Use of Neutron Activation to Determine Cement Content of Portland Cement Concrete

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Many millions of dollars are spent each year by the construction industry for portland cement concrete. This concrete, produced by a variety of concrete mixer designs, varies in specified quality from low-strength concrete used in unstressed members to high-strength concrete used in prestressed and reinforced concrete construction. Uniformity of mixing is a good criterion by which to judge the quality of the concrete mix and mixing adequacy. In this research, cement content of mortar, fineness modulus of the aggregate, ultimate compressive strength, and usual inspection of mixing quality were used to indicate the uniformity of the mixed concrete. With the exception of cement content, all tests to determine the physical characteristics of the concrete were made by conventional ASTM methods.

Cement content of the concrete mortar was determined by neutron activation analysis of Ca^{49} produced in the calcium in the portland cement. The method of cement content determination proved to be feasible and could be used to predict the cement content within approximately ± 0.007 g 95 percent of the time. Analysis of variance generally indicated that no significant effect was observed for fineness modulus, ultimate compressive strength, and cement content for the main effects of mixing time, replication, and position in a concrete mixer for the experiment used in this research.

• DURING the past two years, approximately 800 million barrels of cement have been produced for use in every area of construction work. Of this 800 million barrels, 52 percent was shipped to ready-mix plants. It is estimated that 130 million cu yd of ready-mixed concrete was produced in each of the last two years at a cost of over $3.5 billion.

Testing Methods to Determine Mixing Uniformity

One of the most important characteristics that control the quality of portland cement concrete is the uniformity of mixing. Adequately mixed, portland cement concrete exhibits such desirable qualities as optimum strength, workability, and durability. Because of the demand for concrete in building and road construction, it has become increasingly important to develop some simple method for the evaluation of mixing efficiency.

Manufacturers of concrete mixers are interested in evaluating the mixing efficiency of mixers having different speeds of rotation, different shapes, different blade sizes, and different blade angles. Producers of ready-mixed concrete are interested in securing a uniform mix in the minimum mixing time, and State highway departments and other users of concrete are interested in obtaining concrete having optimum strength and durability from plants supplying concrete for buildings, bridges, and highways.

Concrete mixers of various designs range in size from 1.5 cu ft to 10 cu yd. Common designs in use at central batch plants are the turbine mixer, horizontal tilting drum, and the nontilting horizontal drum. The principal mixer used in concrete highway paving is the 34-E dual drum paver.

With a knowledge of the minimum time required for a specific mixer to produce concrete having a uniform dispersion of aggregate and cement throughout the mix, mixing time may well be reduced from the conventional time required by present specifications. This reduction should result in increased capacity and lower production costs with no sacrifice in quality.

Many tests may be run on samples of fresh concrete selected from a mixer to help evaluate mixing efficiency. To determine the uniformity of a concrete mix, samples from various positions were compared for their air content, moisture content, modulus of rupture, fineness modulus of aggregate, compressive strength, usual appearance for mixing adequacy, and cement content. It was not feasible to run each of these tests because of time and money considerations; therefore, the last four tests were selected to evaluate mixing efficiency.

Cement Content by Neutron Activation

The use of radioactive isotopes in industrial processes and research is expanding rapidly. Because gamma emission from radioisotopes is easy to measure, the identification of constituents of a sample is simplified. Irradiation in an accelerator or a reactor can make the sample radioactive, and a knowledge of the particle emissions from the sample then allows interpretation of the sample's composition.

Neutron activation analysis was used in this research to determine cement content. Cast samples of portland cement mortar were activated in a neutron source. The amount of radioactivity produced in the sample of mortar was proportional to its cement content. A curve was produced by determining the count rate for cement mortar samples containing various known weights of cement. The unknown weight of cement contained in any mortar sample can be determined by activating the sample in a neutron source, counting the activity, and determining the cement content from the cement content vs count rate curve.

Other Methods for Determination of Cement Content

Various methods have been devised in the past for determining the cement content in a sample of concrete. The most prevalent method consists of determining the amount of soluble silica and calcium oxide in a sample by chemical analysis, and then indirectly calculating the percentage of cement by assuming some definite values of calcium oxide and silica in the cement (1). The method was devised for determining the cement content of a large sample of concrete, but can be used equally well in processing small mortar samples. This method is time consuming, requires a well-equipped laboratory with trained personnel, and is not applicable to concrete containing aggregates (such as slag, diatomites, and sodium silicates) which liberate soluble silica under test conditions.

Dunagan (2) suggests a test intended for use in the field for determining the constituents of concrete before the initial hardening. According to this method, the sample is first weighed in air, then in water, and washed over a No. 100 sieve. The aggregate is again weighed in water and the immersed weight of cement is obtained by the difference in the two submerged weights. It is necessary to know the specific gravity of cement to calculate its weight in air. An appreciable error enters the calculations in the assumption that all material passing the No. 100 sieve is cement.

Another procedure for determining the cement content of a sample of freshly mixed concrete consists of using a heavy liquid and a centrifuge process for separating cement from the other ingredients of concrete (3). The heavy media used comprise a liquid mixture of which the specific gravity may be adjusted to a value intermediate between that of cement and fine aggregate, thereby permitting the cement to sink and the aggregate to float. By means of appropriate calibration curves, cement content may be estimated.

The basis of a method by Murdock (4) is the determination of the specific gravity of a cement suspension. After washing a sample of fresh concrete over a No. 100 sieve, hydrometer readings are recorded of the suspension collected. By reference to a control curve obtained from hydrometer readings of water in which known quantities of cement are suspended, the amount of cement can be determined. Here again, the assumption that all material passing through the No. 100 sieve is cement creates an appreciable error in the calculations.

Two additional methods for determining cement content were developed by Chadda (5). In the first method, cement content is estimated by a conductimetric method based on the determination of conductivity of pure water in which known quantities of unset cement-sand mixture have been shaken. From a standard curve showing the relationship between cement concentration and conductivity, the cement content of a sample can be interpolated from its conductivity measurement. Chadda's other method for determining cement content is based on the differential absorption characteristics of cement and sand particles. The percent absorption increases as the concentration of cement increases in the mixture.

The latter two methods can be satisfactorily employed only for the determination of cement content in a freshly prepared cement-sand mixture to which no water has been added.

