36.0	25.0	14.5	19.0	18.5
	17	32.0	21.5	39.3	58.4	82.5	101.0	137.8	161.3	40.0	18.0	23.5	36.0	23.0	15.0	19.0	18.0
	18	32.0	19.5	35.0	50.2	71.4	105.7	143.1	162.2	40.0	18.0	25.0	35.5	21.5	15.0	20.0	14.5
	19	32.3	21.7	44.4	56.3	72.1	118.5	139.2	158.8	40.0	18.5	30.0	37.0	28.0	13.5	18.5	15.5
	20	31.8	18.9	36.0	54.0	83.3	109.8	145.3	161.1	40.0	17.5	26.0	36.5	23.5	15.0	20.5	16.5
	21	31.4	18.4	40.2	56.8	80.0	103.2	147.5	161.2	40.0	18.5	27.5	36.0	25.0	15.0	20.5	15.5
	22	30.8	24.2	48.9	66.3	86.2	115.6	162.8	177.0	40.0	17.5	31.5	35.0	26.5	16.5	19.0	14.0
	23	26.5	----	----	71.1	----	125.0	140.8	171.6	40.0	----	----	26.0	----	12.0	17.0	13.0
	24	33.7	21.0	40.5	59.3	94.0	124.5	150.0	160.0	40.0	18.5	24.5	48.0	17.0	11.5	15.0	13.0
	25	33.7	20.0	30.6	53.5	78.8	111.5	147.1	158.8	40.0	17.0	20.5	45.0	29.3	11.5	16.6	13.5
									Average:	40.0	17.0	25.3	36.1	22.1	13.1	18.8	15.6
	26	32.5	25.0	46.0	63.7	89.4	124.0	142.5	160.8	40.0	14.0	29.0	38.5	22.0	8.5	13.5	11.0
	27	33.0	18.8	41.0	57.8	83.7	113.7	146.3	160.4	40.0	16.5	22.5	44.0	25.0	10.0	11.5	9.5
	28	33.0	22.2	42.7	59.2	82.6	118.5	144.8	161.0	40.0	11.5	26.5	44.0	24.0	8.5	13.5	11.0
	29	32.8	19.8	39.0	50.2	83.2	106.0	149.0	160.1	40.0	14.0	18.5	35.5	12.5	8.0	13.5	10.0
	30	32.0	19.6	43.2	56.1	75.6	128.8	141.9	160.5	40.0	15.5	21.5	38.0	20.5	9.5	13.5	10.0
	31	31.6	21.0	44.0	57.0	69.8	104.0	132.6	160.0	40.0	13.5	19.0	32.0	16.0	8.5	13.5	10.5
	32	31.0	22.6	47.8	59.9	78.2	127.6	148.8	161.2	40.0	12.5	23.5	30.0	18.5	9.0	13.5	12.0
	33	32.2	25.4	33.9	53.0	81.3	121.6	141.3	161.1	40.0	13.5	17.5	37.5	18.5	8.5	13.0	11.5
	34	32.5	24.0	41.9	52.4	70.3	108.7	140.4	160.6	40.0	13.5	26.0	34.0	19.5	9.5	13.0	9.5
	35	32.6	22.8	38.8	50.0	62.8	90.4	149.7	159.4	40.0	12.0	17.5	31.5	19.0	9.0	13.0	10.5
	36	29.6	25.0	46.3	54.9	64.5	93.2	140.4	162.0	40.0	13.5	20.0	26.5	17.5	6.5	13.5	10.0
	37	29.2	24.2	47.3	55.6	66.1	93.1	147.6	161.5	40.0	11.5	15.5	24.0	15.0	8.5	13.0	9.5
	38	30.0	24.1	47.8	59.6	80.8	120.9	141.6	161.4	40.0	13.0	19.0	31.0	13.0	7.5	13.0	11.5
	39	31.6	19.1	47.3	60.0	77.1	114.0	146.2	160.8	40.0	14.5	21.5	34.0	17.5	9.0	12.0	10.0
	40	29.7	24.8	45.8	62.0	78.2	116.0	147.3	162.5	40.0	12.0	20.5	25.5	14.0	7.5	14.5	10.0
	Average:	31.6	22.2	41.6	56.6	80.7	113.5	143.6	161.0	40.0	13.4	21.2	32.2	18.2	8.5	13.2	10.4

