DEVELOPMENT OF A NEUTRON GAGE FOR DETERMINATION OF MIXING EFFICIENCY OF CENTRAL MIX CONCRETE PLANTS

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ABSTRACT: A gage has been developed for rapid measurement of mixing efficiency of central mix concrete plants. It contains a radioactive source of fast neutrons and a detector of slow neutrons. Fast neutrons are moderated by the hydrogen of the mix water, and low energy or "slow" neutrons are produced. Mixer efficiencies determined are based on the assumptions that when the rate of slow neutron detection becomes uniform, the distribution of water in the mix is uniform, and that at this point the distribution of other mix ingredients is also uniform. Measurements are reported for single drum and dual drum mixers, and gage and physical sampling tests for a turbine type mixer.

KEY WORDS: neutrons, neutron sources, radiation counters/sensors/, nondestructive testing, mixers, mixing efficiency, mixing plants, mixing time, water distribution.

CONTENTS

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Determining the mixing efficiency of concrete mixers by present methods is laborious and time consuming, often producing results that are inconclusive or contradictory. These tests are semi-destructive, in that they require stopping the mixer at some pre-determined time and removing a mix sample of sufficient size for compressive strength cylinders, flexural beams, air content and slump measurements, unit weight and aggregate washout tests, water content, cement content, etc. Due to the magnitude of the work required for each sample, relatively few mix batches are tested--so few, in most cases, as to make their statistical significance highly suspect, and the propriety of the determined mix times questionable. This uncertainty is usually resolved by adding a factor-of-safety time increment to the mix time indicated by the tests. Thus, the plant's efficiency is decreased as a result of deficiencies in the state of the measurement art.

These deficiencies, coupled with increasing use of central mix concrete plants, make it imperative that a measurement system be developed that can rapidly, accurately, and non-destructively measure batch mixing time of a large enough sample of any plant's production to produce results that are statistically conclusive.

In an attempt to develop such a measurement system, the neutron gage described in this report was conceived, fabricated, and tested. This work was based on earlier studies of Pocock, Schwartje, Zapata, and Hanna (1), who attempted to determine the efficiency of central mix concrete plants by measuring the attenuation of gamma radiation transmitted through a rotating mixer to a detector placed on its opposite side, and thereby record a signal proportional to the uniformity of mix density.

Their results were promising, but mixer instrumentation was complicated by the separation of source and detector, and also the resolution of recorded gamma ray variation was unsatisfactory due to collimation problems and low source strength. It was felt that increasing the strength of the gamma ray source would present shielding problems and might prove hazardous to the equipment operators. Thus, this was not done. However, this was one of their recommendations for possible future research and may still be considered a possibly worthwhile area of investigation.

One of their recommendations for future research led to the work reported here. This concerned the possibility of developing practical means for transmitting slow neutron pulses through cables of 100 ft or greater length. As was stated in their report, this was primarily a problem in electronics and as a result the project was assigned to the Instrumentation and Data Systems Unit of the Laboratory's Physical Research Section. Mr. Pocock assisted in an advisory and consulting role. Principal credit for solution of the pertinent electronic problems, and for construction and field testing of the gage, must go to W. E. Casey, Electronic Technician of the Instrumentation and Data Systems Unit.

The ensuing study had essentially only one fundamental objective--to develop a measuring system capable of efficiently and accurately determining required concrete mixing time for any type of central mix concrete plant. The system requirements that were established can be considered secondary objectives:

1. To avoid any interference with normal production operation of the mixer under study.

2. To develop a capability for monitoring every batch for any selected time period, permitting measurement of sufficient mix times to ensure statistically significant results.

3. To accomplish non-destructive testing (no stopping of mixer or physical sampling).

4. To produce a printout format that would be easily and rapidly analyzed, with a resolution of 5 seconds or better.

5. To be relatively inexpensive, and as simple and easily operable as possible.

Some degree of success was reached for each of these objectives, as will become evident in the following discussion.

MIX TIME MEASUREMENT SYSTEM

The basic criterion utilized by the neutron gage for determining efficiency of central mix concrete plants is that the concrete is properly mixed when the mix water is uniformly distributed throughout the mix ingredients.

In other words, if a system can be devised that is sensitive to water and has sufficient resolution to indicate the time at which water distribution is uniform, then that system will measure mixer efficiency.

Theoretical Background

The neutron, an electrically neutral nuclear particle, has a mass approximately equal to that of a hydrogen atom. It is usually classified, on the basis of the energy it possesses, as either a "fast" or "slow" neutron (the latter also termed "thermal"). Fast neutrons are those possessing an energy of at least 0.1 million electron volts (Mev) while the energy of slow neutrons is 0.025 Mev or less.

Whenever a field of fast neutrons impinges upon and penetrates a material, the probability is high that some neutrons will collide with nuclear particles of that material. If enough of these collisions occur, the fast neutrons will be reduced to slow or thermal energy levels. Further, the mass of any particle with which a fast neutron collides is directly related to the number of such collisions required for slowing. On the average, fewer collisions are required between a fast neutron and hydrogen nuclei to create a slow neutron, than with heavier targets where the number of collisions required for slowing is much greater. This is because heavier particles will have lower post-collision velocities than lighter ones; hence, less kinetic energy has been transferred to impacted heavier particles. Also, the probability of a fast neutron interacting with a given atomic nucleus is much higher for hydrogen than for any of the other mix elements. (The reader may confirm this by referring to nearly any nuclear physics textbook).

To summarize, when fast neutrons penetrate a concrete mix their greatest slowing is caused by impacts with the hydrogen of the mix water and the probability of such collisions is much higher for hydrogen than for any other mix element.

It can readily be seen, then, that the production of slow neutrons, when bombarding any material with fast neutrons, will be much greater if that material is rich in hydrogen, such as water or paraffin. In essence, then, if a source of high energy or fast neutrons is brought into close proximity with a material, then the number of thermal or slow neutrons produced as a result of this action will be a function (other things being equal) of the quantity of hydrogen in the target material. Therefore, to develop a device that will measure the quantity and distribution of water (HOH) in a material not containing appreciable hydrogen in forms other than water, one needs only a source of fast neutrons and a detector that will sense only slow neutrons. The Michigan neutron gage is such a device.

The Measurement System and Considerations in Its Use

In Figure 1, the gage can be seen completely assembled and also with the protective cover removed. The following components may be noted:

1. The aluminum cover for the housing,

2. The two boron trifluoride slow-neutron detector tubes, connected in parallel,

3. The lead mounting and shielding block for the detector tubes and 30-mc radium beryllium source,

4. The coaxial cable connecting the detector tubes to the preamplifier, and

5. The steel enclosure with a five-stage pulse amplifier mounted in its near end.

When completely assembled, the gage makes a neat 25-lb package, whose mounting is facilitated by the steel bolts that secure the lead block in position and then pass out through the bottom of the enclosure. These bolts are partly visible under the gage in Figure 1.

The complete measurement system (Fig. 2) consists of the gage transmission cables, a ratemeter, and a strip chart recorder. Specifically, the system components are:

1. The Research Laboratory-constructed gage, including the five-stage pulse preamplifier shown schematically in Figure 3.

2. Two 100-ft, RG 8/U, 52-ohm impedance, coaxial transmission cables. One cable transmits a high voltage supply from the voltage source in the ratemeter to the detector tubes, and the other carries the amplified detector tube output pulses to the ratemeter.

3. A Nuclear-Chicago Model 1620B Analytical Count Ratemeter. This unit, as previously stated, supplies the high voltage for the detector tubes. In addition, it takes their amplified pulse output signal and conditions it in such a manner that the ratemeter's output is an analog signal, whose amplitude at any given time is proportional to the rate at which pulses are being received, in counts per minute. A 500-watt voltage regulator was inserted in the voltage line supplying this instrument.

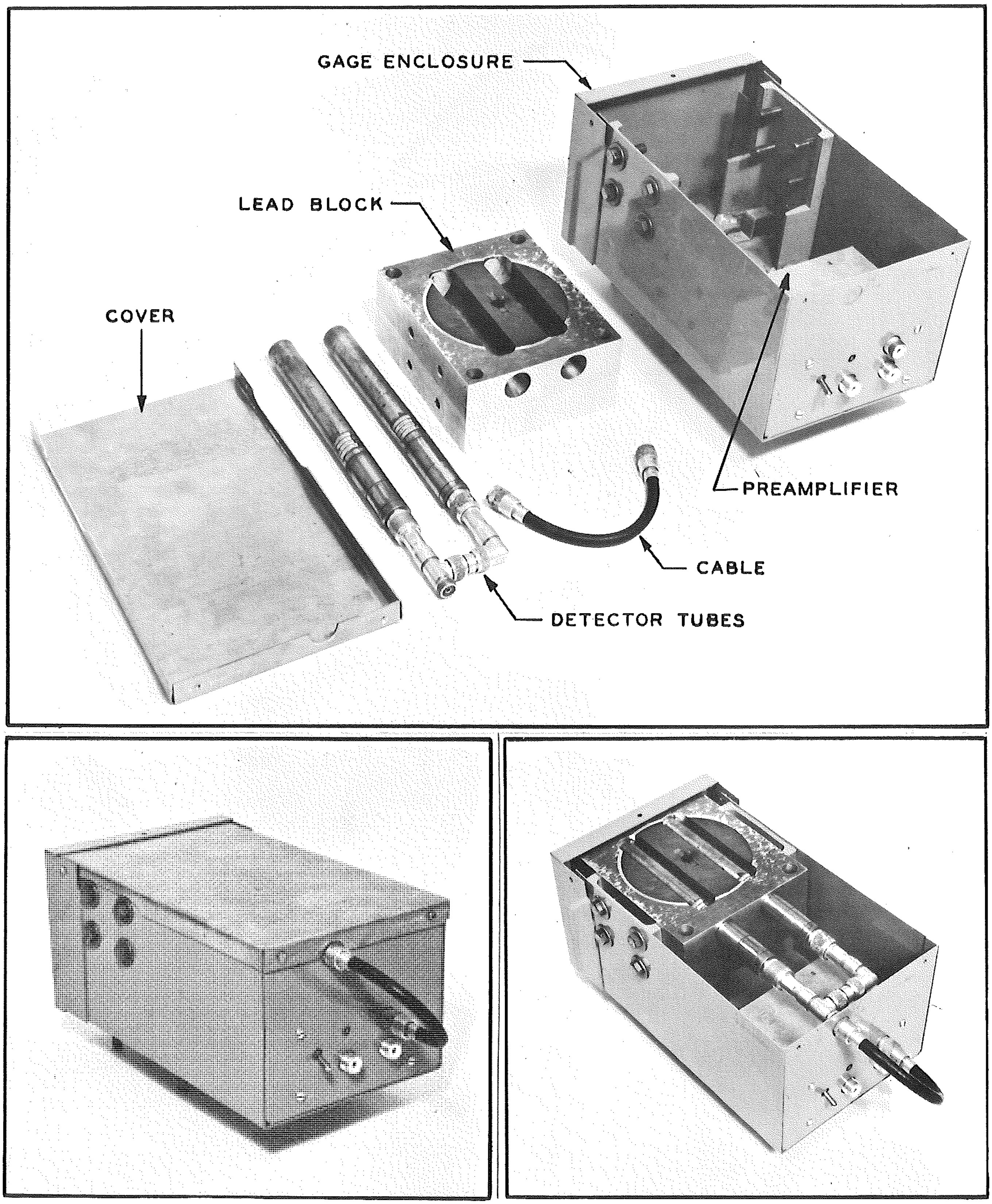


Figure 1. Neutron gage, shown disassembled (above) and also with and without cover in place.