Previous research in this field has been primarily concerned with methods for spot checking samples of fresh concrete to insure a contractor's adherence to design specifications as to the amount of cement present. To this date, no attempt has been made to determine the uniformity of cement dispersion throughout the concrete mix. One of the purposes of this research was to develop a method that will enable manufacturers of mixers, producers of ready-mixed concrete, and users of concrete to investigate the distribution of cement in a mixer operating under a given set of conditions, thereby allowing the optimum mixing time to be determined and operating characteristics of machinery design to be determined. In evaluating mixing efficiency, a sampling program and a rapid and accurate method for determining cement content of mortar samples will be developed.

EQUIPMENT

Van de Graaff Accelerator

Cast mortar samples were activated by Georgia Tech's 1,000,000-volt Van de Graaff positive ion accelerator made by the High Voltage Engineering Corporation.

The Van de Graaff is a special type of electrostatic accelerator which has a highly insulated terminal and a means of maintaining the terminal at a very high static potential with respect to ground. An ion injected into the high potential end of the machine is accelerated and directed by the electrostatic field downward through an evacuated acceleration tube to ground.

As an ion source, a mixture of ordinary and heavy hydrogen (deuterium) is used, which gives a beam containing about 25 μ amps each of protons and deuterons. The 25-μ amp mixed beam of deuterons and H_2^+ ions at 1,000,000 electron volts is directed through the evacuated tube on a target of beryllium metal to produce the reaction

$$ {}_4Be^9 + {}_1d^2 \rightarrow {}_5B^{10} + {}_0n^1 + \text{energy} $$

A small general-purpose thermal neutron irradiator as shown in Figure 1 was constructed for use with the Van de Graaff in performing this project. The beryllium target is surrounded by a mass of paraffin having an aluminum sleeve for positioning the mortar samples several centimeters below the target. The thermal neutron flux at the sample position was of the order of 5×10^6 thermal neutrons per sq cm per sec.

The purpose of the paraffin is to thermalize the fast neutrons, thereby permitting their capture by the Ca^{48} atoms. The cadmium shield merely prevents the escape of thermal neutrons from the irradiator. Figure 2 shows the neutron irradiator situated in the Van de Graaff.

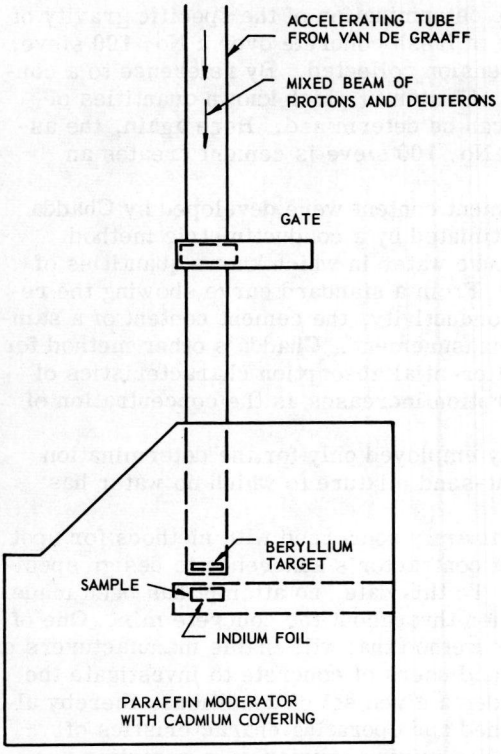

Figure 1. Thermal neutron moderator and the Van de Graaff accelerator.

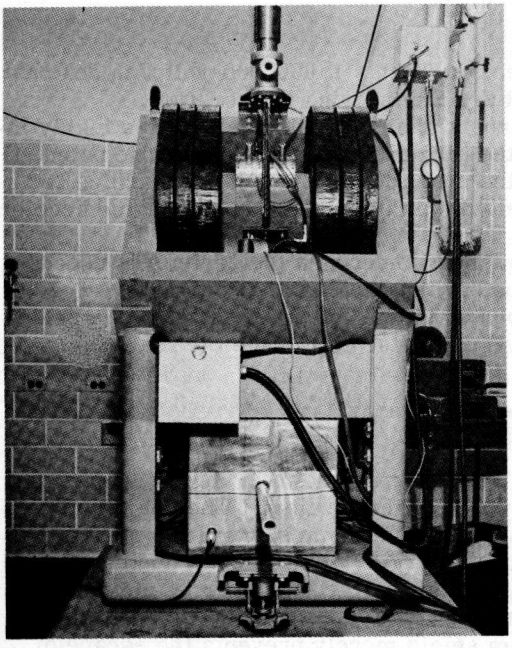

Figure 2. Neutron irradiator in the Van de Graaff accelerator.

Other Methods of Producing Neutrons

Most reactors can produce the neutron flux required for the activation of calcium. However, the Georgia Tech reactor now under construction will not be available for use until late 1962 or early 1963.

Radioactive sources are also available which can produce neutron fluxes of the strength required. The most desirable source to use for this purpose is americium-beryllium, which has the advantage of a long half-life and lack of gamma activity. Shielding is only required for neutron emission. Other sources which could be used either require extensive shielding for gamma radiation, have low specific activity, or have short half-lives. Unfortunately, americium sources of the size required to produce the neutron flux required are not readily available.

Radiation Detection

To date, the use of crystals of thallium-activated sodium iodide [NaI(Tl)] coupled to cesium-antimony phototubes is unchallenged as the most efficient method for detecting gamma rays. The following characteristics of this type of detector have resulted in a widespread application of the scintillation counter as a radiation detector and gamma ray spectrometer: high density of the inorganic crystals, which is mainly responsible for the higher stopping power and greater sensitivity to gamma rays; high light output; suitable index of refraction; response proportional to the incident radiation; and fast decay time.

The basis of a scintillation counting system is the ability of the phosphor to convert into light emissions some fraction of the energy lost by ionization during the passage of a gamma ray through the material. This emitted light is picked up by the sensitive photocathode of a photomultiplier tube. The photocathode produces an electrical pulse similar to the light output from the crystal in both magnitude and duration. Because the electrical pulse coming from the phototube is of insufficient size to activate a scaler, additional amplification is supplied by an external amplifer.