TABLE 2 (Cont.)
DURATIONS AND MAGNITUDES OF TRACE INFLECTIONS
8-cu yd Mixer

Group	Cycle	Intervals Between Points of Inflection Indicated, seconds								Heights of Points Indicated, mm							
		8 to 1	1 to 2	1 to 3	1 to 4	1 to 5	1 to 6	1 to 7	1 to 8	1	2	3	4	5	6	7	8
Group C: Tape 3 7-17-61, Start at 2:15 PM	41	33.0	----	45.2	55.2	72.0	102.0	143.2	159.2	40.0	----	15.5	25.0	9.0	3.0	7.5	5.5
	42	31.6	22.5	46.0	56.2	74.0	129.4	150.2	160.6	40.0	6.5	20.0	35.0	15.0	3.0	9.0	7.0
	43	32.1	21.2	44.4	54.6	79.0	132.6	143.4	160.4	40.0	8.0	22.0	36.0	18.0	3.0	10.5	8.5
	44	32.0	19.6	42.6	53.6	91.0	122.2	148.0	160.4	40.0	8.5	17.5	33.0	17.5	4.0	11.5	11.0
	45	31.2	21.2	39.8	55.8	84.4	118.0	137.6	160.0	40.0	7.0	16.0	31.5	14.0	4.0	10.0	8.5
	46	29.6	23.8	35.8	58.8	81.2	103.6	156.2	165.0	40.0	9.0	15.0	27.0	8.0	4.0	13.0	9.0
	47	29.4	21.6	53.8	60.6	82.2	111.8	138.6	161.0	40.0	9.0	15.0	21.0	9.0	4.0	8.0	7.5
	48	30.8	26.4	44.4	61.0	81.0	128.8	139.2	161.6	40.0	8.5	17.0	32.0	14.0	4.5	10.5	8.0
	49	30.4	20.5	45.4	60.6	84.0	127.4	152.6	161.6	40.0	7.5	18.0	31.0	14.0	5.0	10.0	7.5
	50	29.4	21.4	42.0	59.6	79.6	102.0	143.0	162.2	40.0	7.0	18.0	35.0	15.0	6.0	10.0	8.0
	51	29.8	25.8	48.0	65.8	90.0	123.2	137.6	161.4	40.0	10.0	22.0	33.0	17.0	4.5	11.5	8.0
	Average:	30.8	22.4	44.3	58.3	81.7	118.3	144.5	161.2	40.0	8.1	17.8	30.9	13.7	4.1	10.1	8.0
Group D: Tape 4 7-18-61, 9:15 to 10:35 AM	1	33.5	29.0	39.0	59.0	91.0	142.6	158.0	160.2	40.0	16.0	19.0	47.0	23.0	10.0	17.0	15.0
	2	28.0	----	----	----	-----	-----	-----	159.4	40.0	----	----	----	----	----	----	----
	3	33.3	28.6	42.4	57.0	78.0	109.0	134.6	160.4	40.0	15.0	19.0	48.0	23.0	8.5	17.0	12.5
	4	33.7	21.5	42.0	61.0	80.0	118.0	155.4	159.4	40.0	16.0	25.0	40.0	22.0	10.0	17.0	14.5
	5	33.0	25.0	41.6	52.4	67.0	100.0	130.6	159.8	40.0	14.0	25.0	33.0	23.0	12.0	17.0	14.0
	6	32.7	21.2	45.0	58.8	77.4	121.0	157.6	160.6	40.0	14.0	23.0	42.0	24.0	9.0	14.5	13.0
	7	32.4	23.0	39.4	52.0	77.0	110.0	151.6	160.8	40.0	15.0	23.0	42.0	22.0	10.0	17.0	12.5
	8	32.4	25.0	43.0	50.0	79.6	133.6	149.2	160.4	40.0	15.5	28.0	43.0	19.0	9.5	17.0	15.0
	9	33.4	23.4	40.6	53.0	77.0	115.0	156.4	160.4	40.0	16.5	22.0	41.0	21.0	11.0	15.0	12.0
	10	33.6	23.4	35.0	55.8	78.6	112.6	143.6	159.5	40.0	13.0	23.0	43.0	20.0	10.5	16.0	11.0
	11	32.8	22.0	41.6	56.0	68.4	106.4	132.6	159.4	40.0	16.0	25.0	41.0	23.0	10.5	17.0	14.0
	12	33.0	20.0	41.0	60.0	79.0	111.2	156.4	160.4	40.0	15.0	22.0	40.0	23.0	11.0	18.0	12.0
	13	33.0	22.0	44.0	59.4	83.0	115.4	147.0	160.6	40.0	16.0	24.0	43.0	20.0	9.5	17.0	14.0
	14	34.6	17.0	42.0	56.0	79.6	123.0	142.8	159.8	40.0	17.0	26.0	45.0	23.0	11.0	17.0	12.0
	15	33.0	25.4	39.2	65.4	82.4	133.0	152.4	160.0	40.0	14.0	21.0	40.0	19.0	10.0	18.0	13.5
	16	33.2	29.0	40.4	64.4	88.0	130.4	146.4	160.4	40.0	16.0	23.0	41.0	23.0	12.0	18.5	14.0
	17	35.6	20.0	34.8	59.2	90.0	128.4	153.4	162.4	40.0	15.0	22.0	46.0	28.0	12.0	18.0	12.0
	18	34.0	21.0	38.0	65.6	84.0	145.0	153.4	160.0	40.0	16.0	26.0	47.0	25.0	11.0	17.0	16.0
	19	32.4	26.4	40.4	60.2	90.4	149.8	161.4	161.4	40.0	15.0	23.0	41.0	19.0	11.0	16.0	16.0
	20	32.4	28.0	45.6	57.8	93.0	113.4	150.4	161.4	40.0	15.0	29.0	44.0	19.0	11.0	18.0	16.0
	21	32.6	21.6	38.2	60.2	90.8	111.2	148.0	160.8	40.0	16.0	21.0	43.0	16.0	12.0	17.0	15.0
	22	31.0	22.4	40.0	66.0	85.0	118.0	154.0	161.6	40.0	16.0	23.0	38.0	18.0	12.0	18.0	17.0
	23	31.4	30.0	39.0	59.0	78.0	119.6	136.0	161.2	40.0	16.0	20.0	37.0	24.0	11.0	17.0	16.0
	24	33.8	22.0	40.4	60.4	79.0	-----	-----	-----	40.0	16.0	25.0	38.0	23.0	----	----	----
	Average:	33.1	23.8	40.5	59.0	81.6	121.2	148.7	160.5	40.0	15.4	23.3	41.9	21.7	10.7	17.0	14.0
Group E: Tape 5 7-18-61, 10:45 AM to Noon	25	32.0	20.0	41.8	65.0	83.8	107.0	146.0	160.0	40.0	14.0	22.0	47.0	21.5	12.5	19.0	14.0
	26	32.8	23.6	47.6	52.6	77.0	132.0	141.0	161.0	40.0	16.0	33.0	45.0	29.5	13.0	20.5	14.0
	27	34.4	20.8	40.0	60.0	67.6	116.8	146.4	158.8	40.0	18.0	25.5	43.0	25.0	12.0	20.0	15.5
	28	34.6	23.6	44.6	51.0	60.2	97.6	140.0	158.0	40.0	18.0	34.0	39.0	32.0	12.0	20.0	20.0
	29	32.0	20.0	48.0	61.4	78.4	133.2	148.0	159.4	40.0	17.0	32.0	38.0	27.0	11.0	19.0	15.0
	30	33.0	22.4	47.6	61.6	77.6	103.4	124.0	159.8	40.0	18.0	26.0	44.0	26.0	12.0	21.0	15.0
	31	36.2	16.0	42.0	55.2	73.4	117.0	142.4	159.4	40.0	16.0	31.0	39.0	27.0	11.0	20.0	15.0
	32	32.8	29.0	41.2	54.8	73.0	105.6	125.0	159.8	40.0	19.0	32.0	39.0	29.0	13.0	21.0	18.0
	33	32.2	24.0	47.0	60.4	78.0	128.0	130.6	160.0	40.0	15.5	23.0	39.0	25.0	12.0	21.0	16.0
	34	33.6	22.8	43.0	62.8	78.2	120.0	144.6	159.0	40.0	16.0	26.0	40.0	25.0	13.5	19.0	15.5
	35	33.6	26.4	43.4	55.6	74.0	102.0	150.0	159.4	40.0	13.5	25.0	43.0	28.0	12.5	20.0	16.0
	36	33.4	16.0	46.0	55.6	68.0	117.0	150.0	158.6	40.0	16.5	25.0	38.0	25.0	13.0	19.0	17.5
	37	34.6	19.4	43.0	59.2	72.0	84.0	147.0	157.0	40.0	18.0	27.0	41.0	25.0	13.0	19.0	18.0
	38	33.0	22.4	45.6	54.8	84.6	112.0	148.0	159.0	40.0	17.0	27.0	39.0	26.0	14.0	19.0	17.5
	39	32.6	21.0	42.0	56.6	80.0	134.0	159.0	159.4	40.0	16.5	24.0	43.0	24.0	12.5	21.0	21.0
	40	32.8	30.6	42.4	49.6	61.6	106.0	148.0	159.6	40.0	18.0	26.0	38.0	28.0	12.0	20.0	20.0
	41	34.2	19.6	44.6	53.8	65.0	102.0	135.0	159.0	40.0	17.0	29.0	39.0	30.0	13.0	22.0	17.0
	42	36.4	19.4	36.4	48.6	67.4	111.4	124.6	159.6	40.0	17.0	29.0	38.0	29.0	12.0	21.0	18.0
	43	34.2	28.6	41.6	58.6	66.0	114.4	146.2	158.6	40.0	17.0	22.0	39.0	25.0	12.0	20.0	19.0
	44	31.6	28.2	46.2	58.4	79.4	106.4	148.2	160.2	40.0	18.0	28.0	38.0	20.0	13.0	20.5	16.5
	45	34.0	19.0	40.0	51.4	70.4	-----	-----	-----	40.0	16.0	26.0	41.0	30.0	----	----	----
	Average:	33.5	22.5	43.5	56.5	73.1	112.5	142.2	159.3	40.0	16.8	27.3	40.5	26.5	12.5	20.1	16.9
	Grand Average:	32.8	23.1	43.7	58.0	79.7	115.8	144.3	160.0	40.0	15.6	23.8	37.3	21.6	11.1	17.1	14.2