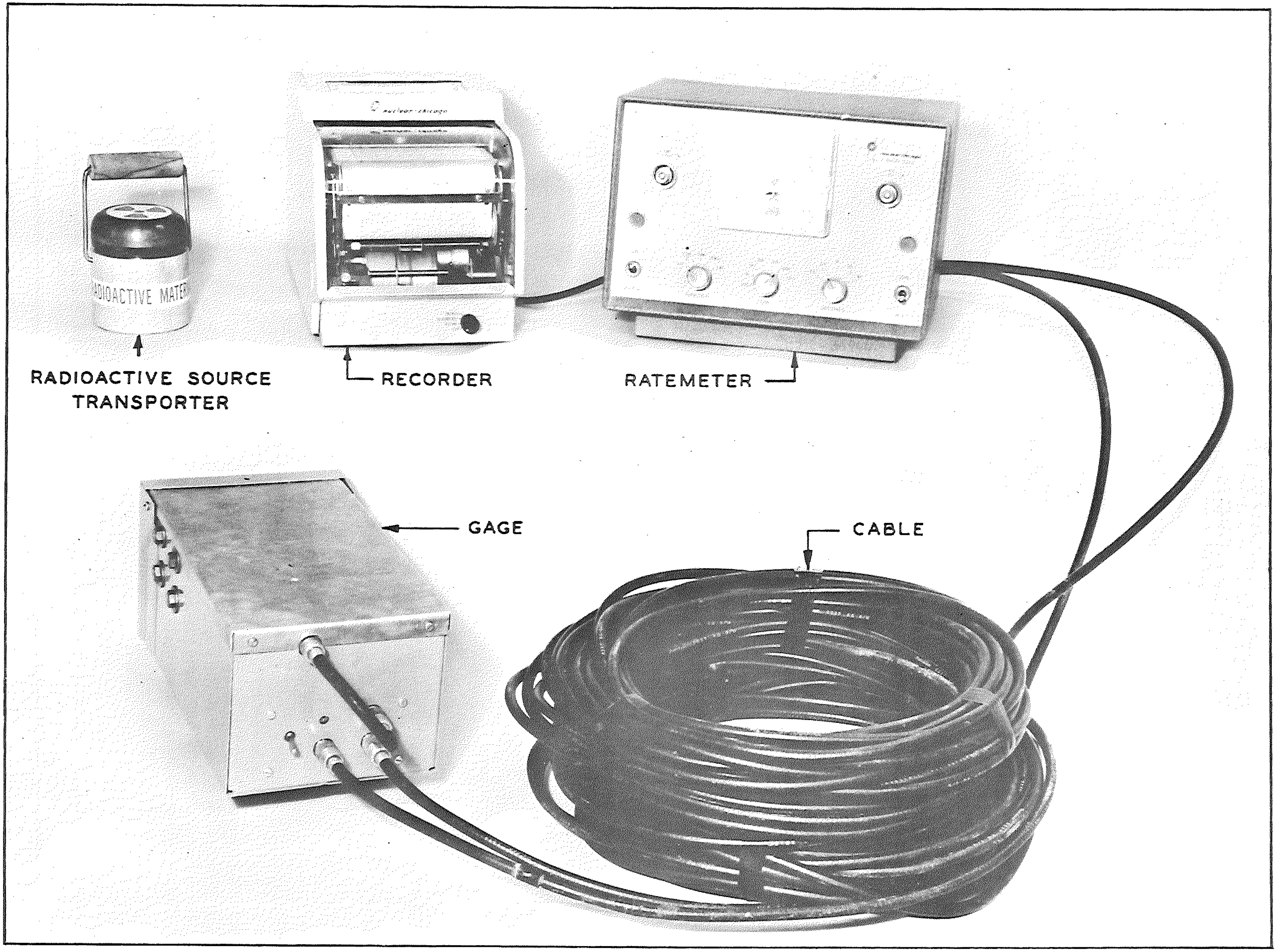


Figure 2. Entire measurement system.

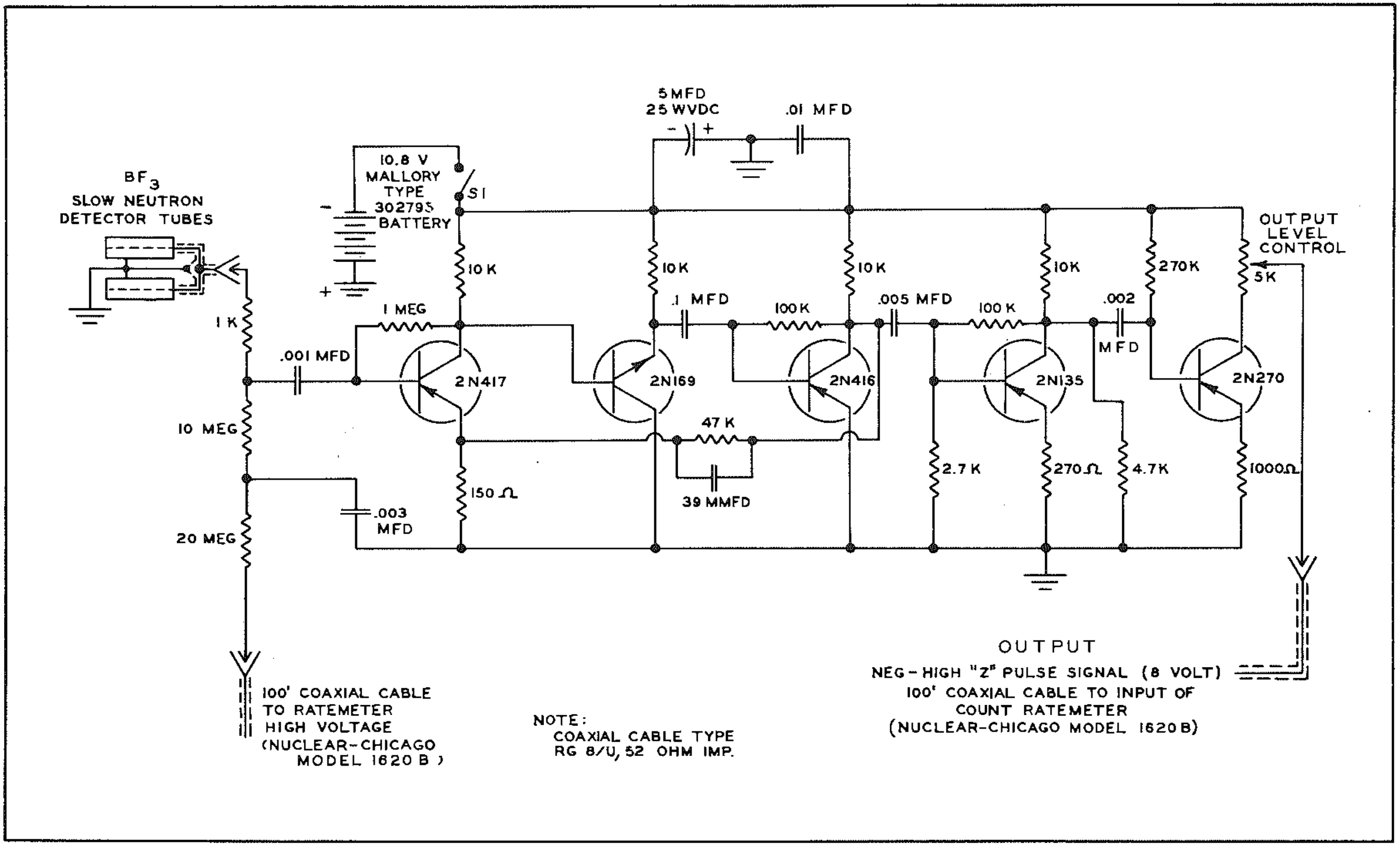


Figure 3. Neutron gage preamplifier.

4. A Nuclear-Chicago Model R 1000A Strip Chart Recorder, manufactured by the Texas Instruments Corp. This instrument records the analog output signal from the ratemeter.

Prior to using this system, it was necessary to determine:

a. The high voltage to be supplied to the detector tubes from the ratemeter power supply.

b. The counts per minute range setting for the ratemeter.

c. The time constant setting for the ratemeter.

d. The gage-to-mix distance effects on sensed counts per minute.

The proper high voltage for the detector tubes was ascertained by plotting the count rate they received from a radioactive source against various high voltages, as in Figure 4. Curves of this type exhibit a level range or "plateau" where count rate is relatively independent of the high voltage. It is standard procedure to adjust the operating high voltage to a value one-third of the length of the plateau above the threshold. For the detector tubes used in this study, the value proved to be 1550 volts.

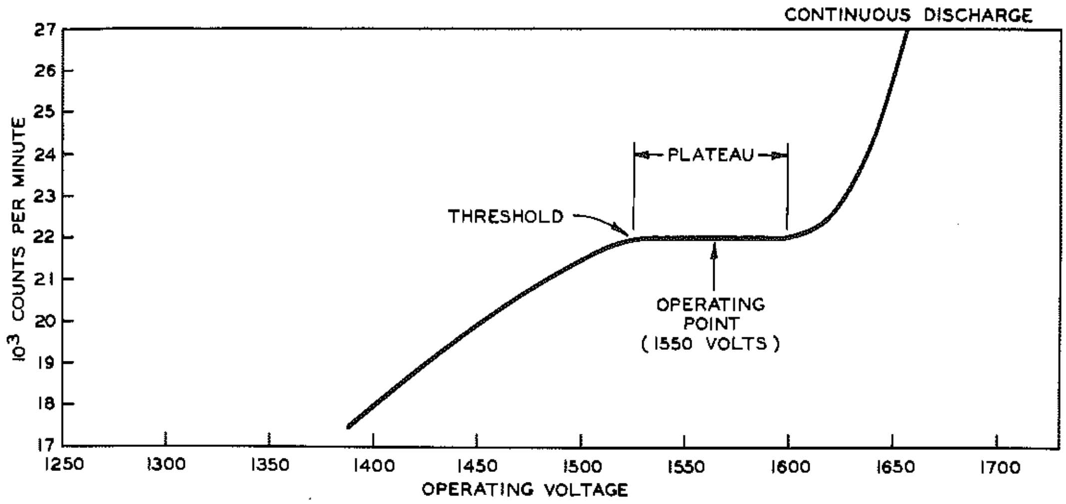


Figure 4. Plateau curve for neutron gage detector tubes.

The counts per minute (cpm) range setting is simply a matter of the amount of radioactive material being utilized, type of sensor, and distance from the material to the sensor. For the conditions of this study, the 3000-cpm range was found adequate.

Radioactive disintegration is a random phenomenon. However, if the emissions resulting from disintegration are averaged over relatively long time periods, they become approximately predictable. Therefore, in using radioactive disintegration as a tool, it is usually specified as a rate--counts per unit of time.

The ratemeter's time constant setting establishes the base time period over which the counts of radioactive emissions are averaged. To optimize accuracy, the count is usually made over a relatively long time period. However, for an application such as in this study it is necessary that the variations during short time intervals be recorded, even though shortening the interval does somewhat decrease the probable accuracy of the average rates. The time constant selected was 10 seconds. To determine the percent of deviation about the most probable average counting rate at the desired probability, the following formula was applied:

$$d = \frac{k}{\sqrt{\frac{nt}{60}}} \times 100 = \frac{k}{\sqrt{\frac{2n\tau}{60}}} \times 100$$

where

d = upper and lower limits of the range, percent
k = confidence constant = 1.96 for 95-percent level
n = average counts per minute = 2500 (approximate mean of the rates encountered in this study)
t = time period for which the ratemeter counts and averages random events
τ = time constant = 1/2t = 10 seconds

$$d = \frac{1.96}{\sqrt{\frac{2 \times 2500 \times 10}{60}}} \times 100 = \pm 7.4 \text{ percent}$$

Therefore, in this study, with the time constant selected and in the count rate range encountered, there is a 95-percent probability that the average recorded count rate does not deviate more than 7.4 percent from the most probable average counting rate. Obviously, as the count rate increases, the probable accuracy increases, and conversely as the count rate decreases, the accuracy decreases.

The effective "sphere of influence," i. e. the volume of concrete slurry being "seen" and measured by the gage at any given instant, is a very important operating property.

Whitehouse and Graham (2) have shown that the sphere of influence for production of slow neutrons by a radium-beryllium source immersed in water is limited to about 15 cm (6 in.). However, as the volume percentage of water in the medium irradiated decreases, the sphere of influence increases. Figure 5 presents the relationship between moisture content and radius of sphere of influence.