For a given crystal size and energy of gamma ray, the greatest total efficiency in counting is obtained from having the source situated in immediate contact with the crystal and on its central axis. In this experiment, not only is this proximity very

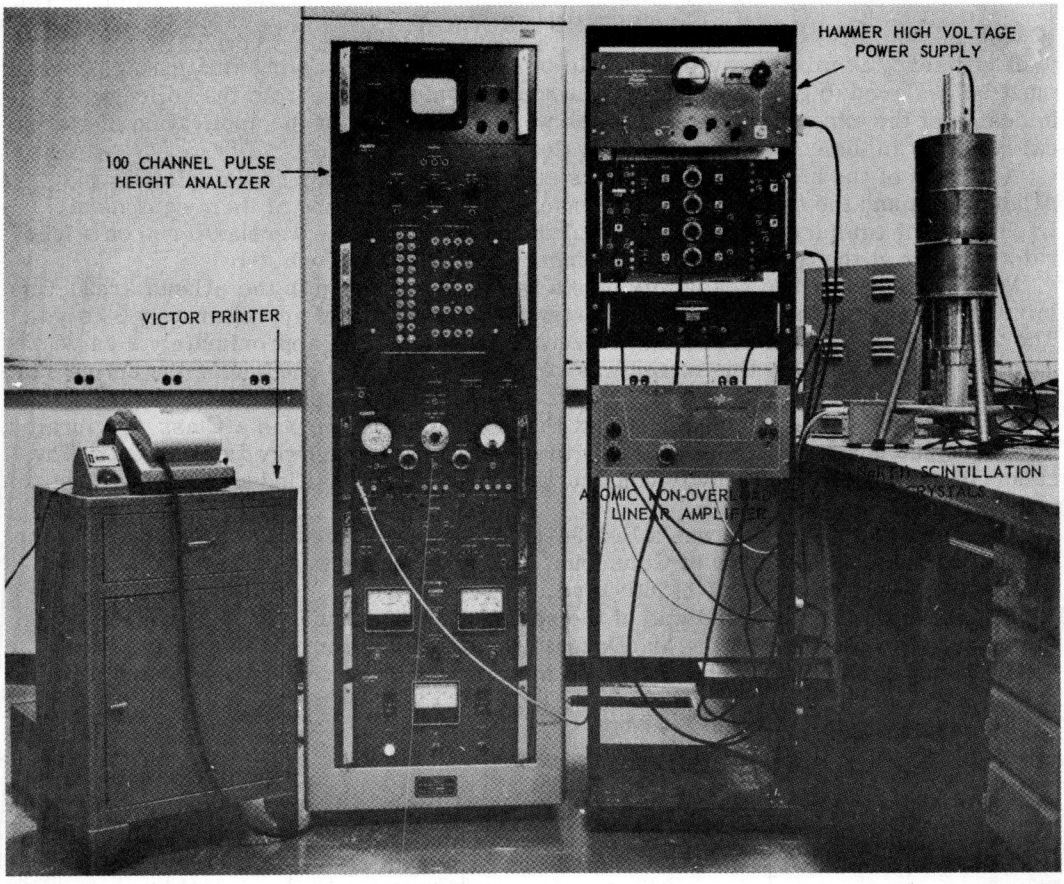

Figure 3. Radiation detection equipment.

nearly attained, but two scintillation crystals are also arranged with the sample situated between them, thereby approximating four-pi geometry. With the source situated in this manner, the emissions are isotropic, and thus a large number of interactions will occur laterally in the crystals.

Figure 3 shows the radiation-detection equipment located in the Radioisotopes Laboratory at Georgia Tech. On the right, the photo shows the two scintillation crystals with lead shields mounted vertically on a small tripod. The high voltage supply is at the top of the right center instrument bank and the external linear amplifier is at the bottom. The instrument in the left center of the photo is a 100-channel pulse height analyzer (Penco) manufactured by the Pacific Electro Nuclear Co. The Penco receives the electrical pulses from the external amplifier and stores them in channels according to their individual size. The memory of the Penco is recorded on tapes by a Victor printer shown at the right of the figure. Figure 4 is a block diagram of the pulse-counting equipment.

Equipment as expensive and elaborate as that shown in Figure 3 is not required for actual testing purposes. The equipment in the figure was used to determine the best energy range for analysis and also the minimum type of equipment that could be used for actual testing purposes.

The minimum equipment needed for measuring the activity of calcium-49 is (a) sodium iodide crystal, (b) linear amplifier, (c) discriminator, and (d) scaler. All of this equipment could be purchased for less than $3,000.

TESTING PROGRAM

If efficiency of mixing equipment is to be evaluated, a sampling and testing program must be designed to give the maximum amount of information from the collected data. In design of the experiment a statistician was consulted about the application of statistical concepts in the collection and the evaluation of these data.

A section of the highway on the Interstate system was under construction in the Atlanta area and the two contractors consented to the sampling of their equipment. Each piece of equipment was a 34-E dual drum paver. Tests were also run on a laboratory mixer at the School of Civil Engineering at Georgia Tech.

Mixers located at two ready mix plants were also sampled in the Atlanta area. One mixer was a tilting horizontal drum mixer with a capacity of approximately 3 cu yd. The second mixer was a nontilting horizontal drum mixer of approximately 2 cu yd capacity. Unfortunately this mixer was replaced with a new one before the entire sampling program was completed and the data for it are not complete.

The mixture selected for sampling at the ready-mix plants was a Class A, vibrated, air-entrained concrete, as specified by the Georgia State Highway Department. The concrete sampled at the highway construction sites was classified as a paving class concrete.

The first mixer sampled was a Rex 34-cu ft dual-drum highway paver owned by the Wright Contracting Company of Columbus, Ga. The mixer was operated at a 10 percent overload giving a mix of 1.385 cu yd.

The second mixer sampled was of the same type but manufactured by the Koehring Company. It was owned by the MacDougald Contruction Company of Atlanta, Ga. Specifications and photographs of the two mixers are shown in Figures 13 and 14 (Appendix B).