TABLE 3
DURATIONS AND MAGNITUDES OF TRACE INFLECTIONS
3.4-cu yd Mixer

Date	Batch No.	Trace No.	Intervals Between Points of Inflection Indicated, seconds						Height of Points Indicated, mm					
			0 to 1	0 to 2	0 to 3	0 to 4	0 to 5	0 to 8	1	2	3	4	5	8
9-19-61	1	33	15	36	37	53	72	85	40	5	8	30	8	7
	2	34	11	32	34	52	73	85	40	3	12	35	8	8
	3	35	14	35	38	48	63	85	40	3	9	30	8	3
	4	36	13	37	39	51	67	85	40	5	10	30	11	6
	5	37	12	34	40	55	75	85	40	4	10	33	10	8
	6	38	12	31	33	52	71	85	40	4	6	35	9	5
	7	39	12	36	37	60	82	85	40	3	10	38	12	15
	8	40	12	37	40	60	84	90	40	4	10	40	9	12
	9	47	13	35	38	56	69	79	40	3	9	40	6	2
	10	107	11	34	36	48	70	85	40	3	7	30	4	2
	11	108	12	33	36	44	63	85	40	3	12	30	4	2
	12	109	14	36	40	55	72	86	40	3	12	35	5	4
	Average		12.6	34.7	37.3	52.8	71.8	85.0	40.0	3.6	9.6	33.8	7.8	6.2
9-20-61	13	8	12	37	39	47	60	74	40	7	15	29	10	5
	15	10	14	32	36	44	55	74	40	8	16	33	8	3
	16	11	14	36	39	53	71	74	40	7	15	35	13	13
	17	12	15	36	40	54	70	79	40	6	11	35	12	5
	18	14	15	36	40	52	62	75	40	8	10	36	13	7
	19	15	13	35	40	47	60	75	40	7	12	32	8	4
	20	16	11	35	40	42	55	75	40	7	14	35	8	3
	21	28	14	36	39	48	61	75	40	5	9	34	11	7
	23	30	14	32	37	45	60	75	40	6	12	35	13	5
	24	32	11	38	41	55	70	75	40	6	13	38	15	17
	25	56	11	34	38	52	70	75	40	8	15	45	15	13
	26	58	14	37	40	48	65	75	40	8	16	30	10	6
	27	59	12	36	40	48	65	74	40	8	15	35	9	6
	28	60	13	33	36	44	60	75	40	7	14	33	8	4
	29	62	14	37	40	48	65	75	40	6	14	31	8	6
	31	66	13	37	40	52	69	75	40	7	13	35	9	8
	32	67	14	38	41	52	69	75	40	7	12	35	8	7
	33	69	13	36	40	50	66	77	40	8	17	32	10	8
	34	70	14	38	39	46	60	75	40	8	17	34	8	4
	35	73	13	38	40	54	67	76	40	7	15	32	8	4
	36	74	14	37	41	53	71	75	40	5	15	38	10	5
	37	75	14	37	41	48	66	75	40	7	13	30	8	4
	38	76	14	35	38	43	57	75	40	7	12	28	6	3
	40	78	11	37	39	48	65	75	40	6	13	32	10	7
	41	79	11	32	38	58	73	76	40	7	15	36	15	16
	42	80	13	36	38	55	71	75	40	5	15	40	15	17
	43	81	11	33	36	54	71	75	40	5	12	40	14	16
	44	82	11	34	37	45	60	75	40	5	12	30	6	3
	45	83	14	36	38	43	55	75	40	6	16	30	5	2
	46	84	13	36	40	45	61	75	40	4	14	28	4	3
	47	85	11	36	38	53	72	75	40	2	9	38	14	18
	48	87	12	36	40	58	79	96	40	3	20	35	8	2
	Average		12.9	35.7	39.0	49.5	64.9	75.8	40.0	6.3	13.5	34.0	10.0	7.2
9-22-61	49	2	13	31	34	41	68	77	40	7	17	40	8	8
	50	4	15	36	39	49	68	78	40	9	15	30	9	5
	51	6	13	33	36	46	66	76	40	6	17	32	10	8
	52	7	14	36	39	50	70	78	40	8	13	40	10	10
	53	8	14	36	38	46	66	78	40	8	11	30	8	6
	54	10	14	37	40	47	71	79	40	9	14	30	10	5
	55	12	14	36	39	47	66	76	40	7	10	30	8	5
	56	14	14	34	38	44	64	76	40	8	15	40	8	7
	57	15	12	36	38	47	75	86	40	7	15	40	10	11
	58	16	12	34	38	46	65	77	40	8	12	35	10	5
	59	18	10	31	32	44	65	75	40	8	15	35	12	6
	60	19	11	34	36	52	77	87	40	8	14	40	6	4
	61	20	14	36	39	50	71	76	40	9	13	36	12	8
	62	22	11	33	34	47	63	77	40	8	10	30	8	5
	63	23	12	37	41	54	76	81	40	6	15	40	9	9
	64	24	11	37	40	51	69	78	40	7	10	30	10	7
	65	26	14	35	37	46	63	82	40	7	15	29	10	5
	68	30	13	35	39	50	74	85	40	6	13	40	4	1
	69	31	9	34	36	46	76	88	40	2	10	30	7	2
	70	32	12	34	37	45	75	83	40	2	10	30	2	1
	71	34	11	33	36	47	62	83	40	9	15	35	12	6
	72	35	10	34	36	51	75	82	40	3	10	32	5	5
	73	37	12	36	40	54	74	83	40	4	10	30	8	6
	74	39	12	36	38	44	65	83	40	0	12	27	4	1
	75	41	10	34	35	45	62	82	40	8	15	33	11	5
	76	42	9	33	35	48	69	82	40	8	13	36	8	6
	77	43	9	33	35	60	80	99	40	7	15	40	13	10
	78	44	11	34	37	59	70	81	40	5	12	40	8	2
	79	46	12	33	36	45	66	74	40	6	14	35	8	5
	80	48	12	37	41	71	86	90	40	5	12	40	8	8
	82	55	13	36	40	54	73	76	40	5	10	31	14	14
	83	56	14	37	42	54	70	75	40	5	12	30	9	9
	84	60	14	34	40	51	73	74	40	8	15	35	12	12
	Average		12.2	34.7	37.6	49.4	70.1	80.5	40.0	6.5	13.0	34.3	8.8	6.2