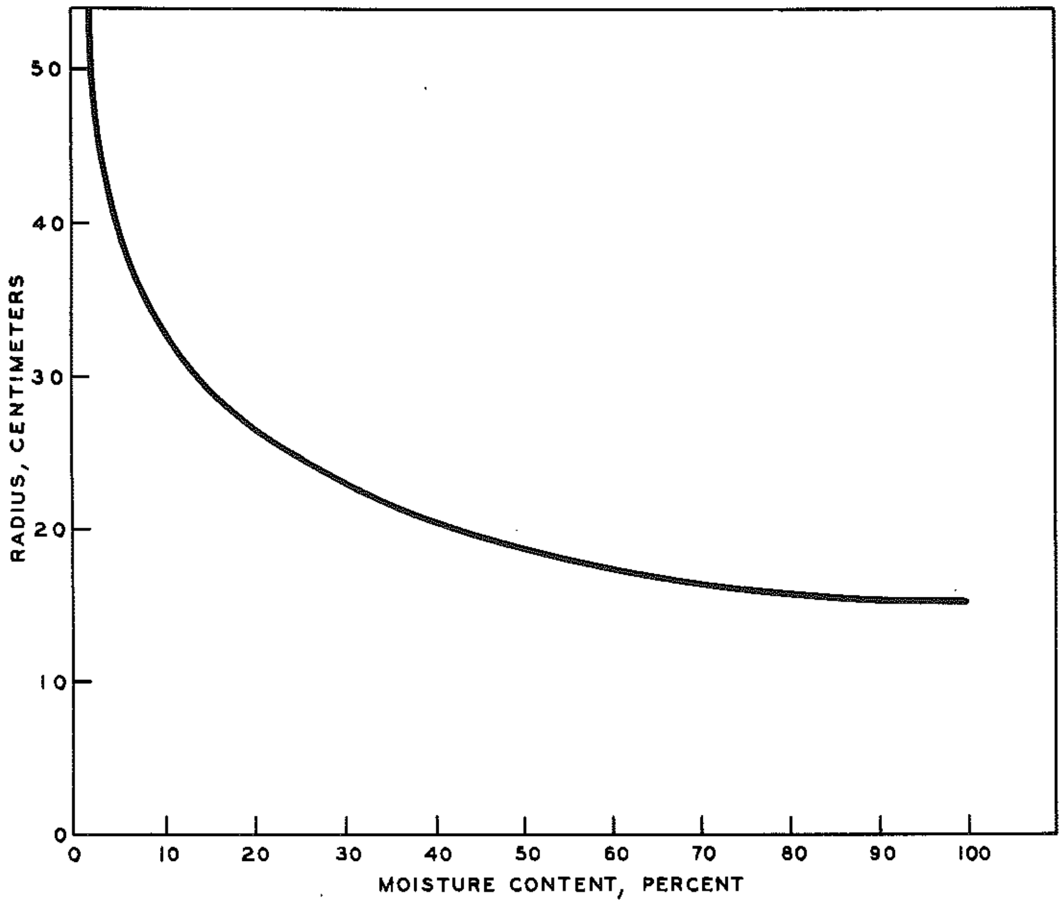


Figure 5. Effect of moisture content on radius of sphere of influence.

The volume percentage of water in concrete used in Michigan highway construction varies depending on whether that concrete is intended for pavement or structures, and on the type of sand, aggregate, air entraining agents, retarders, etc., in the mix. An approximate average water content would be 13.5 percent.

Figure 5 gives an influence radius of about 30 cm (12 in.) for a material containing 13.5-percent moisture by volume, assuming of course that the material contains no appreciable hydrogen in forms other than water. Therefore, assuming a sphere of influence of 12-in. radius and that the gage is located immediately adjacent to the material but not within it, we have a half-sphere "seen" volume at any given instant of $1/2\ (4/3\ \pi r^3)$ or about 2.0 cu ft. With the types and sizes of mixers commonly used by Michigan contractors, the gage is instantaneously measuring about 1.5 to 3.0 percent of the total slurry.

TYPICAL MIXER EFFICIENCY DETERMINATION

The following typical example of a mixer efficiency determination is presented so one may follow this operation from start to finish, thus demonstrating the measurement system and its application. The mixer selected as example is the 3.4-cu yd unit (subsequently termed "Mixer 1") of the Eisenhour Construction Co. For clarity, the method is presented in successive steps:

1. The first step consisted of a visit to the mixer site to determine the gage mounting location and solve any mounting problems, to select a location for the small instrument trailer, and to determine a transmission line path. Also, a short time study of approximately 50 batches was made during this visit to determine the mix ingredient input phasing and durations.

2. A second visit was for the purpose of placing the instrument trailer, installing the gage on the mixer and placing and connecting the transmission line. This completed the installation and at this time record taking began.

3. Recording mix times does not interfere in any way with operation of the plant and can be continued for as many batches or as long as desired. In this particular case, 140 batch recordings were taken in two days with about 70 batches monitored each day. This was considered adequate, as this was an experimental field run on the only central mix plant that happened to be operating then near Lansing.

4. After completing the data recording phase of the efficiency determination, all equipment was dismantled and returned to the Laboratory. All traces were turned over to the Data Processing Unit for reduction and analysis.

Figure 6 shows a typical trace to facilitate explanation of the data reduction method utilized. Event marks appear at various points along the curve. These marks fix in time the beginning and end of the material input cycle and the mix cycle itself, up to and including discharge. These marks are placed by the instrumentation operator during the recording period to facilitate data reduction. In Figure 6, Point A represents the start of mixer charging; Point B, the time at which all materials (including water) are in the mixer; Point C, a curve slope approximating zero (and based on the initial hypothesis, the time at which the mix water is uniformly distributed); Point D is C plus an arbitrarily selected 5-second safety factor; and Point E, the start of discharge of the completed mix. The elapsed time between Points B and D is the required mix time.

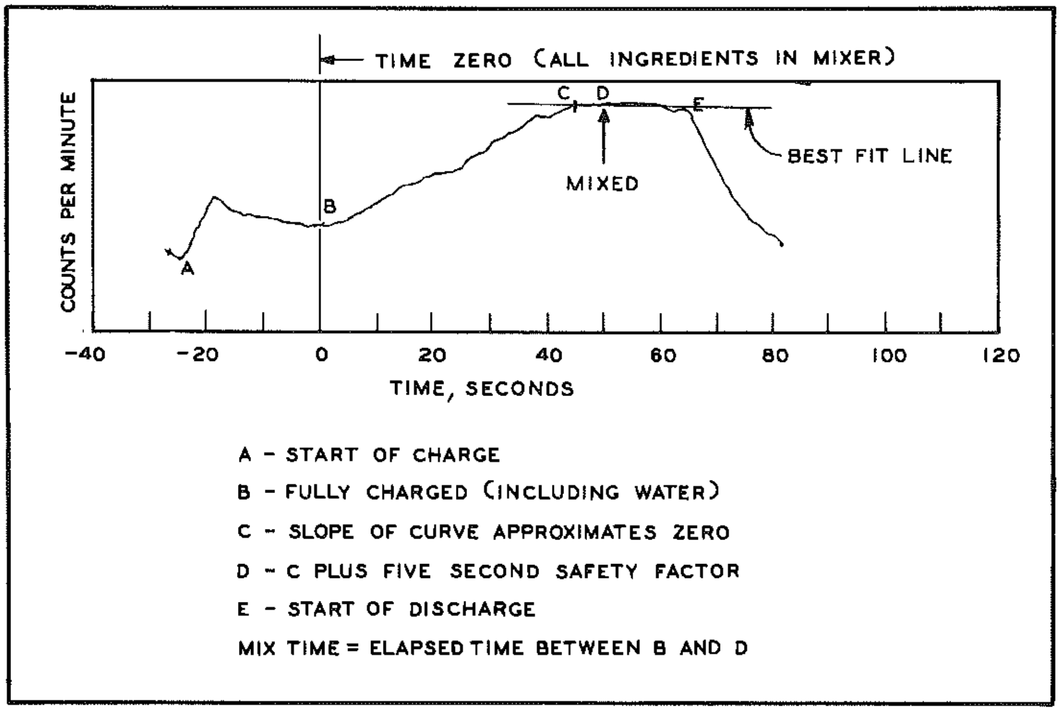


Figure 6. Typical neutron gage system trace for Mixer 1. The best fit line (zero slope) was estimated and placed during data reduction.

Because of the large number of traces contemplated in mixer evaluations of this and subsequent studies, a procedure was developed to facilitate rapid data reduction and analysis. This was as follows:

1. The first operation is to locate the "plateau" area of the curve (see Figs. 6, 7, 10, and 16), and to place a visually estimated best fit horizontal line--zero slope--through this area.

2. Next, Point C is determined by locating that point on the best fit horizontal line at which the slope first becomes zero. The curve may go through other direction reversals where its slope momentarily equals zero, but only that point where the plateau segment is intersected is used here.

3. Then, a 5-second segment is scaled off in an increasing time direction from Point C, thereby locating Point D. This 5-second safety factor was added because on many traces the precise location of C was very difficult to determine.

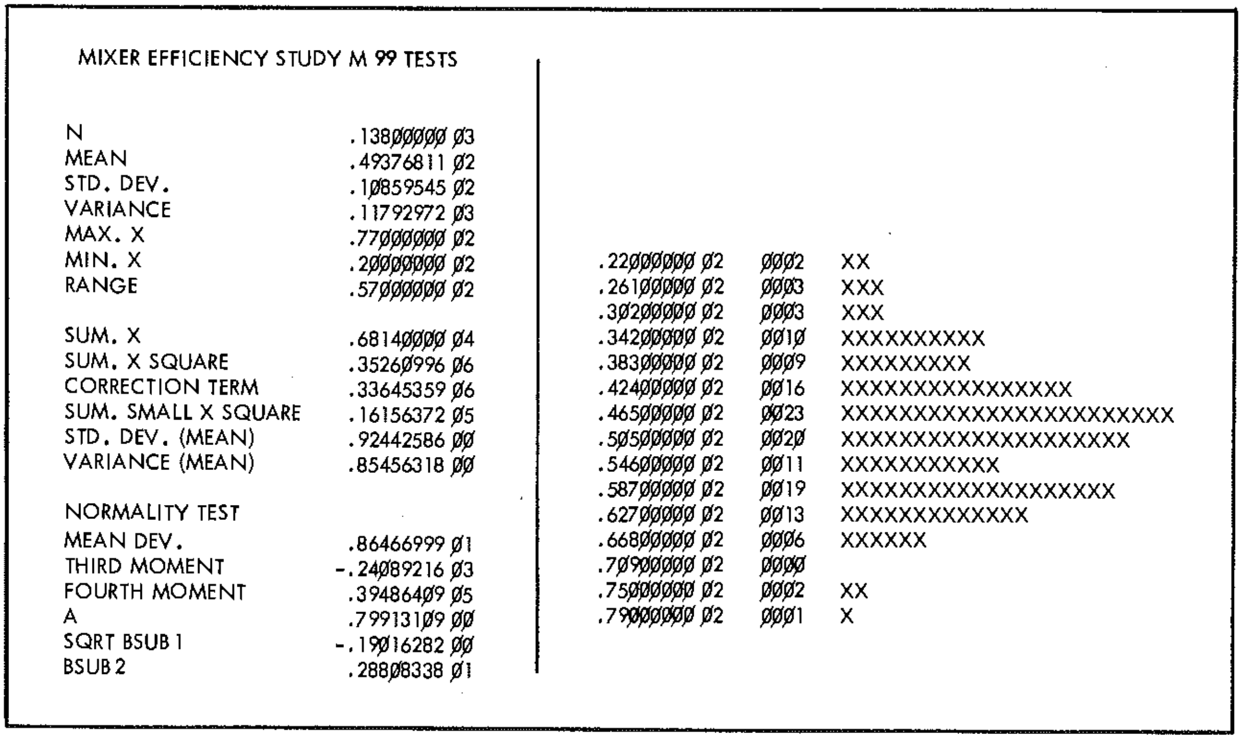
4. Time in seconds is scaled off from Point B (mixer completely charged) to Point D (water uniformly distributed). The time thus determined is the required mix time for the particular batch represented by the trace being analyzed.