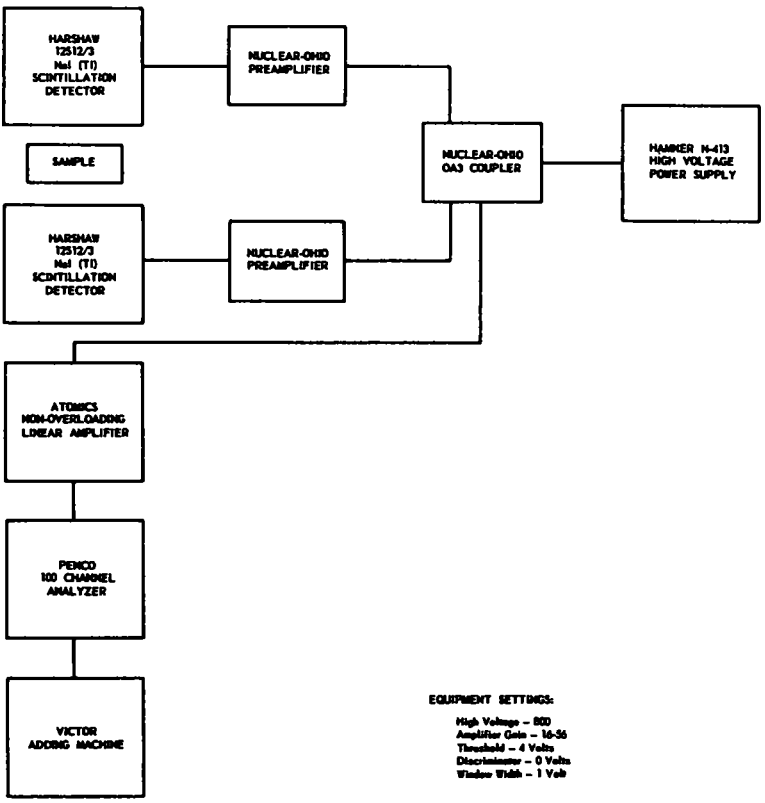

Figure 4. Schematic diagram of pulse counter.

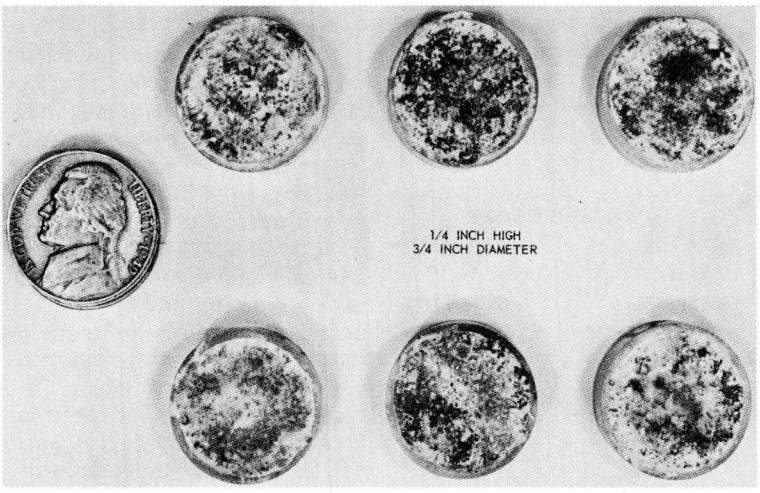

Figure 5. Cement mortar samples used for evaluating cement content.

Because of design, samples could not be withdrawn directly from the mixer but had to be collected as the concrete was discharged on to the roadbed.

The third mixer selected for sampling was a 3.5-cu yd horizontal tilting drum type manufactured by the T.L. Smith Corporation and owned by MacDougald Warren, Inc. The Hapeville Plant of MacDougald Warren, Inc., was selected because of its interest and cooperation, and because it possessed a standard type of stationary mixer used in the commercial production of ready-mixed concrete. Figure 15 (Appendix B) shows the plant and specifications of the mixer.

Again, because of design, it was impossible to withdraw samples directly from the different locations within the mixer. Therefore, after the predetermined mixing time, the mixer was tilted, and during the 20 to 25 sec necessary for discharge into a waiting truck, samples were drawn from the stream of concrete.

A laboratory mixer in the concrete laboratory at Georgia Tech was next sampled. A picture of this Worthington 6.0-cu ft nontilting horizontal drum mixer and its specifications are given in Appendix B.

A partial experiment was run on a 2-cu yd Koehring nontilting horizontal drum at the Campbell Materials Company before its breakdown and replacement. Figure 16 (Appendix B) shows the plant of the Campbell Materials Company in Atlanta and gives the specifications for the mixer.

Design of the Experiment

The experiment was chosen to consist of five different mix times: 30, 45, 60, 120, and 180 sec. Three samples were collected during the discharge of each batch and represented three different positions of the concrete in the mixer. The samples were evaluated for visual appearance of mixing adequacy, compressive strength, gradation of aggregate, and cement content. For the Hapeville and Georgia Tech mixers, the sampling and testing program was replicated three times to give a total of 45 samples for each mixer. The highway paving mixer experiments were replicated twice to give a total of 30 samples for each mixer, and the Campbell experiment was interrupted in the middle of the second replications.

The five mixing times used throughout the experiment were randomly selected and every effort was made to eliminate systematic errors. The materials used for any one mixer used during the tests were purchased from the same suppliers; the constituents of the batch were unchanged except for minor adjustment in water; the same person did the timing throughout the tests; the collection and processing of samples were as identical as possible; and the testing procedure was not altered.

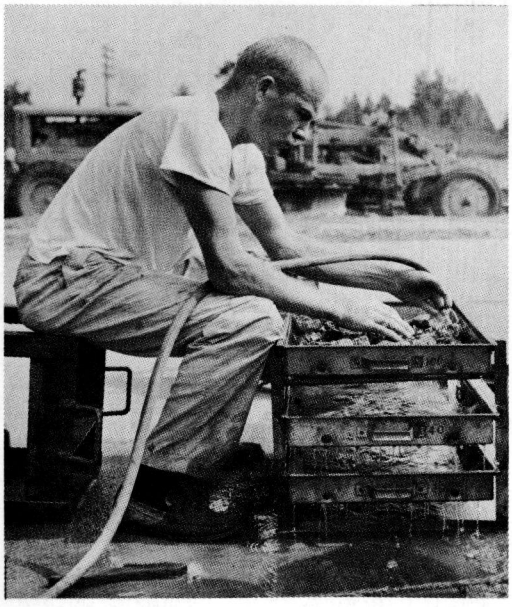

Figure 6. Washing technique for removing cement from aggregate.