TABLE 3 (Cont.)
DURATIONS AND MAGNITUDES OF TRACE INFLECTIONS
3.4-cu yd Mixer

Date	Batch No.	Trace No.	Intervals Between Points of Inflection Indicated, seconds						Height of Points Indicated, mm					
			0 to 1	0 to 2	0 to 3	0 to 4	0 to 5	0 to 8	1	2	3	4	5	8
9-23-61	85	3	11	36	41	52	75	80	40	0	7	28	4	0
	86	4	12	37	42	50	68	78	40	2	9	30	7	2
	87	5	12	37	41	49	64	78	40	2	7	27	4	0
	88	6	11	36	41	49	64	77	40	2	7	28	3	0
	89	7	11	36	40	54	67	77	40	2	8	32	10	4
	90	8	11	37	41	60	67	81	40	4	8	35	9	4
	91	11	12	38	40	58	65	76	40	3	6	32	10	3
	92	12	11	37	42	56	66	79	40	3	10	34	8	3
	93	13	11	37	42	58	68	83	40	3	8	35	11	1
	94	14	13	38	41	52	60	76	40	3	8	32	5	1
	95	15	12	37	41	55	68	76	40	4	6	30	10	5
	Average		11.5	36.9	41.1	53.9	66.6	78.3	40.0	2.5	7.6	31.2	7.4	2.1
9-27-61	96	1	8	36	38	47	60	99	40	4	8	30	5	0
	97	3	17	39	43	61	77	86	40	4	9	40	6	2
	98	4	14	39	41	65	75	85	40	4	7	40	5	0
	99	5	14	38	40	54	68	76	40	4	8	38	5	1
	100	6	12	38	40	57	72	83	40	4	9	40	7	1
	101	7	14	33	35	48	65	74	40	5	12	35	5	2
	102	9	11	34	37	55	73	86	40	4	10	40	10	1
	103	10	12	37	40	49	69	74	40	5	7	35	9	10
	104	11	15	35	38	46	67	74	40	4	10	36	9	4
	105	13	14	38	39	50	64	74	40	6	10	35	10	5
	106	15	17	40	41	48	67	76	40	5	10	30	8	4
	•107	16	14	39	40	51	63	74	40	4	12	29	7	3
	108	17	13	38	41	48	66	73	40	5	11	28	5	4
	109	18	15	39	40	52	73	74	40	3	12	35	8	8
	110	19	11	35	37	58	73	74	40	3	8	30	10	10
	111	20	14	37	40	53	65	74	40	4	9	32	5	2
	112	22	11	36	39	56	75	83	40	4	8	35	5	1
	113	23	12	37	40	52	69	75	40	5	11	30	8	7
	114	26	13	37	40	55	75	92	40	4	10	35	8	3
	116	29	13	34	38	42	63	74	40	6	10	29	7	4
	118	43	7	40	42	51	74	75	40	4	12	28	7	4
	119	45	10	39	41	53	70	75	40	4	8	28	4	2
	120	46	7	36	38	46	65	75	40	4	9	29	7	3
	121	47	12	38	41	48	69	75	40	3	10	29	5	3
	123	49	12	38	40	44	64	75	40	3	12	30	4	1
	124	50	12	34	37	46	61	75	40	3	7	35	10	3
	125	51	8	33	41	46	74	75	40	3	11	30	6	3
	126	53	15	38	41	50	74	75	40	4	7	28	6	5
	127	55	13	35	39	49	71	75	40	4	10	30	9	7
	129	57	15	38	41	48	67	75	40	5	11	27	8	4
	130	58	12	36	39	44	64	82	40	5	9	30	6	1
	131	68	25	37	41	47	71	75	40	17	26	40	14	10
	132	69	24	37	41	48	68	75	40	15	18	40	10	8
	133	70	22	36	38	46	67	75	40	14	20	40	12	9
	135	74	21	37	40	48	71	75	40	13	21	40	13	12
	136	16	20	35	35	47	75	105	40	12	18	40	15	7
	138	19	24	38	39	55	73	76	40	13	18	40	12	8
	Average		14.1	36.9	39.5	50.4	69.1	78.2	40.0	5.8	11.3	33.7	7.8	4.4
9-28-61	139	9	25	40	42	52	65	75	40	16	18	40	15	11
	141	11	29	38	41	53	63	73	40	17	23	40	18	15
	143	13	21	38	40	50	59	73	40	16	24	40	12	10
	144	15	19	39	41	53	66	75	40	15	17	40	18	15
	145	17	13	36	38	54	70	75	40	14	23	40	19	14
	146	19	21	34	36	47	57	81	40	15	18	40	18	15
	147	20	22	36	39	49	58	75	40	15	16	40	19	14
	148	21	16	39	43	56	70	79	40	14	20	40	14	11
	149	23	27	40	43	55	71	75	40	16	25	40	20	16
	150	24	27	40	43	57	68	75	40	14	24	40	25	20
	Average		22.0	38.0	40.9	52.6	64.7	75.6	40.0	15.2	20.8	40.0	17.8	14.1
	Grand Average		13.6	35.5	39.0	50.8	68.1	78.7	40.0	6.7	12.6	34.5	9.9	6.7