5. After completing these four steps for all traces from a particular mixer, the resultant mix times are entered on coding sheets from which a punched card deck is prepared.

6. This deck is then input to the Department's digital computer and the data operated upon in accordance with a computer library routine called "Distat." This is a distribution routine producing printouts identical to those included in Figures 7, 10, 12, and 16. It presents in both graphical and tabular form the distribution of the data and includes all pertinent distribution properties, viz. mean, standard deviation, range, standard deviation of the mean, skewness, and the peakedness or elongation factor. A number of other statistical factors are included in the printout, most of which are used primarily to determine these distribution properties.

7. Once the Distat printout is obtained, all that remains is to put the data into some more usable form, such as the curve of Figure 7. This is prepared very simply by retabulating the batch column of the printout so that each successive entry is a cumulation of all batches previously tabulated. This cumulative batch column is then converted to cumulative percent and plotted versus the mix times, resulting in a curve such as that in Figure 7.

If it is required that the mix time to be specified includes 100 percent of the batches measured, then Steps 5, 6, and 7 could be eliminated and the maximum mix time determined in Step 4 would be specified. This is probably not the best engineering decision as the economic aspects of different selections should be considered. This matter is covered in more detail later in this report.



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MIN. X                   .20000000 02    .22000000 02   0002   XX
RANGE                    .57000000 02    .26100000 02   0003   XXX
                                         .30200000 02   0003   XXX
SUM. X                   .68140000 04    .34200000 02   0010   XXXXXXXXXX
SUM. X SQUARE            .35260996 06    .38300000 02   0009   XXXXXXXXX
CORRECTION TERM          .33645359 06    .42400000 02   0016   XXXXXXXXXXXXXXXX
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STD. DEV. (MEAN)         .92442586 00    .50500000 02   0020   XXXXXXXXXXXXXXXXXXXX
VARIANCE (MEAN)          .85456318 00    .54600000 02   0011   XXXXXXXXXXX
                                         .58700000 02   0019   XXXXXXXXXXXXXXXXXXX
NORMALITY TEST                           .62700000 02   0013   XXXXXXXXXXXXX
MEAN DEV.                .86466999 01    .66800000 02   0006   XXXXXX
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FOURTH MOMENT            .39486409 05    .75000000 02   0002   XX
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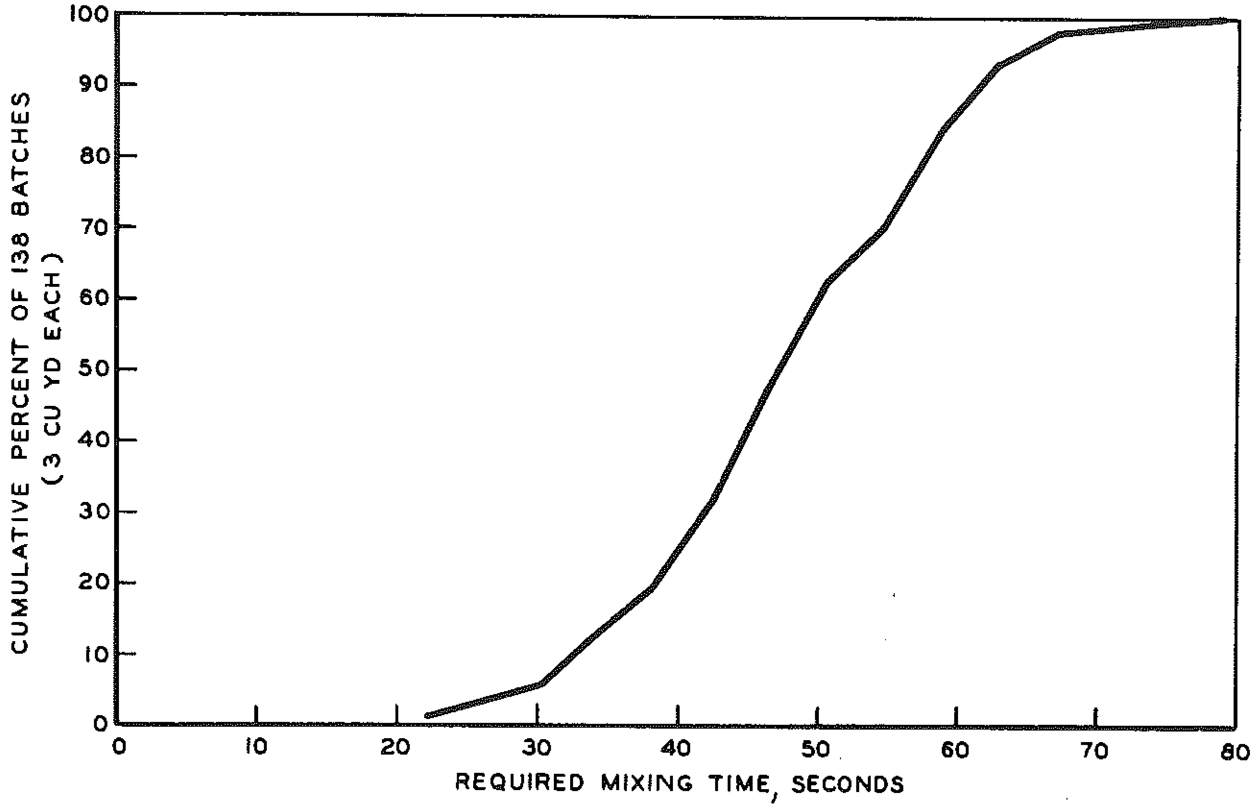

Figure 7. Mixer 1 facsimile Distat printout (top) and cumulative frequency distribution for mixing efficiency. Sample trace for this mixer is shown in Figure 6.

In general, this entire evaluation would take from a week to ten days. However, in situations where results are needed immediately, this time could probably be cut in half by the establishment of a high priority.

MIXER EFFICIENCY RESULTS

Determination of specific mixer efficiencies was only incidental to this study, in that the project was aimed at development and evaluation of a mixer efficiency measurement system. However, during the course of study, four different mixers were evaluated, and thus the results of these evaluations have been included here for information. They are not presented in the order of testing.

Mixer 1--3.4-cu yd Single-Drum Type

A 3.4-cu yd single-drum type mixer owned and operated by the Eisenhour Construction Co. (Fig. 8) was tested in mid-June 1963. This unit was producing concrete for the widening lanes of M 99 south of Lansing on Construction Projects USS 33011B, C3, and USS 33011D, C4. Although rated at 3.4 cu yd, it was producing batches of only 3.0 cu yd at a rotational speed of approximately 15.5 rpm. A typical phasing of mix ingredients into the drum was as follows (taking zero as the start of the charge cycle):

Aggregate - 0 to 23 seconds
Sand - 17 to 27 seconds
Cement - 0 to 11 seconds*
Water - 0 to 24 seconds

Mix times for a total of 138 batches were monitored for this mixer over a two-day period. They spanned a range of 22 to 79 seconds with a mean of 49 seconds. Figure 7 presents the cumulative frequency distribution of the batches studied. This mixer, at the time of study, was operating at a Department specified mix time of 90 seconds.

Mixer 2--6.8-cu yd Dual-Drum Type

Another study involved one drum of a dual-drum type unit (Fig. 9). The plant was being operated by the L. A. Davidson Construction Co.,

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*Cement timing is for approximately 95 percent of the cement in the hopper. Clearing the last few pounds often required an additional 15 to 20 seconds.

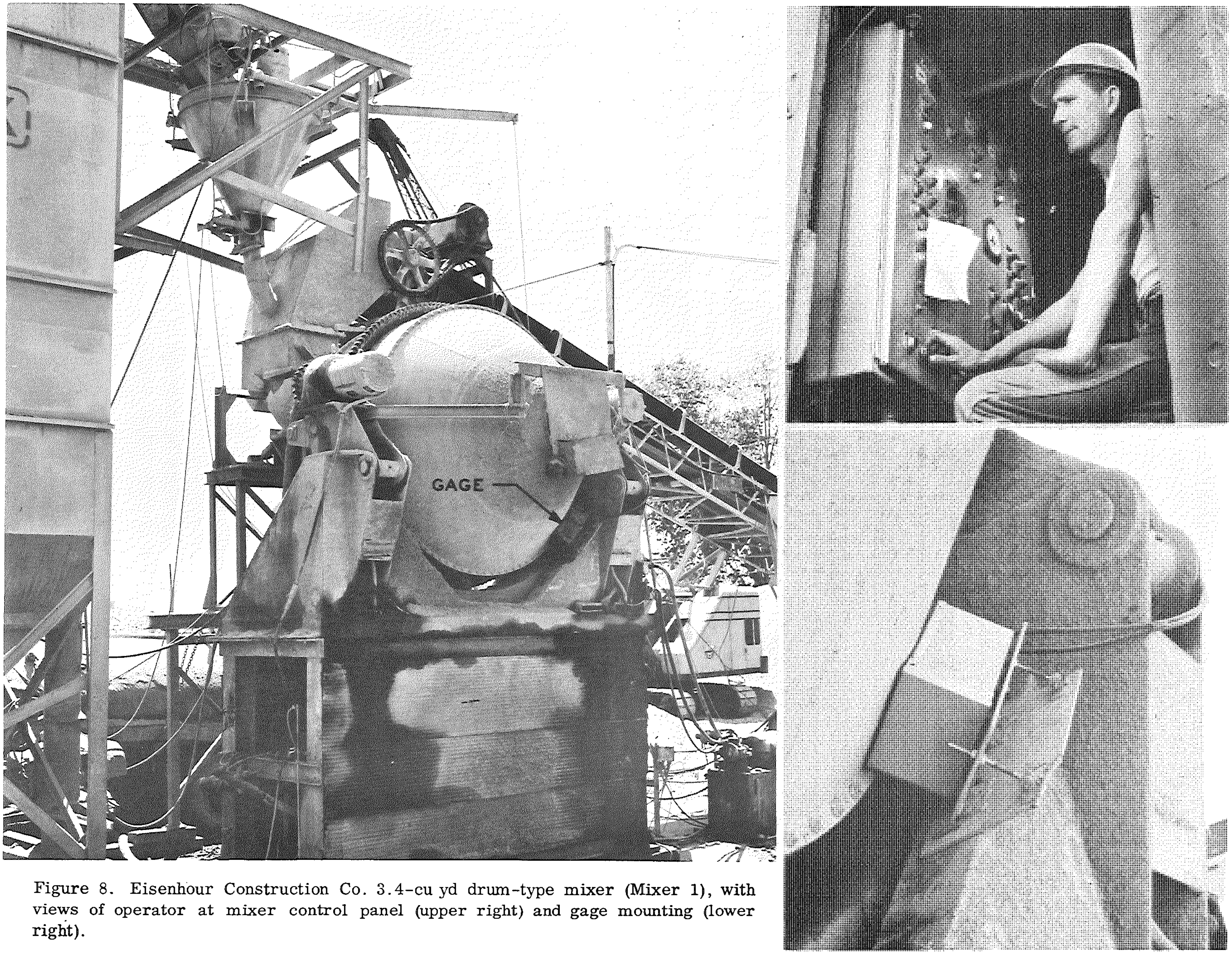
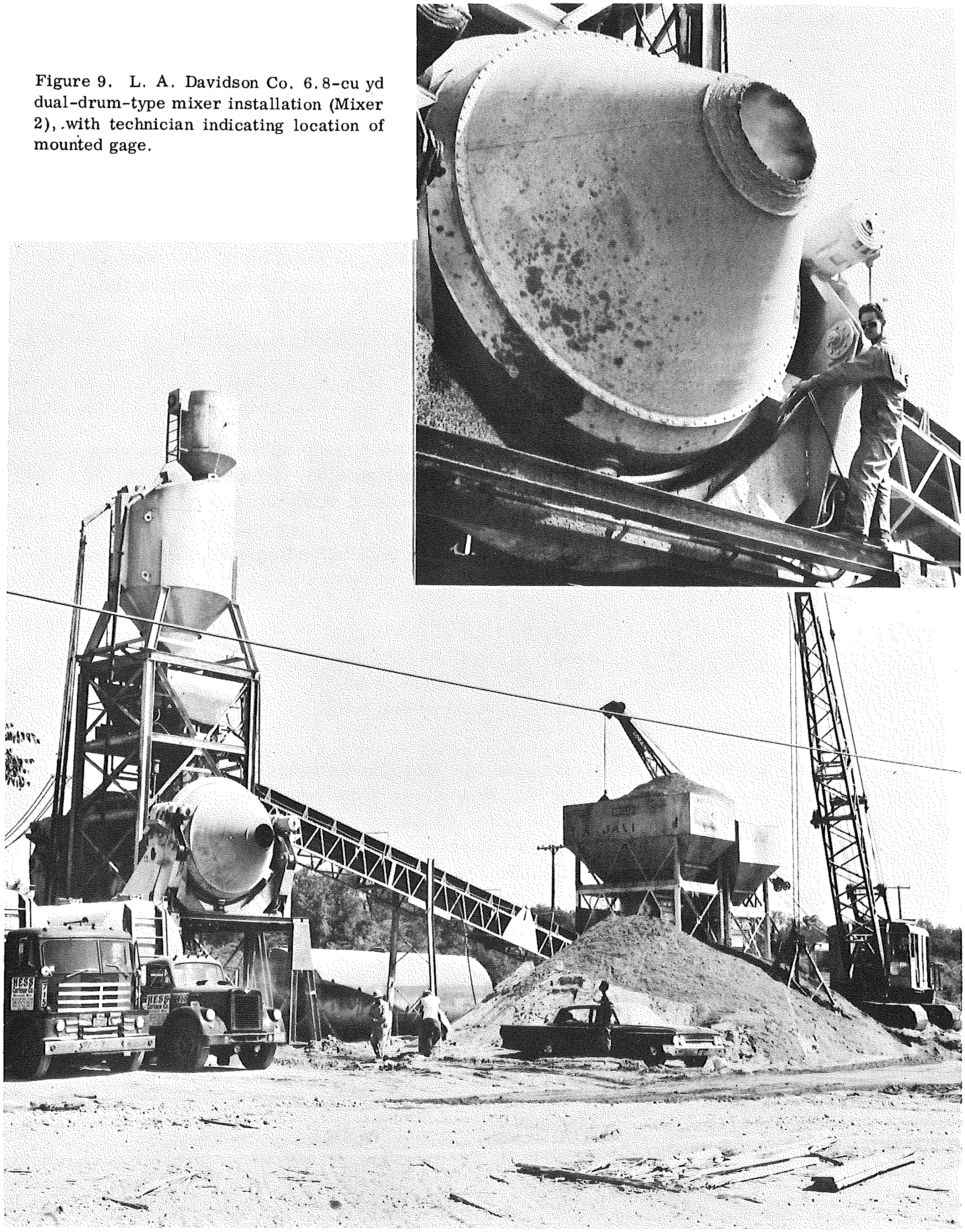