Processing of Samples

Immediately after being drawn, the three samples were visually graded in one of three categories (well mixed, fair, and poor) and then processed for future testing. (Criteria for classification are as follows: well-mixed— uniform dispersion of batch constituents, proper workability; fair— uniform dispersion of cement and coarse and fine aggregate, dry or excessively wet giving ununiform workability; and poor— segregation of one or more constituents of the batch, dry or excessively wet giving ununiform workability.) Two mortar samples to be used in determining the dispersion of cement by neutron activation were collected from each of the three samples. These small samples were secured by first taking 50 to 100 g of the concrete mix, removing any large aggregate by passing the wet concrete through a No. 4 sieve, and then filling $\frac{3}{4}$-in. diameter by $\frac{1}{4}$- in. high polystyrene containers with the concrete mortar. Figure 5 shows six of the mortar samples ready for the determination of cement content. Conventional 6-in. diameter by 12-in. high compressive strength cylinders were cast, and the remainder of each sample was used for a gradation test of the aggregate contained in the concrete. Figure 6 shows the samples of fresh concrete used for the gradation test were washed over No. 4, 50, and 200 sieves to remove the cement in preparation of the sample for the gradation test.

Testing of Samples

To relate mixing time to uniformity of a concrete mix, strength and gradation of aggregate were evaluated in addition to the dispersion of cement. Tests were run first for determining the uniformity of the aggregate gradation in each sample. After being washed, the aggregate was dried at 235 F for 24 hr and its fineness modulus determined. (Fineness modulus is a numerical coefficient used to describe the sieve analysis of an aggregate. The percentage of material coarser than each sieve size is calculated, and the sum of these percentages divided by 100 is the fineness modulus. The larger the aggregate, the higher is its fineness modulus.) The 28-day ultimate compressive strength of the concrete was determined from the 6- by 12-in. cylinders under testing conditions prescribed by the American Society of Testing and Materials (C85-54).

Determination of Cement Dispersion

In determining the dispersion of portland cement throughout a concrete mix by the use of radioisotopes, two methods are immediately available in designing the experiment.

The first method utilizes the nuclear radiations emitted from a radioactive source that has been added to the mixer. The cement is tagged with an appropriate isotope, and after predetermined periods of mixing, samples from different parts of the batch are compared for radioactivity. Two objections or obstacles arise in using this method: (a) the inability to tag uniformly the large quantity of cement used in most commercial-size mixers, and (b) the danger of radiation exposure to plant personnel due to the dust generated during mixing of the concrete and the danger to workmen while placing

radioactive concrete. These objections prevented the application of radioisotopes to the mixer.

The second method consists of activation analysis. This procedure allowed the samples to be collected without the danger of radiation exposure and to be processed in a laboratory with proper shielding and suitable monitoring devices to eliminate any health hazard. In activation, the samples to be analyzed are placed in a high flux of slow neutrons produced by the Van de Graaff for a length of time sufficient to produce a measurable amount of radioisotope of the element to be determined. The activity present is a quantitative measurement of the element. Concrete mortar samples are collected from different parts of the batch, activated, and compared for radioactivity.

The problem consisted of finding an element within the portland cement that was not present in the other constitutents of the concrete batch. Table 1 gives the chemical properties of the typical cement and aggregate used.

By weight, calcium oxide comprises about 65 percent of portland cement. For the material used in this experiment, calcium is only present in a very small percentage in the coarse aggregate, and is not found at all in the fine aggregate. Because only 1 percent of the coarse aggregate passes a No. 4 sieve, only a minute fraction of the calcium present in a mortar sample would be contributed by the coarse aggregate.

An investigation of calcium was made to determine whether an isotope existed which, when subjected to neutron activation, would become traceable. It was also

TABLE 1

CHEMICAL ANALYSIS OF PORTLAND CEMENT AND FINE AND COARSE AGGREGATE[a]

Material	Source	Chemical Compound	Percent by Weight
Portland cement	Universal Atlas, Birmingham, Ala.		
		CaO	65.66
		SiO_2	22.24
		Al_2O_3	5.96
		Fe_2O_3	2.16
		SO_3	1.88
		MgO	0.93
		Ins. res.	0.40
		K_2O	0.15
		Na_2O	0.03
Fine aggregate[b]	Taylor Sand Co., Junction City, Ga.		
		SiO_2	98.00
		Al_2O_3	1.20
		H_2O	0.56
		Org. matter	0.18
		Fe_2O_3	0.06
Coarse aggregate[c]	Tyrone Rock Products Co., Quarry 2, Mt. View, Ga.		
		SiO_2	74.70
		Al_2O_3	13.92
		Fe_2O_3	3.84
		CaO_3	3.76
		Na_2O	2.80
		K_2O	0.76
		MgO	0.20

[a]Values typical of proportions of chemical compounds found in other sources of aggregate and cement used in this research.
[b]Alluvial deposit known as Tuscaloosa formation.
[c]Biotite granite gneiss.

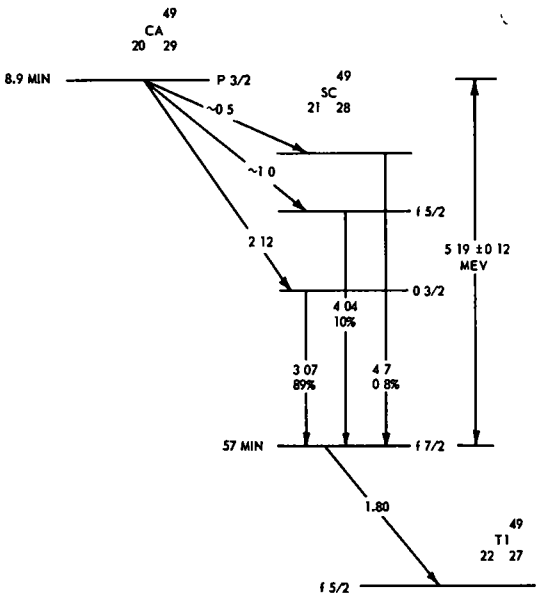

Figure 7. Decay scheme of Ca^{49} and Sc^{49}.