TABLE 4
GROUP 1. BATCH CHARGE AND CLUMPING TIMES (NO DEAD TIMES)
3.4-cu yd Mixer

Date	Batch No.	Trace No.	Seconds from Start of Charge: Pen Contacted Chart	End of Charge	Clumping: Start	Clumping: End	Mixing: Stopped	Mixing: Resumed	Discharge	Total Clumping Time, seconds	Total Dead Time, seconds	Total Mixing Time, seconds: From Start of Charge	From End of Charge
9-19-61	1	33	15	19	37	72			85	35		85	66
	2	34	11	29	34	73			85	39		85	56
	3	35	14	25	38	63			85	25		85	60
	4	36	13	25	39	67			85	28		85	60
	5	37	12	22	40	75			85	35		85	63
	6	38	12	29	33	71			85	38		85	56
	7	39	12	19	37	82			85	45		85	66
	8	40	12	19	40	84			90	44		90	71
	9	47	13	24	38	69			79	31		79	55
	10	107	11	26	36	70			85	34		85	59
	11	108	12	28	36	63			85	27		85	57
	12	109	14	25	40	72			86	32		86	61
	Average		12.6	24.2	37.3	71.8			85.0	34.4		85.0	60.8
9-20-61	13	8	12	17	39	60			74	21		74	57
	14*	9*	15*	24*	35*	56*			307*	21*		307*	283*
	15	10	14	23	36	55			74	19		74	51
	16	11	14	18	39	71			74	32		74	56
	17	12	15	16	40	70			79	30		79	63
	18	14	15	17	40	62			75	22		75	58
	19	15	13	18	40	60			75	20		75	57
	20	16	11	16	40	55			75	15		75	59
	21	28	14	17	39	61			75	22		75	58
	22*	29*	14*	17*	41*	59*			267*	18*		267*	250*
	23	30	14	32	37	60			75	23		75	43
	24	32	11	16	41	70			75	29		75	59
	25	56	11	21	38	70			75	32		75	54
	26	58	14	24	40	65			75	25		75	51
	27	59	12	17	40	65			74	25		74	57
	28	60	13	26	36	60			75	24		75	49
	29	62	14	17	40	61			75	21		75	58
	30*	63*	13*	18*	38*	51*			123*	13*		123*	105*
	31	66	13	20	40	69			75	29		75	55
	32	67	14	21	41	69			75	28		75	54
	33	69	13	18	40	66			77	26		77	59
	34	70	14	16	39	60			75	21		75	59
	35	73	13	17	40	67			76	27		76	59
	36	74	14	15	41	71			75	30		75	60
	37	75	14	16	41	66			75	25		75	59
	38	76	14	15	38	57			75	19		75	60
	39*	77*	13*	16*	39*	53*			145*	14*		145*	129*
	40	78	11	14	39	65			75	26		75	61
	41	79	11	18	38	73			76	35		76	58
	42	80	13	21	38	71			75	33		75	54
	43	81	11	26	36	71			75	35		75	49
	44	82	11	16	37	60			75	23		75	59
	45	83	14	19	38	55			75	17		75	56
	46	84	13	19	40	61			75	21		75	56
	47	85	11	16	38	72			75	34		75	59
	48	87	12	15	40	79			96	39		96	81
	Average		12.9	18.7	39.0	64.9			75.8	25.9		75.8	57.1

* Not used in averages (Chauvenet's criterion).

TABLE 4 (Cont.)

GROUP 1. BATCH CHARGE AND CLUMPING TIMES (NO DEAD TIMES)

3.4-cu yd Mixer

Date	Batch No.	Trace No.	Seconds from Start of Charge: Pen Contacted Chart	End of Charge	Clumping: Start	Clumping: End	Mixing: Stopped	Mixing: Resumed	Discharge	Total Clumping Time, seconds	Total Dead Time, seconds	Total Mixing Time, seconds: From Start of Charge	From End of Charge
9-22-61	49	2	13	35	34	68			77	34		77	42
	50	4	15	25	39	68			78	29		78	53
	51	6	13	30	36	66			76	30		76	46
	52	7	14	27	39	70			78	31		78	51
	53	8	14	23	38	66			78	28		78	55
	54	10	14	28	40	71			79	31		79	51
	55	12	14	42	39	66			76	27		76	34
	56	14	14	26	38	64			76	26		76	50
	57	15	12	26	38	75			86	37		86	60
	58	16	12	22	38	65			77	27		77	55
	59	18	10	29	32	65			75	33		75	46
	60	19	11	29	36	77			87	41		87	58
	61	20	14	23	39	71			76	32		76	53
	62	22	11	26	34	63			77	29		77	51
	63	23	12	27	41	76			81	35		81	54
	64	24	11	24	40	69			78	29		78	54
	65	26	14	29	37	63			82	26		82	53
	66*	27*	10*	29*	39*	65*			100*	26*		100*	71*
	67*	29*	10*	25*	36*	80*			116*	44*		116*	91*
	68	30	13	24	39	74			85	35		85	61
	69	31	9	24	36	76			88	40		88	64
	70	32	12	24	37	75			83	38		83	59
	71	34	11	31	36	62			83	26		83	52
	72	35	10	31	36	75			82	39		82	51
	73	37	12	29	40	74			83	34		83	54
	74	39	12	28	38	65			83	27		83	55
	75	41	10	26	35	62			82	27		82	56
	76	42	9	26	35	69			82	34		82	56
	77	43	9	25	35	80			99	45		99	74
	78	44	11	22	37	70			81	33		81	59
	79	46	12	30	36	66			74	30		74	44
	80	48	12	34	41	86			90	45		90	56
	81*	50*	12*	25*	38*	78*			121*	40*		121*	96*
	82	55	13	25	40	73			76	33		76	51
	83	56	14	25	42	70			75	28		75	50
	84	60	14	21	40	73			74	33		74	53
	Average		12.2	27.5	37.6	70.1			80.5	32.5		80.5	53.0
9-23-61	85	3	11	38	41	75			80	34		80	42
	86	4	12	39	42	68			78	26		78	39
	87	5	12	35	41	64			78	23		78	43
	88	6	11	34	41	64			77	23		77	43
	89	7	11	36	40	67			77	27		77	41
	90	8	11	34	41	67			81	26		81	47
	91	11	12	39	40	65			76	25		76	37
	92	12	11	32	42	66			79	24		79	47
	93	13	11	30	42	68			83	26		83	53
	94	14	13	34	41	60			76	19		76	42
	95	15	12	30	41	68			76	27		76	46
	Average		11.5	34.6	41.1	66.6			78.3	25.5		78.3	43.7

* Not used in averages (Chauvenet's criterion).