Figure 8. Eisenhour Construction Co. 3.4-cu yd drum-type mixer (Mixer 1), with views of operator at mixer control panel (upper right) and gage mounting (lower right).

Figure 9. L. A. Davidson Co. 6.8-cu yd dual-drum-type mixer installation (Mixer 2), with technician indicating location of mounted gage.



and at the time of study (August 1963) was producing concrete for Project CS 82-75, C3. Each drum of the mixer had a maximum capacity of 6.8 cu yd, but was producing batches of only 6.0 cu yd. The rotational velocity of the drum while loaded was approximately 11.0 rpm. Phasing of mix constituents into the mixer was not recorded in detail on this unit, but the total input time for all ingredients was recorded, and averaged approximately 16 seconds.

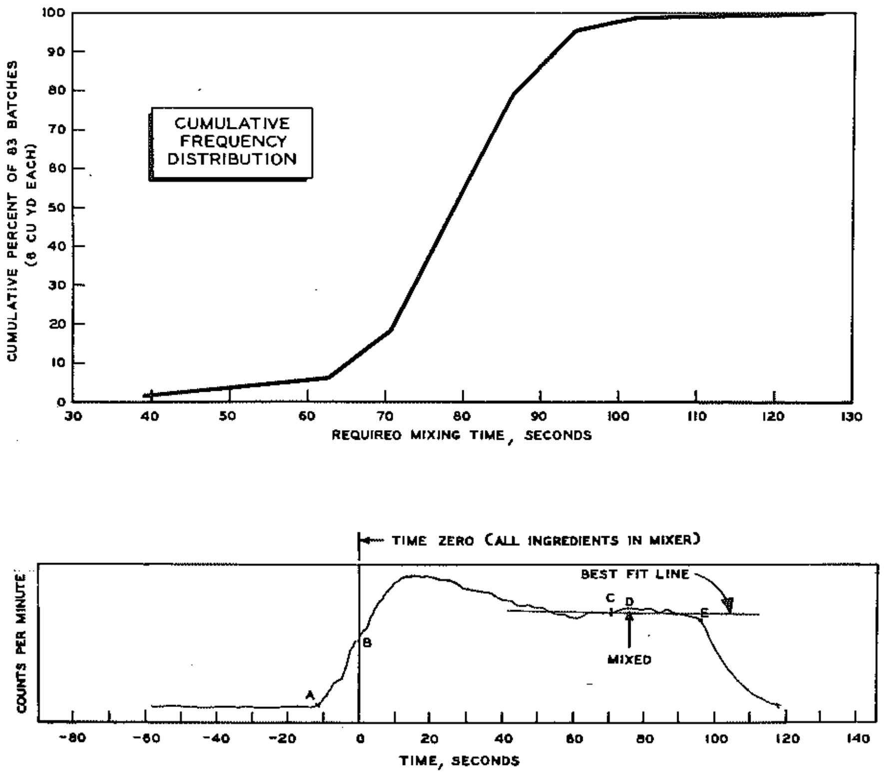
Mix times were measured for a total of 83 batches, or approximately 500 cu yd. The times for these batches ranged from 39 to 126 seconds with a mean value of 83 seconds. A typical trace and the cumulative frequency distribution for this unit are shown in Figure 10.

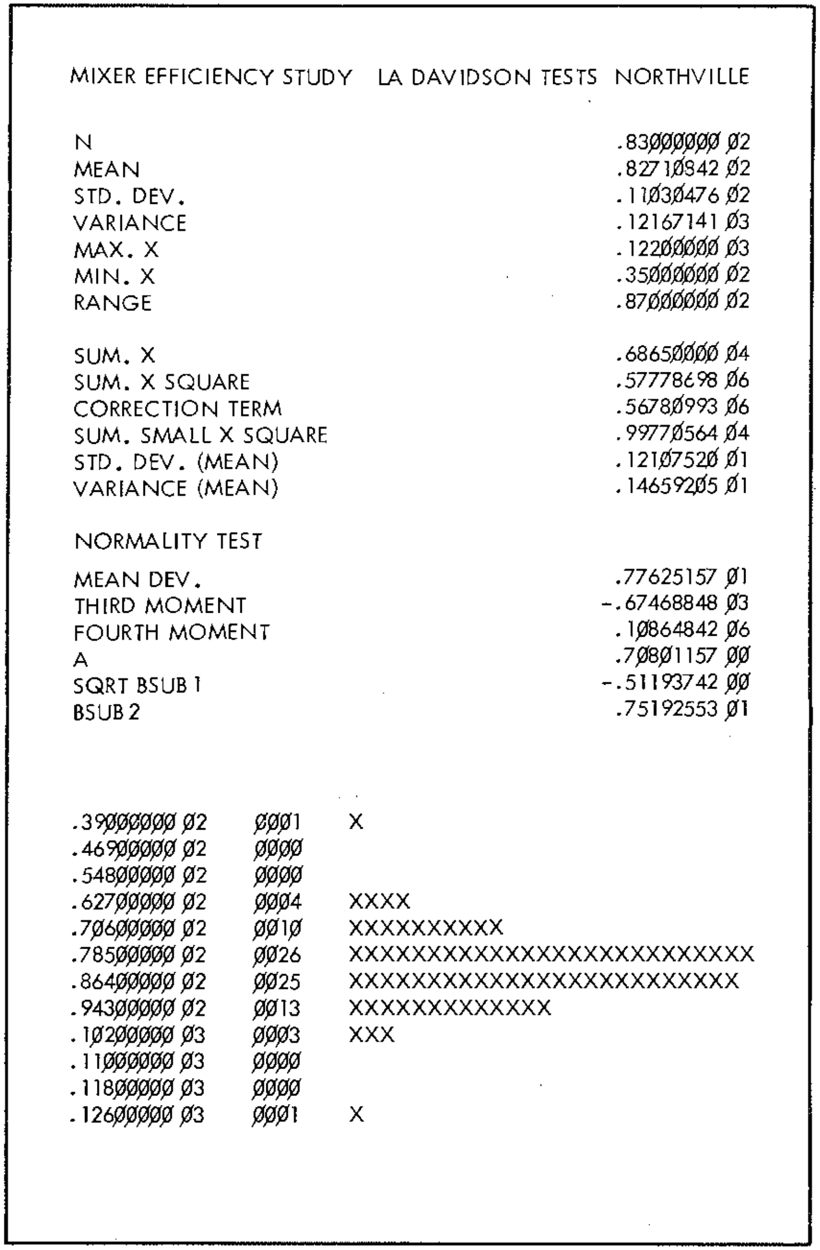
Mixer 3--6.8 cu yd Single-Drum Type

The third mixer studied (Fig. 11) was a 6.8-cu yd single-drum type operated by the L. A. Davidson Construction Co., producing 5-cu yd batches for Project BI 82111A, C19 at the time of study in September 1963. The drum's rotational velocity varied from 11.0 rpm unloaded to 10.5 rpm when loaded, and typical phasing of mix ingredients into the drum was as follows:

Aggregate - 0 to 5 seconds
Sand - 46 to 60 seconds
Cement - 5 to 35 seconds
Water - 0 to 25 seconds

A typical Mixer 3 trace and the cumulative frequency distribution curve are shown in Figure 12. Mix times were measured for a total of 131 batches, and varied from 44 to 107 seconds, with a mean of 71 seconds. These three time values, however, are not a good representation of data for this mixer, due to the non-normality of actual mix time distribution as shown in the bar graph in Figure 12. For unknown reasons, the data exhibit a bimodal distribution (i.e., two peaks). The statistical difference between the means of the two data groups comprising these peaks was found to be significant at the 0.01 level and nearly so at the 0.001 level. This indicates with a high degree of certainty that two distinct groups of data are involved, which means that some physical change occurred in the mixing process during this study. The change was probably in the ingredient input phasing, but possibly in some other area of the process.





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STD. DEV.                            .11030476 02
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MIN. X                               .35000000 02
RANGE                                .87000000 02

SUM. X                               .68650000 04
SUM. X SQUARE                        .57778698 06
CORRECTION TERM                      .56780993 06
SUM. SMALL X SQUARE                  .99770564 04
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VARIANCE (MEAN)                      .14659205 01

NORMALITY TEST

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FOURTH MOMENT                        .10864842 06
A                                    .70801157 00
SQRT BSUB 1                         -.51193742 00
BSUB 2                               .75192553 01


.39000000 02     0001    X
.46900000 02     0000
.54800000 02     0000
.62700000 02     0004    XXXX
.70600000 02     0010    XXXXXXXXXX
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.86400000 02     0025    XXXXXXXXXXXXXXXXXXXXXXXXX
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.12600000 03     0001    X
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Figure 10. Mixer 2 sample trace (upper left), facsimile Distat print-out (right), and cumulative frequency distribution.