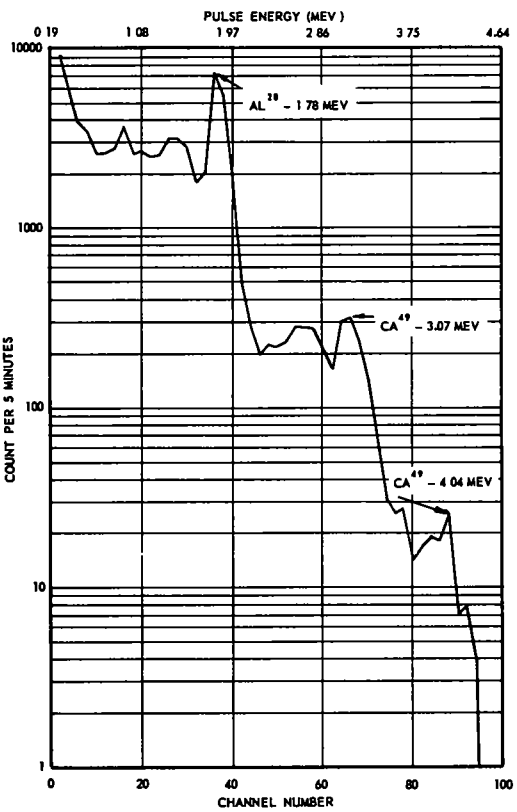

Figure 8. Gamma-ray spectrum of activated mortar sample.

necessary to examine isotopes of the other chemical elements constituting concrete to insure that their energy of radiation and disintegration did not interfere with calcium measurements. The results of this investigation are given in Table 2.

Although not in great abundance, $_{20}Ca^{48}$ was selected as the target nucleus which, after activation in the Van de Graaff, becomes the radioactive isotope $_{20}Ca^{49}$. This isotope was selected because of its relatively short half-life and traceable energy emissions during decay.

When bombarded by thermal neutrons, $_{20}Ca^{48}$ undergoes the following transformation:

$$_{20}Ca^{48} + {}_{0}n^{1} \rightarrow {}_{20}Ca^{49}$$

$_{20}Ca^{49}$ has been found to decay with a half-life of 8.9 ± 0.2 min. The decay scheme, as determined by Martin, Cork, and Burson (6), is shown in Figure 7.

The gamma ray spectrum of an activated cement mortar sample was studied to insure that the 3.07-mev (million-electron-volts) gamma ray emitted by Ca^{49} could be detected using the two 3-in. diameter sodium iodide (thallium) crystals and the Penco 100-channel pulse height analyzer. The spectrum of an activated cement mortar sample as determined by the scintillation counting system is shown in Figure 8.

A calibration of the 100-channel analyzer was necessary to determine in which channel the 3.07-mev sum peak would fall. Sources with known energy emissions were counted and plotted against channel number to give a calibration curve. The channel numbers corresponding to the different energy peaks are given in Table 3. From the calibration curve shown in Figure 9, it was possible to select the channel in which a 3.07-mev energy pulse would fall.

A decay study was then made on the 3.07-mev energy peak of an activated mortar sample as a check of its half-life. After activation, the sample was transferred to the scintillation counter and three 5-min counts were recorded. The peak was found to cover channels 62-74. Table 4 gives the total counts recorded for the 3.07-mev peak at the end of each counting period.

Figure 10 is a partial plot of the spectrum at the end of each 5-min counting period; this plot shows the decay of the 3.07-mev energy peak. The figure shows the total counts recorded in channels 62-74

TABLE 2

ISOTOPES INHERENT IN ELEMENTS OF CONCRETE USED IN THE EXPERIMENT

Target Isotope	Abundance (%)	Radio-Nuclei	Type of Decay	Half-Life	Activation Cross-Section (barns)	Energy of Radiation and Disintegration	
						mev	%
$_1H^2$	0.015	$_1H^3$	β^-	12.26 yr	0.6	0.18	
$_8O^{18}$	0.204	$_8O^{19}$	β^-	29.4 sec	0.21 mb	4.5	30
						2.9	70
						1.6	70
$_{11}Na^{23}$	100.	$_{11}Na^{24}$	γ		0.6	4.122	100
			β^-	14.97 hr		4.17	0.003
						1.380, 2.758	
$_{12}Mg^{26}$	11.29	$_{12}Mg^{27}$	γ		50	1.75	58
			β^-	9.45 min		1.59	42
						0.834, 1.015	
$_{13}Al^{27}$	100.	$_{13}Al^{28}$	γ		0.21	2.87	100
			β^-	2.27 min		1.78	
$_{14}Si^{30}$	3.05	$_{14}Si^{31}$	γ		0.12	1.49	
			β^-	2.62 hr		1.264	0.07
$_{16}S^{34}$	4.215	$_{16}S^{35}$	γ		0.26	0.167	100
			β^-	87 days			
$_{16}S^{36}$	0.017	$_{16}S^{37}$	β^-	5.04 min	0.14	1.6	90
						4.3	10
						3.09	
$_{19}K^{39}$	93.08	$_{19}K^{40}$	γ		3	1.33	89
			β^-	1.25×10^9 yr		1.46	11
$_{19}K^{40}$	0.012	K^{41}	Electron capture				
$_{19}K^{41}$	6.91	$_{19}K^{42}$	β^-	12.52 hr	1.0	2.04	25
						3.58	75
						1.51	20
$_{20}Ca^{44}$	2.06	$_{20}Ca^{45}$	γ		0.63	0.254	
			β^-	164 days			
$_{20}Ca^{46}$	0.0033	$_{20}Ca^{47}$	β^-	4.7 days		0.70	76
						1.94	24
			γ			0.50	5
						0.81	5
						1.29	71
$_{20}Ca^{48}$	0.185	$_{20}Ca^{49}$	β^-	8.9 min	1.1	1.0, 2.12	
			γ			3.07	89
						4.04	10
						4.7	0.8
$_{26}Fe^{54}$	5.84	$_{26}Fe^{55}$	Electron capture	2.60 yr	0.7		
$_{26}Fe^{58}$	0.31	$_{26}Fe^{59}$	β^-	45.1 days	0.7	0.271	46
						0.462	54
			γ			1.560	0.3
						1.099	57
						1.289	43

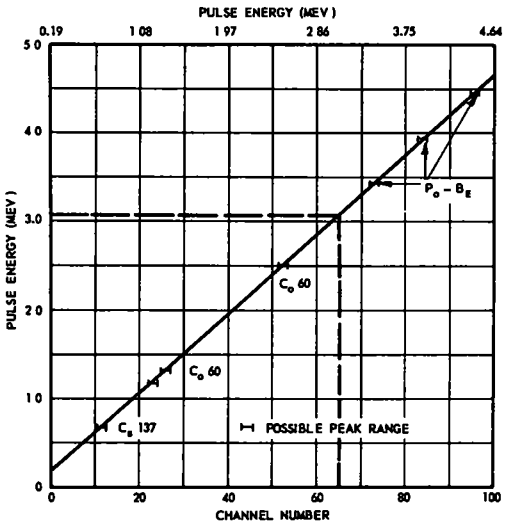

Figure 9. Calibration curve for scintillation spectrometer.