TABLE 4 (Cont.)
GROUP 1. BATCH CHARGE AND CLUMPING TIMES (NO DEAD TIMES)
3.4-cu yd Mixer

Date	Batch No.	Trace No.	Seconds from Start of Charge: Pen Contacted Chart	End of Charge	Clumping: Start	Clumping: End	Mixing: Stopped	Mixing: Resumed	Discharge	Total Clumping Time, seconds	Total Dead Time, seconds	Total Mixing Time, seconds: From Start of Charge	From End of Charge
9-27-61	96	1	8	41	38	60			99	22		99	58
	97	3	17	31	43	77			86	34		86	55
	98	4	14	32	41	75			85	34		85	53
	99	5	14	33	40	68			76	28		76	43
	100	6	12	23	40	72			83	32		83	60
	101	7	14	26	35	65			74	30		74	48
	102	9	11	37	37	73			86	36		86	49
	103	10	12	29	40	69			74	29		74	45
	104	11	15	36	38	67			74	29		74	38
	105	13	14	35	39	64			74	25		74	39
	106	15	17	31	41	67			76	26		76	45
	107	16	14	21	40	63			74	23		74	53
	108	17	13	16	41	66			73	25		73	57
	109	18	15	21	40	73			74	33		74	53
	110	19	11	22	37	73			74	36		74	52
	111	20	14	19	40	65			74	25		74	55
	112	22	11	28	39	75			83	36		83	55
	113	23	12	30	40	69			75	29		75	45
	114	26	13	28	40	75			92	35		92	64
	115*	28*	13*	33*	40*	75*			125*	35*		125*	92*
	116	29	13	36	38	63			74	25		74	38
	117*	30*	12*	31*	39*	71*			133*	32*		133*	102*
	118	43	7	26	42	74			75	32		75	49
	119	45	10	22	41	70			75	29		75	53
	120	46	7	21	38	65			75	27		75	54
	121	47	12	20	41	69			75	28		75	55
	122*	48*	13*	21*	39*	68*			132*	29*		132*	111*
	123	49	12	25	40	64			75	24		75	50
	124	50	12	26	37	61			75	24		75	49
	125	51	8	19	41	74			75	33		75	56
	126	53	15	20	41	74			75	33		75	55
	127	55	13	27	39	71			75	32		75	48
	128*	56*	16*	32*	41*	72*			218*	31*		218*	186*
	129	57	15	37	41	67			75	26		75	38
	130	58	12	33	39	64			82	25		82	49
	131	68	25	26	41	71			75	30		75	49
	132	69	24	31	41	68			75	27		75	44
	133	70	22	30	38	67			75	29		75	45
	134*	71*	18*	33*	33*	62*			269*	29*		269*	236*
	135	74	21	24	40	71			75	31		75	51
	136	16	20	30	35	75			105	40		105	75
	137*	18*	19*	26*	38*	84*			157*	46*		157*	131*
	138	19	24	34	39	73			76	34		76	42
	Average		14.1	27.7	39.5	69.1			78.2	29.6		78.2	50.5
9-28-61	139	9	25	36	42	65			75	23		75	39
	140*	10*	23*	32*	38*	65*			174*	27*		174*	142*
	141	11	29	36	41	63			73	22		73	37
	142*	12*	22*	35*	40*	68*			135*	28*		135*	100*
	143	13	21	39	40	59			73	19		73	34
	144	15	19	36	41	66			75	25		75	39
	145	17	13	58	38	70			75	32		75	17
	146	19	21	61	36	57			81	21		81	20
	147	20	22	49	39	58			75	19		75	26
	148	21	16	31	43	70			79	27		79	48
	149	23	27	30	43	71			75	28		75	45
	150	24	27	30	43	68			75	25		75	45
	Average		22.0	40.6	40.9	64.7			75.6	23.8		75.6	35.0
	Grand Average		13.6	26.7	39.0	68.1			78.7	29.1		78.7	52.0

* Not used in averages (Chauvenet's criterion).

TABLE 5
GROUP 2. BATCH CHARGE, CLUMPING, AND DEAD TIMES
3.4-cu yd Mixer

Date	Batch No.	Trace No.	Seconds from Start of Charge: Pen Contacted Chart	End of Charge	Clumping: Start	Clumping: End	Mixing: Stopped	Mixing: Resumed	Discharge	Total Clumping Time, seconds	Total Dead Time, seconds	Total Mixing Time, seconds: From Start of Charge	From End of Charge
9-20-61	1	33	12	16	36	59	77 760	715 1740	1768	23	638 980	150	134
	2	57	9	13	34	61	104	178	200	27	74	126	113
	3	61	16	16	39	65	82	109	123	26	27	96	80
	4	65	12	16	39	63	75	197	226	24	122	104	88
	5	71	13	14	38	63	103	165	188	25	62	126	112
9-22-61	6	3	14	24	39	83	100	138	159	44	38	121	97
	7	5	10	28	35	62	100 270	202 319	325	27	102 49	174	146
	8	9	13	24	40	68	112	189	211	28	77	134	110
	9	11	12	25	40	80	120	239	260	40	119	141	116
	10	13	12	28	38	80	152	179	198	42	27	171	143
	11	17	14	20	38	70	200	385	423	32	185	238	218
	12	33	16	24	39	71	128	208	233	32	80	153	129
	13	61	10	18	39	70	85	152	202	31	67	135	117
9-23	14	9	10	47	41	67	85	182	202	26	97	105	58
9-27-61	15	8	13	20	41	86	122	347	360	45	225	135	115
	16	14	10	27	39	71	97	244	256	32	147	109	82
	17	24	10	30	38	75	96	158	169	37	62	107	77
	18	32	12	26	40	87	105	205	217	47	100	117	91
9-28	19	25	23	27	41	68	81	1051	1096	27	970	126	99
	Average		12.9	23.3	38.6	71.0			358.7	32.4	223.6	135.2	111.8

TABLE 6
GROUP 3. BATCH CLUMPING AND DEAD TIMES (NO CHARGE TIMES RECORDED)
3.4-cu yd Mixer

Date	Batch No.	Trace No.	Seconds from Start of Charge: Pen Contacted Chart	End of Charge	Clumping: Start	Clumping: End	Mixing: Stopped	Mixing: Resumed	Discharge	Total Clumping Time, seconds	Total Dead Time, seconds	Total Mixing Time, seconds: From Start of Charge	From End of Charge
9-19-61	1	18	15		40	86	93	169	171	46	76	95	
	2	23	14		35	74	75	86	88	39	11	77	
	3	46	12		38	70	88	148	149	32	60	89	
9-20	4	19	15		40	59	85	251	270	19	166	104	
	5	89	12		40	96	104	151	166	56	47	119	
9-22	6	25	10		36	65	108	184	208	29	76	132	
9-23	7	31	10		40	73	108	127	142	33	19	123	
9-27	8	12	13		41	79	89	123	144	38	34	110	
	9	17	24		39	75	81	152	168	36	71	97	
9-28-61	10	18	22		38	63	136	460	510	25	324	186	
	11	31	24		39	61	105	153	204	22	48	156	
	12	37	24		39	61	76	152	178	22	76	102	
	13	41	22		38	66	88	129	136	28	41	95	
	14	43	25		35	72	78	278	296	37	200	96	
	15	51	22		40	65	98	237	298	25	139	159	
	16	53	24		40	64	132	376	387	24	244	143	
	17	57	22		39	66	84	652	676	27	568	108	
	18	63	24		33	64	94	335	352	31	241	111	
	19	67	23		40	62	128	246	255	22	118	137	
	20	111	11		38	88	130	195	235	50	65	170	
	Average		18.4		38.4	70.5			251.7	32.1	131.2	120.5	