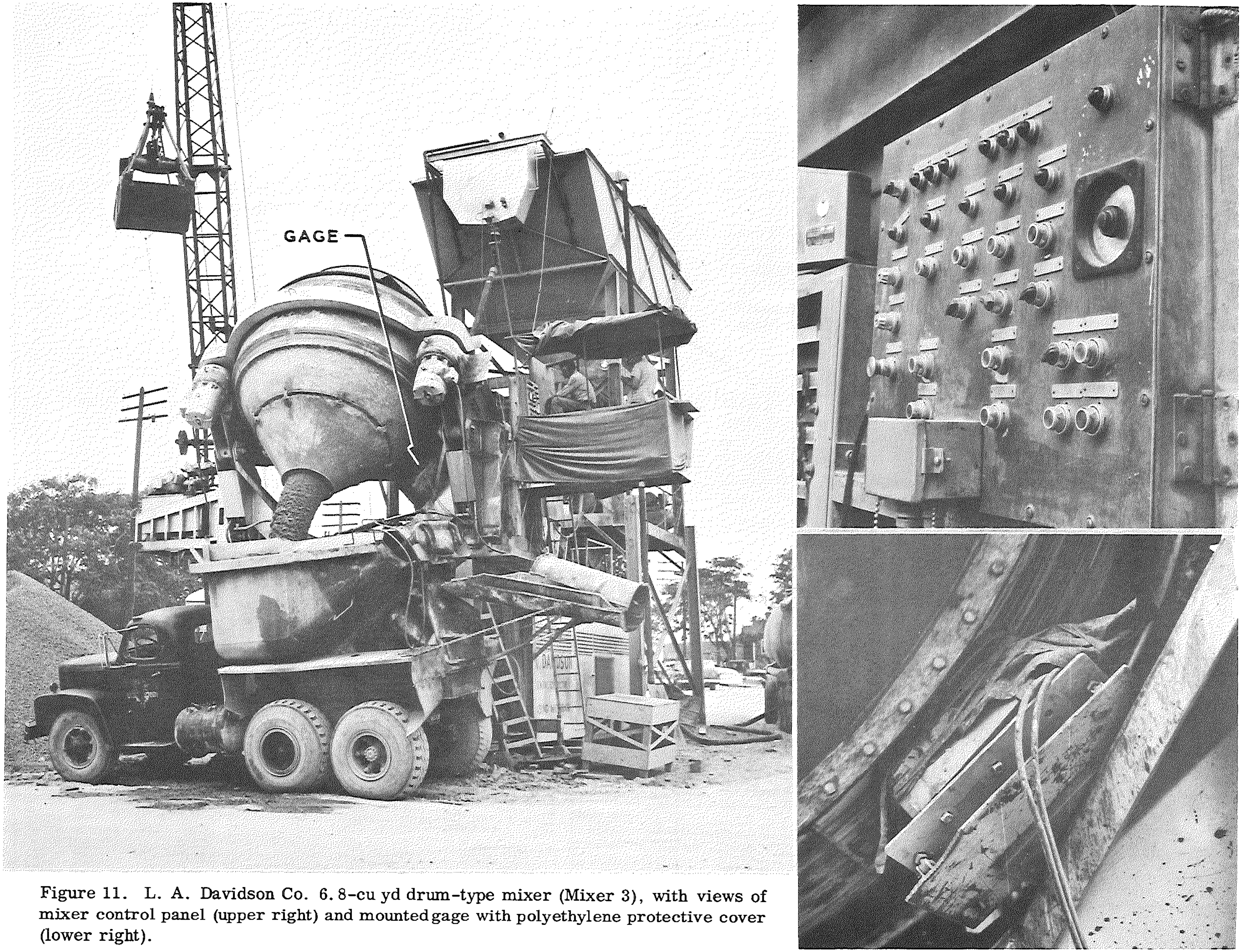
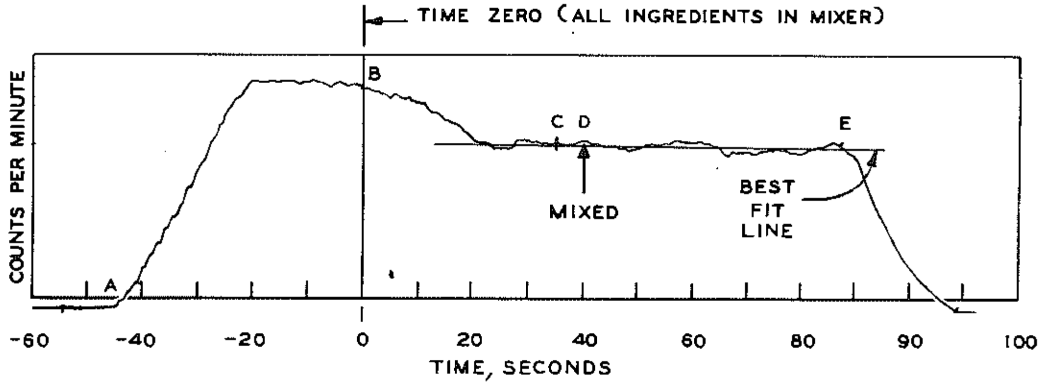


Figure 11. L. A. Davidson Co. 6.8-cu yd drum-type mixer (Mixer 3), with views of mixer control panel (upper right) and mounted gage with polyethylene protective cover (lower right).



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COMBINED DISTRIBUTION

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MEAN DEV.                  .11363422 02      .93700000 02   0005   XXXXX
THIRD MOMENT               .48895113 03      .98200000 02   0004   XXXX
FOURTH MOMENT              .84850053 05      .10300000 03   0001   X
A                          .83656332 00      .10700000 03   0001   X
SQRT BSUB 1                .19508977 00
BSUB 2                     .24923604 01
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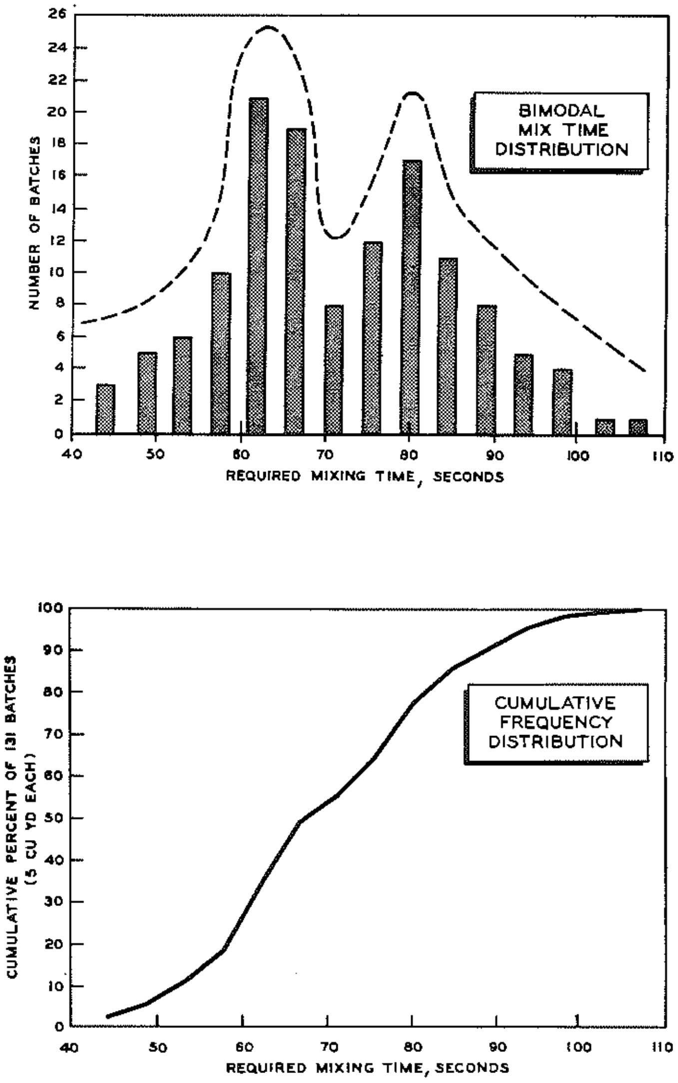


Figure 12. Mixer 3 sample trace (upper left), Distat printout (lower left), and two distribution curves.

Mixer 4--3.5-cu yd Turbine Type

The fourth central mixer evaluated was of a type somewhat unusual in Michigan highway work. This was a 3.5-cu yd T. L. Smith turbine-type mixer (Figs. 13, 14, 15). This mixer deviates from the normal drum type in that the tub or drum, similar to a large pan, is stationary and the blades revolve about a vertical center axis within it, while in the drum type, the blades are fixed to the drum's interior surface and the entire unit rotates around a nearly horizontal axis. The unit is completely automatic, under remote direction. Its manufacturers assert it to be more efficient (faster loading, mixing, and discharging), and easier to clean and maintain than the more widely used drum types.

The unit studied was the mixer component of the Anderson Sand and Gravel Co. stationary central mix concrete plant at Zilwaukee, Michigan. Although it had a maximum batch capacity of 3.5 cu yd, batches of only 2.75 cu yd were being produced at the time of study. The concrete being produced was the first for this plant, and was being supplied for Project CS 9-49, C2 in Bay County. The rotational speed of the mixer blades was approximately 20 rpm, and typical mix ingredient phasing into the tub was as follows:

Aggregate, Sand - 0 to 16 seconds
Cement - 0 to 7 seconds
Water - 0 to 14 seconds

A total of 386 batches or about 1070 cu yd were monitored during the tests. Mix times ranged from a low of 21 to a high of 63 seconds, with a mean mix time of 32 seconds. A typical trace and the cumulative frequency distribution are shown in Figure 16.

At the same time that this work was being performed, personnel from the Department's Testing Laboratory Division were also present at the site, performing tests on physical samples from batches mixed for 30, 45, 60, and 90 seconds. Michigan's present specification (Appendix) for concrete mixing time is designed to ensure that physical properties of the concrete produced are uniform throughout the mix, as follows:

Test	Maximum Variation
Slump	1 in.
Air Content	1 percent
Coarse Aggregate Content	6 percent
Unit Weight of Mortar	3 pcf

Figure 13. Anderson Sand and Gravel Co. plant containing 3.4-cu yd turbine-type Mixer 4.

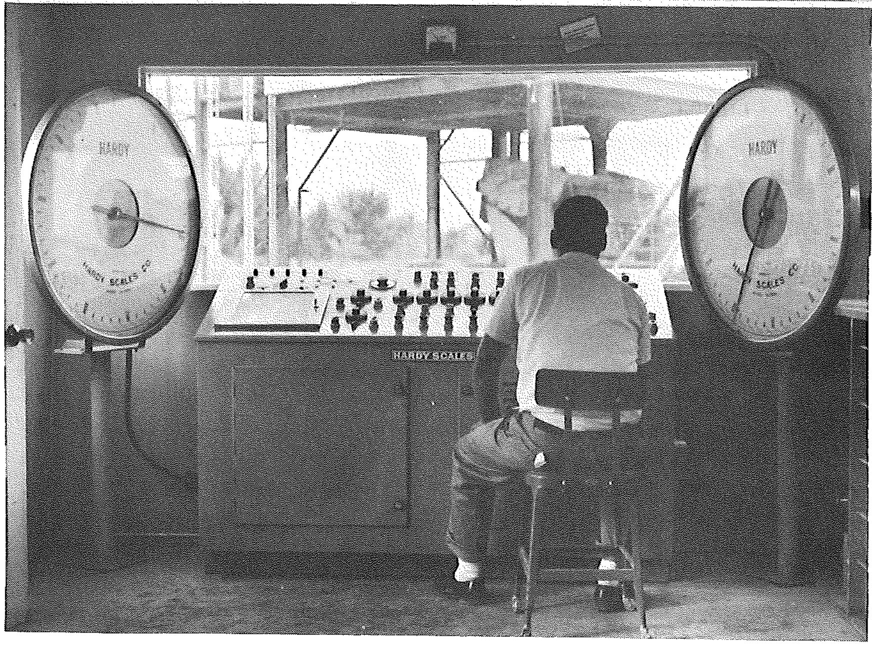


Figure 14. Operator and control panel for turbine-type mixer.