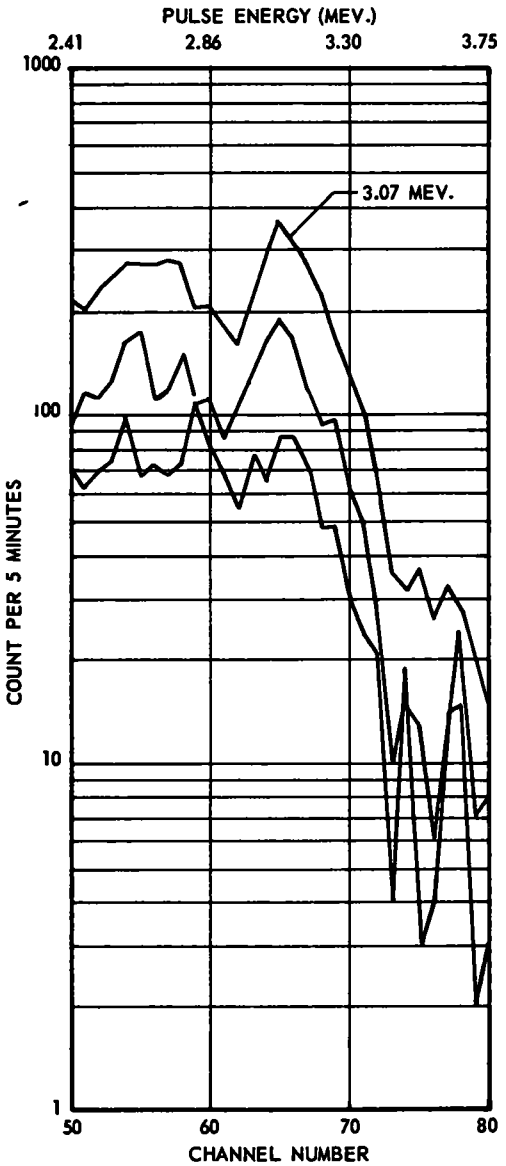

Figure 10. Decay of 3.07-mev peak.

for the three 5-min counts spaced 8 min apart. From Figure 11, the half-life of the peak was determined by reading the time on the abscissa corresponding to a 50 percent reduction in activity on the ordinate scale. A plot of the data determined the half-life of the peak to be 8.5 min. The difference of 0.4 min between theoretical and observed decay time for $^{20}Ca^{49}$ was probably due to the presence of sulfur-37 and oxygen-19.

When irradiated, $_{16}S^{36}$ nuclei enter the excited state of $_{16}S^{37}$ and decay, emitting 3.09-mev gamma rays with a half-life of 5.04 min. Sulfur ionization therefore contributes to some of the activity recorded in the 3.07-mev peak of the spectrum, but this should in no way reduce the accuracy in cement content determination, because sulfur is only present in the cement in very small quantities. Because $_8O^{19}$ has a half-life of 29.4 sec and counting did not start until 90 sec had elapsed from irradiation, the amount of activity caused by this isotope was considered to be negligible.

With the half-life of $_{20}Ca^{49}$ known to be approximately 8.9 min, it was decided that an irradiation period of 10 min for the collected mortar samples would give a sufficient number of counts to determine the cement content adequately. During this period the increase in activity is nearly linear with the time of irradiation.

The intensity of the beam on the Van de Graaff varies during this 10-min period among different samples and from day to day. Therefore, it was necessary to monitor the varying neutron flux with a small piece of indium foil that was irradiated along with each sample. The counts obtained from the indium foils were first normalized to correct for the varying foil weight, and then further normalized to correct for the variation

in neutron flux. The count of each mortar sample could then be normalized to the value that would have been recorded had the neutron flux been constant during the testing period. An example of the calculations necessary to normalize the count for each sample is given in Appendix C.

After a 10-min exposure to the thermal neutron flux, the samples were removed from the irradiator and taken to the counting room. One min was allowed for the transfer of the sample and an additional 30 sec for transferring the monitoring indium foil, with each then being counted for 5 min.

The outputs from the two photomultiplier tubes were added electronically, giving a single composite spectrum which could be seen on the Penco pulse height analyzer scope. The spectrum was then printed on tape to give a permanent record of each sample's activity. The observed 5-min count of the indium foil was recorded by a Geiger-Mueller counter.

To determine the cement content of mortar samples collected, a standard chart or graph of cement content vs count was developed. Laboratory samples were made with known quantities of cement and were activated, counted, and plotted. Because of the random decay of radioactive isotopes, three observations were made of each standard sample and the best line through the points was determined by the method of least squares. The resulting cement content vs count rate curve is shown in Figure 12. It was from this graph that point estimates of the cement of cast mortar samples were determined for mortar samples containing unknown amounts of cement.

TABLE 3

GAMMA SOURCES FOR ENERGY CALIBRATION OF SCINTILLATION SPECTROMETER

Isotope	Energy Peaks (mev)	Channel No.
Cs^{137}	0.667	11½
Co^{60}	1.17	23
	1.33	26
	2.50	52½
Po-Be	3.43	73
	3.94	84
	4.45	96

TABLE 4

DECAY STUDY OF 3.07-MEV ENERGY PEAK

Time After End of Irradiation (min)	Count, Channels 62-74
1 - 6	2,409
9 - 14	1,242
17 - 22	648

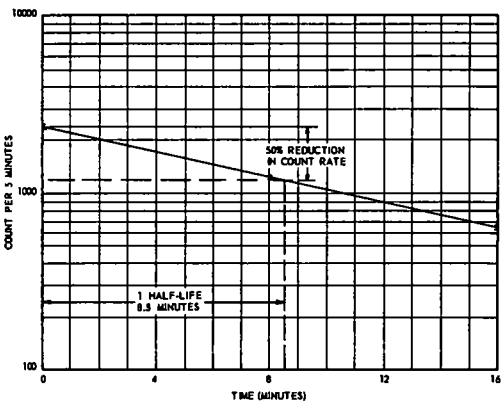

Figure 11. Half-life determination of 3.07-mev peak.