TABLE 7
GROUP 4. BATCH CLUMPING TIMES
(NO DEAD TIMES--CHARGE TIMES NOT RECORDED)
3.4-cu yd Mixer

Date	Batch No.	Trace No.	Seconds from Start of Charge: Pen Contacted Chart	End of Charge	Clumping: Start	Clumping: End	Mixing: Stopped	Mixing: Resumed	Discharge	Total Clumping Time, seconds	Total Dead Time, seconds	Total Mixing Time, seconds: From Start of Charge	From End of Charge
9-19-61	1	9	8		33	61			75	28		75	
	2	10	9		34	65			76	31		76	
	3	13	16		41	71			75	30		75	
	4	14	17		41	67			75	26		75	
	5	15	17		42	72			75	30		75	
	6	16	12		32	64			75	32		75	
	7	17	6		32	65			75	33		75	
	8	19	16		41	70			75	29		75	
	9	20	13		38	71			75	33		75	
	10	21	10		35	71			75	36		75	
	11	29	15		39	65			75	26		75	
	12	30	15		35	66			75	31		75	
	13	31	13		38	66			75	28		75	
	14	32	14		40	69			86	29		86	
	15	49	12		37	69			85	32		85	
	16	51	14		36	65			75	29		75	
	17	52	16		39	72			75	33		75	
	18	53	12		38	66			75	28		75	
	19	54	14		38	60			75	22		75	
	20	55	14		37	53			75	16		75	
	21	57	9		32	49			75	17		75	
	22	58	13		22	50			75	28		75	
	23	59	11		34	55			75	21		75	
	24	60	11		34	73			75	39		75	
	25	61	8		32	69			75	37		75	
	26	62	6		32	70			79	38		79	
	27	63	9		31	60			75	29		75	
	28	64	12		35	65			84	30		84	
	29	65	9		32	66			75	34		75	
	30	66	6		31	60			76	29		76	
	31	67	9		34	62			75	28		75	
	32	110	12		36	72			85	36		85	
	33	111	12		36	72			85	36		85	
	34	112	12		38	68			85	30		85	
	35	113	12		37	75			85	38		85	
	36	114	12		38	70			85	32		85	
	37	115	13		38	72			85	34		85	
	Average		11.9		35.6	65.8			77.6	30.2		77.6	
9-20-61	38	2	16		43	69			75	26		75	
	39	3	15		40	60			75	20		75	
	40	4	17		42	59			75	17		75	
	41	5	14		39	55			75	16		75	
	42	6	13		38	57			75	19		75	
	43	7	15		40	62			75	22		75	
	44	13	12		36	68			73	32		73	
	45	17	14		36	52			75	16		75	
	46	18	14		40	60			75	20		75	
	47	21	17		40	63			75	23		75	
	48	22	15		39	62			75	23		75	
	49	23	14		40	62			75	22		75	
	50	24	12		39	59			77	20		77	
	51	25	14		39	62			75	23		75	
	52	26	17		38	69			75	31		75	
	53	27	15		41	61			79	20		79	
	54	34	17		39	60			80	21		80	
	55	35	15		41	65			75	24		75	
	56	36	14		40	61			86	21		86	
	57	37	12		40	70			75	30		75	
	58	38	13		39	65			75	26		75	
	59	39	13		40	62			75	22		75	
	60	40	14		41	65			75	24		75	
	61	41	13		39	68			98	29		98	
	62	42	11		37	61			75	24		75	
	63	44	13		40	69			75	29		75	
	64	45	15		39	72			75	33		75	
	65	46	11		36	60			75	24		75	
	66	47	16		40	60			75	20		75	
	67	48	15		41	67			75	26		75	
	68	50	15		40	58			75	18		75	
	69	51	17		42	65			75	23		75	
	70	52	12		35	62			75	27		75	
	71	53	15		42	68			75	26		75	

TABLE 7 (Cont.)
GROUP 4. BATCH CLUMPING TIMES
(NO DEAD TIMES--CHARGE TIMES NOT RECORDED)
3.4-cu yd Mixer

Date	Batch No.	Trace No.	Seconds from Start of Charge: Pen Contacted Chart	End of Charge	Clumping: Start	Clumping: End	Mixing: Stopped	Mixing: Resumed	Discharge	Total Clumping Time, seconds	Total Dead Time, seconds	Total Mixing Time, seconds: From Start of Charge	From End of Charge
9-20-61	72	54	13		41	67			75	26		75	
	73	55	12		38	66			89	28		89	
	74	64	13		39	58			75	19		75	
	75	68	15		39	66			75	27		75	
	76	72	11		33	65			75	32		75	
	77	86	13		38	76			81	38		81	
	78	88	13		40	79			92	39		92	
	79	92	13		39	69			75	30		75	
	Average		14.0		39.2	63.9			76.9	24.7		76.9	
9-22-61	80*	21*	12*		39*	78*			183*	39*		183*	
	81	28	13		35	59			81	24		81	
	82	36	14		39	73			83	34		83	
	83	38	12		36	60			83	24		83	
	84	40	13		38	64			84	26		84	
	85	45	13		38	70			101	32		101	
	86	52	12		41	87			94	46		94	
	87	62	12		38	75			79	37		79	
	Average		12.7		37.8	69.6			84.0	31.8		84.0	
9-23-61	88	10	10		37	63			79	26		79	
	89	16	10		40	65			83	25		83	
	90	20	12		30	58			75	28		75	
	91	21	10		40	59			75	19		75	
	92	22	11		38	55			75	17		75	
	93	23	10		38	55			75	17		75	
	94	25	10		39	73			84	34		84	
	95	26	6		36	61			75	25		75	
	96	27	10		38	64			75	26		75	
	97	28	13		40	68			75	28		75	
	98	29	10		37	65			77	28		77	
	99	30	8		40	70			84	30		84	
	100	32	10		38	69			76	31		76	
	Average		10.0		37.8	63.5			77.5	25.7		77.5	
9-27-61	101	33	12		38	68			74	30		74	
	102	35	16		41	67			75	26		75	
	103	37	16		41	71			75	30		75	
	104	39	12		41	74			75	33		75	
	105	40	14		40	70			82	30		82	
	106	41	13		40	68			75	28		75	
	107	42	13		41	74			75	33		75	
	108	59	12		38	64			75	26		75	
	109	60	14		41	71			75	30		75	
	110	61	16		41	73			75	32		75	
	111	64	23		41	69			75	28		75	
	112	65	24		40	70			75	30		75	
	113	66	22		38	69			75	31		75	
	114	75	23		40	72			75	32		75	
	115	76	23		39	69			75	30		75	
	116	77	28		41	70			75	29		75	
	117	78	27		41	69			75	28		75	
	118	80	24		39	70			75	31		75	
	Average		18.4		40.1	69.9			75.3	29.8		75.3	
9-28-61	119	1	22		38	65			75	27		75	
	120	2	22		41	66			75	25		75	
	121	3	24		42	68			75	26		75	
	122	4	21		39	74			75	35		75	
	123	5	29		45	75			75	30		75	
	124	6	23		38	71			106	33		106	
	125*	8*	24*		36*	68*			125*	32*		125*	
	126	14	17		37	60			78	23		78	
	127	26	17		36	62			86	26		86	
	128*	29*	19*		39*	63*			187*	24*		187*	
	129	30	20		39	58			75	19		75	
	130	32	22		42	58			75	16		75	
	131	33	21		40	68			89	28		89	
	132	34	21		38	69			75	31		75	
	133	36	21		44	63			75	19		75	
	134	38	21		37	58			75	21		75	