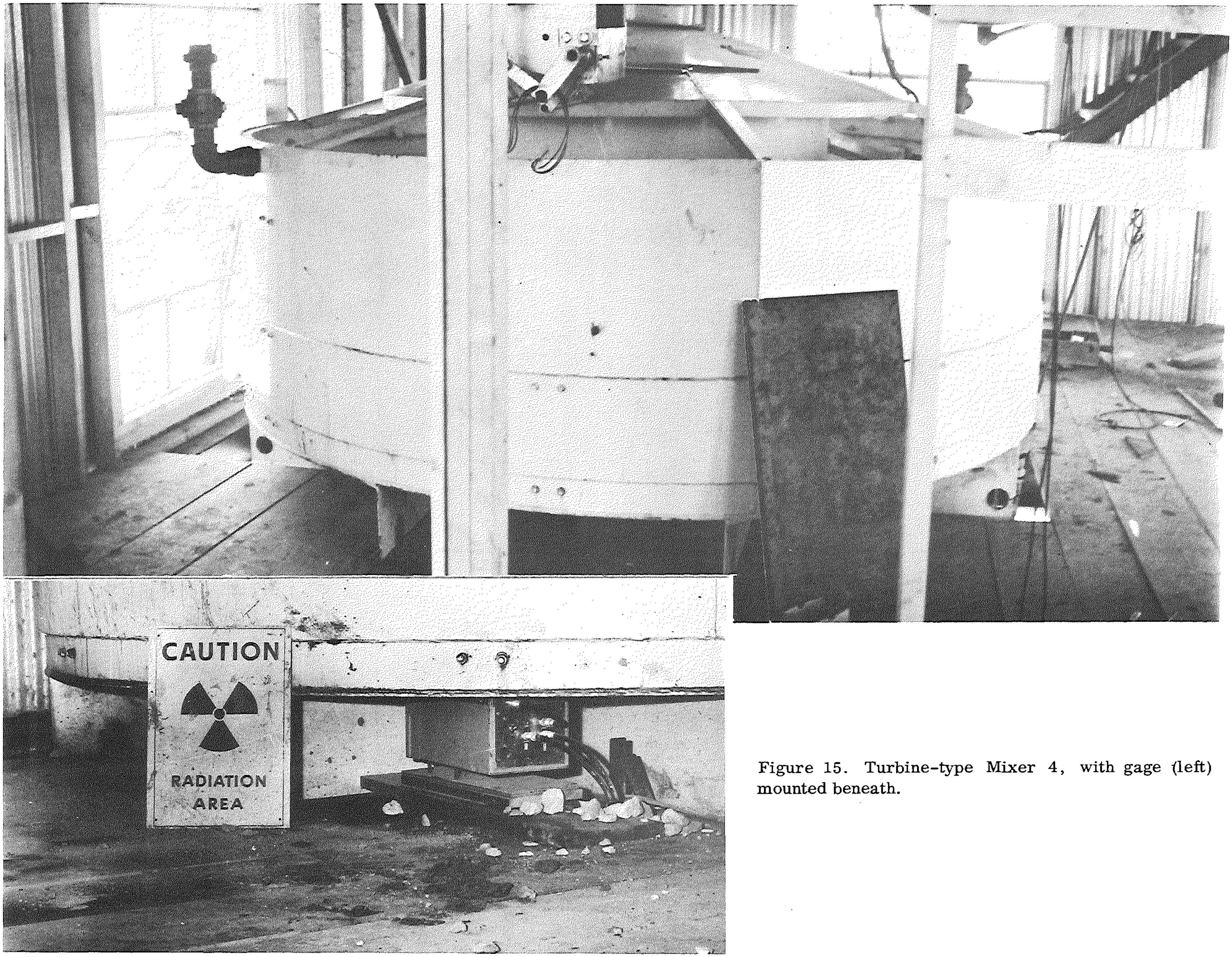
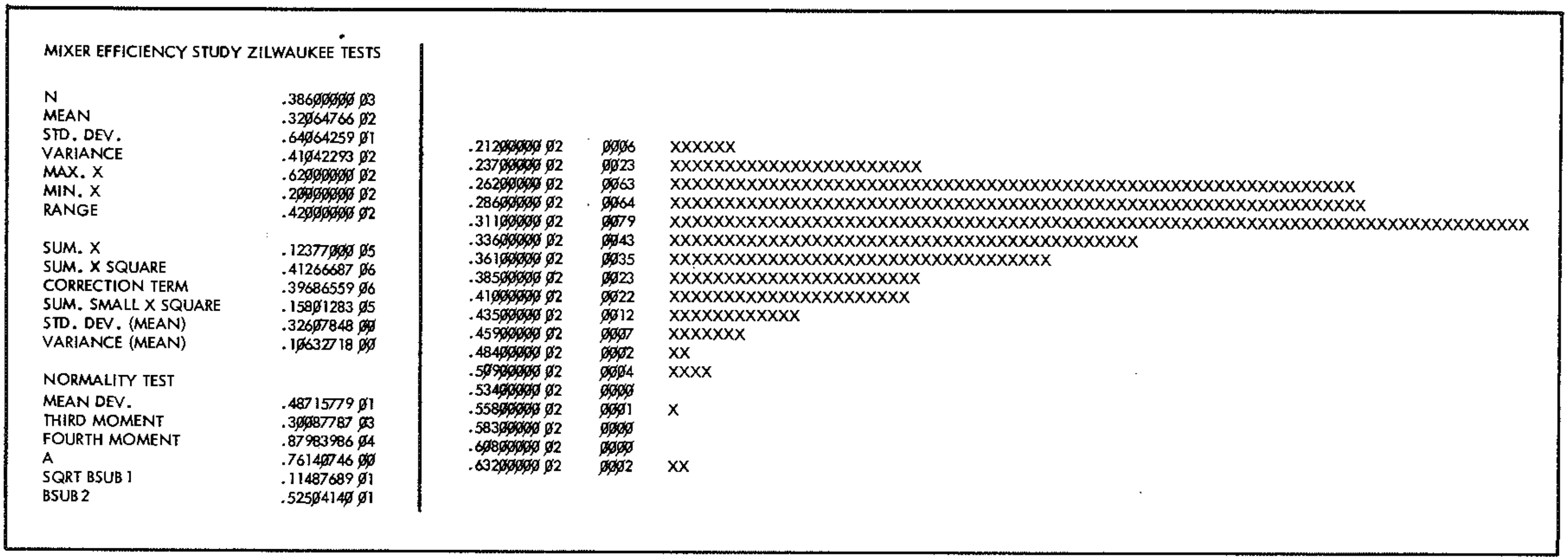


Figure 15. Turbine-type Mixer 4, with gage (left) mounted beneath.



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MIXER EFFICIENCY STUDY ZILWAUKEE TESTS

N                       .38600000 03
MEAN                    .32064766 02
STD. DEV.               .64064259 01    .21200000 02   0006   XXXXXX
VARIANCE                .41042293 02    .23700000 02   0023   XXXXXXXXXXXXXXXXXXXXXXX
MAX. X                  .62000000 02    .26200000 02   0063   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
MIN. X                  .20000000 02    .28600000 02   0064   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
RANGE                   .42000000 02    .31100000 02   0079   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                                        .33600000 02   0043   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
SUM. X                  .12377000 05    .36100000 02   0035   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
SUM. X SQUARE           .41266687 06    .38500000 02   0023   XXXXXXXXXXXXXXXXXXXXXXX
CORRECTION TERM         .39686559 06    .41000000 02   0022   XXXXXXXXXXXXXXXXXXXXXX
SUM. SMALL X SQUARE     .15801283 05    .43500000 02   0012   XXXXXXXXXXXX
STD. DEV. (MEAN)        .32607848 00    .45900000 02   0007   XXXXXXX
VARIANCE (MEAN)         .10632718 00    .48400000 02   0002   XX
                                        .50900000 02   0004   XXXX
NORMALITY TEST                          .53400000 02   0000
MEAN DEV.               .48715779 01    .55800000 02   0001   X
THIRD MOMENT            .30087787 03    .58300000 02   0000
FOURTH MOMENT           .87983986 04    .60800000 02   0000
A                       .76140746 00    .63200000 02   0002   XX
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BSUB 2                  .52504140 01
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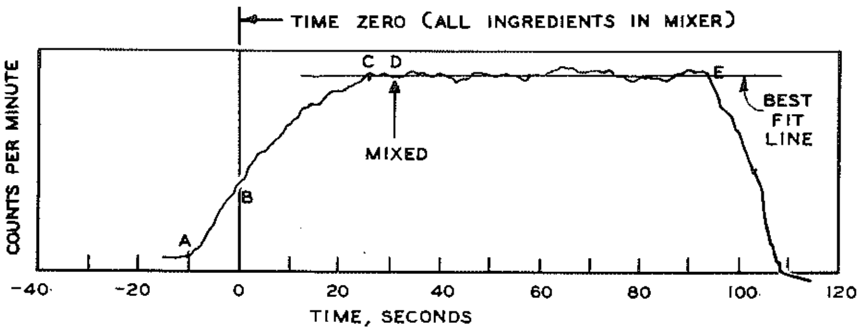

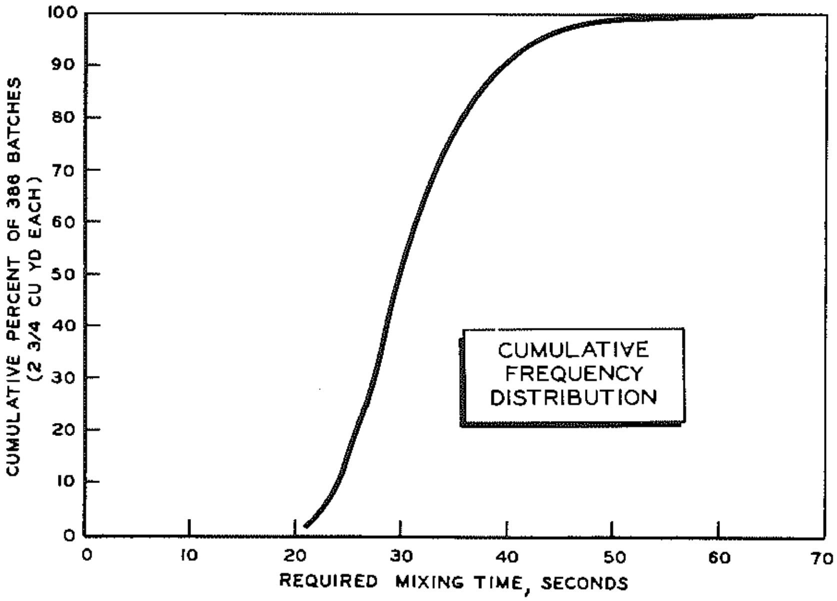

Figure 16. Mixer 4 sample trace (lower left), facsimile Distat printout (top), and cumulative frequency distribution.

Verifying these mix properties requires that a process of physical sampling be performed on a number of production batches of the mixer under study. Samples are taken from the front, center, and back of the mixer to ascertain any effects of position within the mixer. Measurements are then made on portions of these samples to determine the minimum mix time at which the four properties are within specified ranges. Results of the tests on the twelve physical samples taken from this mixer have been reported by Cortright, Legg, and Vogler (3).

If the experimental neutron gage is measuring a mix characteristic intimately related to the physical properties of the concrete, then the mix times it reports should correlate with those based on physical sampling. To assess the degree of correlation between the two methods, gage measurements were made on all batches from which physical samples were subsequently taken, with the results given in Table 1.

TABLE 1
CONCRETE BATCH TEST RESULTS
FROM GAGE MONITORING AND PHYSICAL SAMPLING

Mixer Operating Time, sec(1)	Batch No.	Mix Time Required (Gage), sec (1)	Mix Water Volume, gal	Sample Variation(2)			
				Slump	Air Content	Coarse Agg. Content	Unit Weight of Mortar
				Spec. Max.: 1 in.	Spec. Max.: 1 percent	Spec. Max.: 6 percent	Spec. Max.: 3 pcf
30	1	Unmixed	65.7	F	S	S	S
	2	30	59.4	S	S	S	S
	3	Unmixed	54.0	F	S	S	S
45	1	29	57.0	S	S	S	S
	2	28	62.0	S	S	S	S
	3	25	66.0	S	S	S	S
60	1	36	65.7	S	F	S	S
	2	43	64.4	S	S	S	S
	3	24	52.2	S	S	S	S
90	1	31	65.7	S	S	S	S
	2	31	65.7	F	S	S	S
	3	25	57.2	S	S	S	S

(1) After all ingredients had entered mixer.

(2) Each batch sampled at three locations in mixer. Designations "S" (satisfactory) or "F" (failed) based on results for three samples for each property.

In four batches of the twelve sampled, at least one property ranged beyond specification limits. The neutron gage indicated failure (insufficient mixing) in only two of these four batches; however, it must be remembered that the gage defines only the time required to distribute the mix water uniformly throughout the other mix ingredients. It was not designed to determine the effects of continued mixing of a concrete batch once the water is uniformly distributed, and two of the batches were considerably overmixed.

The mix time specified as a result of the physical sampling tests was 45 seconds. What mix time would have been specified, if only the neutron gage had been used for evaluating the mixer? The first step would be to work up the gage information in some form similar to Table 2 to facilitate its study. On the basis of these tabulated data for Mixer 4, representing measurements on over 1000 cu yd of concrete, one will conclude that the simple choice is to specify a mix time for which the probability is 1.0 that all batches are fully mixed. This, however, is not necessarily the best engineering decision, since it gives no weight to the economic aspects of the selection. The table discloses that a downgrading of the probability of full mixing to 0.95 results in a 26.6-percent production increase, and further downgrading to probabilities of 0.90 or 0.85 results in the much lower production increases of 5.0 percent and 3.8 percent, respectively.

To arrive at a completely rational mix time, representing maximum engineering economy, would require an extensive quality control program in which all economic ramifications of slightly undermixed concrete but increased production were determined and weighed in arriving at the optimum compromise. Such a program, although very desirable, is beyond the scope of this study.

It is possible, however, to arrive at a reasonable decision on the basis of Table 2 information. These figures fully clarify the sacrifice of quality that must be made for any increase in production with consequent reduction of construction cost. Selecting a mix time of 43 seconds (95 percent) means that one batch out of every 20 is somewhat undermixed. This does not seem an unreasonable price to pay for a 26.6-percent production increase, especially when one considers that it takes 15 seconds to discharge the mixer and that the concrete receives some further mixing during this period. Further reduction of mix time to the 90- or 85-percent level appears unwarranted since the resulting production increases are meager--5.0 and 3.8 percent, respectively.

TABLE 2
GUIDE TO SELECTION OF MIXING TIMES FOR CENTRAL MIX CONCRETE PLANTS

	Mixer and Sampling	Cumulative Percent of Batches	Operation Times, seconds				Batches Produced per 10-hr Day (75% Efficiency)	Increased Capacity, batches per day	Percent Increase	Difference in Percent Increase
			Charge	Mix	Discharge	Total				
Mixer 1	Single-Drum Type	100	27	79	18	124	218	0	0	0
	3.4 cu yd drum	95	27	64	18	109	248	30	13.7	13.7
	138 batches measured	90	27	61	18	106	255	37	17.0	3.3
	3 cu yd each	85	27	59	18	104	260	42	19.3	2.3
Mixer 2	Dual-Drum Type	100	16	126	18	160	169	0	0	0
	6.8 cu yd drum	95	16	94	18	128	211	42	24.8	24.8
	83 batches measured	90	16	92	18	126	214	45	26.6	1.8
	6 cu yd each	85	16	89	18	123	220	51	30.1	3.5
Mixer 3	Single-Drum Type	100	60	107	19	186	145	0	0	0
	6.8 cu yd drum	95	60	94	19	173	156	11	7.6	7.6
	131 batches measured	90	60	89	19	168	161	16	11.0	3.4
	5 cu yd each	85	60	85	19	164	165	20	13.8	2.8
Mixer 4	Turbine-Type	100	17	63	15	95	285	0	0	0
	3.5 cu yd drum	95	17	43	15	75	361	76	26.6	26.6
	386 batches measured	90	17	40	15	72	375	90	31.6	5.0
	2.75 cu yd each	85	17	38	15	70	386	101	35.4	3.8

The point is that had the mixer been rated by the neutron gage, independently of any physical sampling, the specified mix time would have been 43 seconds. This correlates excellently with the 45-second time determined by physical sampling. Although representing only one mixer, this confirms the value of continued development of the gage.

Table 2 also includes data on the other three mixers, evaluated with the neutron gage but without physical sampling. It appears that the 95-percent level is as near optimum for these machines as for Mixer 4. Of these three, only Mixer 3 is questionable, with a reduction from the 100-percent level to 95 percent increasing production only 7.6 percent. However, this mixer's charge time was 60 seconds, and its discharge time 19 seconds. With fixed operation times of this magnitude, small decreases in actual mix time have little effect on overall production.

The Department's specified mix time would be somewhat excessive for each of the mixers studied, in comparison to maximum batch mix time measured on each unit. Compared to maximum mix times of 95 percent of the batches measured, it would be excessive. As a consequence of many cases such as these, the Department is often called upon to go into the field and evaluate various contractors' mixers so that more accurate and equitable times may be determined. The neutron gage should prove an excellent tool for this purpose.

CONCLUSIONS

In the author's opinion, the gage is a qualified success--"qualified" because it has not been fully established that uniform distribution of water throughout a concrete mix is a valid measure of the adequacy of mixing, and coupled with this, an uncertainty exists as to the sphere of area measured by the gage. A "success," however, in that each of the original five specific objectives was realized to some degree, and also in the good correlation obtained with mix times determined by physical sampling.

It is appropriate to restate here that the gage determines required mix times only. In its present configuration and with the associated equipment used, it does not measure slump, air content, unit weight of mortar, or coarse aggregate content, except insofar as these variables are a function of the degree of distribution of mix water. However, with its ability to readily measure large numbers of concrete batches, it furnishes better information for many purposes than previously available. For example, it is highly improbable that the bimodal mix time distribution exhibited by one of the mixers studied would have been discovered by any other mix time measuring equipment now in use. Moreover, on special projects it would be a relatively simple matter to monitor every batch produced. Or if time were a problem on a particular project and increased production were desired, reduced mix times of known consequences could be considered. The engineer responsible for such a decision would have sufficient information to decide on controlled downgrading of production mixes, and he would have a measure of the consequences of the quality-versus-time compromise being effected.

Other possible areas of investigation are suggested by the results of this study:

1. A comprehensive study of those mixer variables affecting mix time, e.g., ingredient input phasing, wearing of blades, rotational velocities, etc. This could readily include transit mixers as well as central mix plants.

2. A study to determine the cause or causes of the wide variations in mix times for any mixer supposedly operating under fixed, controlled conditions, such as those encountered in this work:

Mixer 1--22 to 79 seconds
Mixer 2--39 to 126 seconds
Mixer 3--44 to 107 seconds
Mixer 4--21 to 63 seconds

No attempt was made in this study to determine the cause of these variations, since the purpose here was to develop and test a gage facilitating such work.

These are but a few of the possibilities opened by use of the gage. There are likely to be many others. Further work with the gage and improvement of its sensitivity and resolution may disclose other capabilities. For the present it seems reasonable to conclude that another highly useful tool has been added to the highway engineer's complement.

REFERENCES

1. Pocock, B. W., Schwartje, W. H., Zapata, C. A., and Hanna, R. E. "Inspection of Mixer Efficiencies at Central Concrete Mixing Plants by Means of Gamma Rays." Michigan Department of State Highways Research Report No. R-378, February 1963.

2. Whitehouse, W. J. and Graham, G. A. R. "Ratio of Neutron Absorption Cross-Sections of Boron and Hydrogen." Canadian J. Res., Vol. 25A, pp. 261-75, 1947.

3. Cortright, D. N., Legg, F. E., Jr., and Vogler, R. H. "Performance Tests on a Large Stationary Turbine-Type Concrete Mixer at Various Mixing Times." Michigan Department of State Highways Testing Laboratory Division, Report No. TA-7, March 1964.

APPENDIX

EXCERPT FROM THE
MICHIGAN DEPARTMENT OF STATE HIGHWAYS
1965 STANDARD SPECIFICATIONS
5.05.03 c, Pages 357-60

c. Mixing:

1. General Requirements. -The mixer shall meet the size and type required for the item of work to be constructed and shall be approved by the Engineer before being used on the work.

Each batch shall be mixed for a period of time not less than that specified in the following table, after the materials for the batch are in the mixer. The mixing time shall include the transfer time between drums when a multi-compartment paver is used.

Nominal Capacity (Cu. Ft.)		Minimum Mixing Time (Sec.)
More Than	To and Including	
Revolving Drum Type Mixers		
7	16	90
16	34	54
Turbine Type Mixers		
All Sizes		45

For mixers having a nominal capacity greater than 34 cubic feet the concrete materials shall be mixed for such time as is necessary to produce concrete which is uniform within the following limits, but in no case will the mixing time be less than 60 seconds. Concrete shall be completely mixed before being discharged from the mixer. The requirements prescribed for the particular grade of concrete shall be met by all concrete placed and, in addition, individual batches shall comply with the uniformity requirements hereinafter set forth. The contractor shall provide a batching and mixing plant of such efficiency to produce concrete which is uniform throughout the batch within the following limits:

Test	Maximum Variation
Slump	1 inch
Air Content of Concrete	1 per cent
Coarse Aggregate Content	6 per cent
Unit Weight of Mortar (Air-free)	3 lb./cu. ft.

Coarse aggregate content, using the washout test, shall be computed from the following relation:

$$CA = \frac{a}{b} \times 100$$

Where: CA = percentage of coarse aggregate in concrete
a = dry weight of coarse aggregate retained on the No. 4 sieve resulting from washing all material finer than this sieve from the fresh concrete
b = weight of sample of fresh concrete from which coarse aggregate is recovered.

The unit weight of the air-free mortar shall be calculated as follows:

$$M = \frac{b - c}{V - \left(A + \frac{c}{G \times 62.4}\right)}$$

Where: M = unit weight of air-free mortar in pounds per cubic foot
b = weight in pounds of sample used in washout test
c = weight of saturated surface dry coarse aggregate retained on the No. 4 sieve as determined from washout test
V = volume of fresh concrete used in washout test in cubic feet., found by dividing b by the weight per cubic foot of the fresh concrete
A = volume of air in washout sample found by multiplying V by the percentage of air divided by 100
G = specific gravity of coarse aggregate (saturated, surface dry).

The variation within a batch will be determined, for each property listed, as the difference between the highest value and the lowest value obtained from different portions of the same batch. To verify the uniformity of the concrete, samples will be taken to represent the first, middle, and last portions of the batch discharged from the mixer. Labor, sampling equipment, and materials required for testing the uniformity of the concrete mixture shall be furnished without charge by the Contractor. The tests will be performed by the Engineer. At least 3 batches will be sampled and tested, but the Engineer may elect to sample and test additional batches. For each of the tests listed above, at least 2/3 of the batches tested shall have variability not greater than the specified limit, and the average variation based upon all batches tested shall not exceed the specified limit. Simultaneous compliance of all properties, within a given batch, will not be required.

After operational procedures of batching and mixing are established so as to provide compliance with the foregoing uniformity requirements, no changes in mode of operation will be permitted without again re-establishing that these requirements are being met.

Mixing time shall be measured from the time all cement and aggregates are in the drum. The batch shall be so charged into the mixer that some water will enter in advance of cement and aggregate, and all water shall be in the drum by the end of the first quarter of the specified mixing time. The rate of rotation of the mixer shall be that recommended by the manufacturer for mixing concrete....

The volume of mixed concrete in each batch shall not exceed the AGC rated capacity of the mixer and as stamped on the mixer. The drum shall be entirely emptied after each batch before recharging....