* Not used in averages (Chauvenet's criterion).

TABLE 7 (Cont.)
GROUP 4. BATCH CLUMPING TIMES
(NO DEAD TIMES--CHARGE TIMES NOT RECORDED)
3.4-cu yd Mixer

Batch No.	Trace No.	Seconds from Start of Charge: Pen Contacted Chart	End of Charge	Clumping: Start	Clumping: End	Mixing: Stopped	Mixing: Resumed	Discharge	Total Clumping Time, seconds	Total Dead Time, seconds	Total Mixing Time, seconds: From Start of Charge	From End of Charge
135	39	22		42	67			75	25		75	
136	40	28		43	69			75	26		75	
137	42	22		38	66			75	28		75	
138	44	23		39	58			75	19		75	
139	45	21		40	65			85	25		85	
140	46	27		40	68			75	28		75	
141	48	23		42	67			75	25		75	
142	49	24		41	63			75	22		75	
143	50	25		38	60			75	22		75	
144	52	24		42	65			75	23		75	
145	54	21		38	64			75	26		75	
146	55	24		40	65			93	25		93	
147	56	25		43	65			75	22		75	
148	58	20		37	65			87	28		87	
149	60	22		40	70			75	30		75	
150*	61*	20*		35*	67*			146*	32*		146*	
151	62	21		39	65			75	26		75	
152	64	24		41	66			75	25		75	
153	68	25		48	88			96	40		96	
154	69	21		42	66			102	24		102	
155	71	20		37	62			96	25		96	
156	72	21		40	63			75	23		75	
157	74	22		41	65			75	24		75	
158	75	28		43	63			75	20		75	
159	77	21		42	63			75	21		75	
160	78	20		39	59			75	20		75	
161	51	20		47	67			75	20		75	
162	61	19		44	67			75	23		75	
163	62	14		40	61			75	21		75	
164	63	13		40	64			77	24		77	
165	64	13		41	65			75	24		75	
166	65	15		41	63			75	22		75	
167	67	16		42	63			75	21		75	
168	68	16		41	63			75	22		75	
169	69	16		42	67			75	25		75	
170	70	16		44	67			75	23		75	
171	71	18		45	65			75	20		75	
172	73	16		41	66			75	25		75	
173*	74*	12*		40*	74*			124*	34*		124*	
174	75	16		41	58			75	17		75	
175	76	13		40	64			81	24		81	
176	77	15		41	67			78	26		78	
177	78	13		38	74			75	36		75	
178	79	14		42	72			75	30		75	
179	80	15		42	73			75	31		75	
180	81	15		43	72			75	29		75	
181	83	16		43	69			75	26		75	
182	91	18		40	60			75	20		75	
183	92	18		41	69			75	28		75	
184	93	17		40	64			76	24		76	
185	95	16		37	65			75	28		75	
186	100	20		45	81			107	36		107	
187	101	13		41	73			99	32		99	
188	102	13		36	64			81	28		81	
189	103	17		43	81			110	38		110	
190	104	15		41	65			88	24		88	
191	105	13		39	64			79	25		79	
192	106	16		39	64			75	25		75	
193	107	14		39	64			93	25		93	
194	108	12		40	69			88	29		88	
195	109	12		37	61			75	24		75	
196	110	17		40	70			77	30		77	
197	113	12		40	75			77	35		77	
198*	115*	18*		40*	94*			132*	54*		132*	
199	118	17		44	76			77	32		77	
200	119	13		39	70			75	31		75	
201	120	15		40	74			76	34		76	
Average		18.9		40.6	66.5			79.3	25.9		79.3	
Grand Average		15.7		39.0	66.0			78.1	27.0		78.1	

9-28-61

* Not used in averages (Chauvenet's criterion).

TABLE 8

GROUP 5. BATCHES DISCHARGED BEFORE END OF CLUMPING PERIOD
WITH AND WITHOUT CHARGE TIMES (NO DEAD TIMES)
3.4-cu yd Mixer

Date	Batch No.	Trace No.	Seconds from Start of Charge: Pen Contacted Chart	End of Charge	Clumping: Start	Clumping: End	Mixing: Stopped	Mixing: Resumed	Discharge	Total Clumping Time, seconds	Total Dead Time, seconds	Total Mixing Time, seconds: From Start of Charge	From End of Charge
9-19-61	1	41	13	21	40				85			85	64
	2	42	10	29	36				85			85	56
	3	43	10		35				93			93	
	4	44	10		38				85			85	
	5	117	12		36				85			85	
9-20	6	31	13	33	40				74			74	41
9-22-61	7	47	14	25	40				74			74	49
	8	49	10	30	35				73			73	43
	9	51	15	27	40				75			75	48
	10	53	10		38				75			75	
	11	54	10		38				74			74	
	12	57	12	23	40				77			77	54
	13	58	12	22	42				75			75	53
	14	59	15	23	41				79			79	56
9-27-61	15	21	10	28	40				74			74	46
	16	25	6	29	38				80			80	51
	17	27	14	28	42				76			76	48
	18	31	12	27	39				72			72	45
	19	38	15		42				75			75	
	20	44	13	31	40				75			75	44
	21	52	14	26	41				75			75	49
	22	20	18	23	37				75			75	52
	23	22	27	30	42				75			75	45
9-28-61	24	47	23		39				75			75	
	25	82	16		42				75			75	
	26	112	17		41				77			77	
	27	114	18		42				76			76	
	28	116	14		42				76			76	
	29	117	16		41				76			76	
	Average		13.8	26.8	39.6				77.2			77.2	49.6