RESULTS

Analysis of Variance

Analysis of variance is probably the most powerful procedure in the field of experimental statistics. It allows the data collected to be rigorously analyzed and conclusions to be accompanied by probability statements as to the correctness of the inferences. To carry out the analysis, it is necessary to formulate a mathematical model in terms of the unknown parameters and the associated random variables. The quantitative physical characteristics (dependent variables) of interest in this study are the following:

1. Aggregate fineness modulus.
2. Compressive strength.
3. Cement content of mortar.
4. Visual evaluation of mixing.

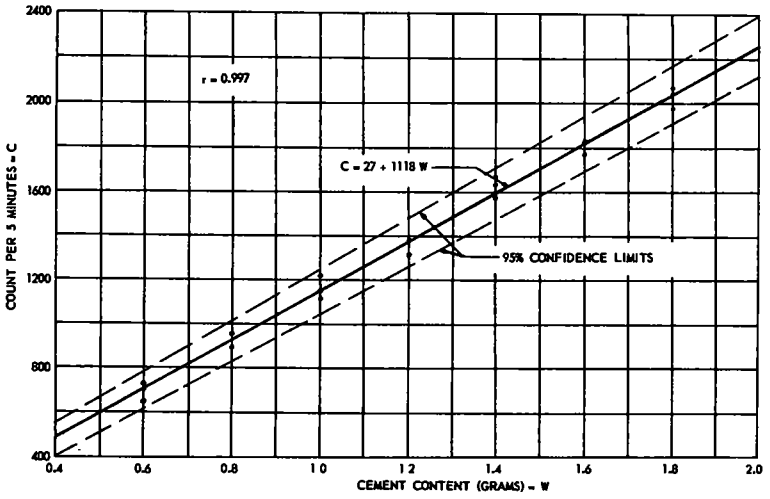

Figure 12. Cement content vs count.

Aggregate fineness modulus and cement content may appear to be independent variables because they are set by the particular mix samples. However, in this investigation, the constituents enter the mixer in segregated slugs. This research is concerned with the determination of the dispersion of the constituents; therefore, aggregate fineness modulus and cement content are dependent variables.

The independent variables of interest are as follows:

1. Mixing time (T) 30, 45, 60, 120, and 180 sec.
2. Position (P) of concrete in discharge stream or in mixer.
3. Replication (R) (experiment is run two or three times for each mixer).

Analysis was made on the strength and fineness modulus characteristics, and on the average of the two cement content determinations for each sample. The primary variables used in this analysis is shown in Table 5. The mathematical model can be written as

$$y_{ijk} = \mu + T_i + R_j + RT_{ij} + P_k + PR_{jk} + PT_{ik} + PRT_{ijk}$$

In effect, this formula states that for an individual concrete sample, the strength, fineness modulus, or cement content (determination) for the kth position in the jth replication, mixed for i seconds, will be an expected value μ, plus the sum of any main effects and interaction effects due to the three independent variables. This design is known as a split-plot experiment. RT is used as an estimate of the main plot error, and PRT is taken as an estimate of the split-plot error.

TABLE 5

PRIMARY VARIABLES FOR ANALYSIS OF VARIANCE

Factor	Abbreviation	Subscript	No. Levels	Model
Mix time	T	i	5	Fixed
Replication	R	j	3(2)[a]	Fixed
Discharge position	P	k	3	Fixed

[a] Wright and McDougald paving jobs.

Fineness Modulus

In Appendix A Tables 6, 8, 10, 12, and 14 give the values of aggregate fineness modulus of the samples collected during the experiment. Results of the analysis of variance are shown in Tables 7, 9, 11, and 13.

From Table 9, the interaction term, PR, is significant at the 1 or 5 percent level. The interaction terms are not significant in any of the other tables. The position is highly significant and replication is significant in Table 11. All other analysis of variance tables did not indicate any significant effect of mix time, replication or position of fineness modulus.

In Table 11 by rejecting the hypothesis that the position of the concrete in the discharge stream does not affect the fineness modulus, it is possible to determine which positions differ. By the application of Tukey's procedure of contrasts (7), one can conclude that the fineness modulus in position 1 differs significantly from the fineness modulus in positions 2 and 3, and that there is no significant difference between the fineness modulus in positions 2 and 3.

Compressive Strength

Compressive strength is universally used as the index of concrete quality, but, used alone, it may be misleading. Samples drawn from two different batches of concrete may exhibit similar strength even though their uniformity of mixing is quite different. A sample with inadequate moisture content may be unacceptable from the standpoint of workability, yet may give high strength after being cast in a cylinder mold.

Tables 15, 17, 19, 21, and 23 show the ultimate compressive strengths obtained in breaking tests on the 6- by 12-in. concrete cylinders. The analysis of variance computed for compressive strengths of concrete is given in Tables 16, 18, 20, and 22.

Numerous articles have been published correlating the strength of concrete with mixing time. It is the present consensus that 1 min is the minimum length of time for suitable mixing of concrete, and that 2 min is highly desirable. The value of F computer in the analysis of variance for testing the mixing time effect in Tables 16, 18, 20, and 22 indicated there was not a significant difference in strength for different mixing times. Position and replication also is not significant.

Immediately evident in Table 20 is the highly significant value of $F = 12.23$ for testing the position hypothesis. From the data of this experiment, the strength of concrete varied significantly among each of the three positions in the discharge stream. Observing the F values computed in the various other tables, one must accept the hypothesis that there is no significant difference in strength because of interaction effect among the independent variables.

Cement Content

Figure 11 shows the line of cement content vs count and gives its equation and correlation coefficient, r. The value of r (0.997) indicates a nearly perfect degree of association between the two related variables. The 95 percent confidence limits are also shown in Figure 11.

Because there is an underlying physical relationship between observed count and cement content, it is appropriate to make point estimates of the cement content associated with a particular count. However, because the observed count is subject to variation, a confidence interval estimate is also needed to enable probability statements to be made about the true cement content of the samples.

For this experiment, a 95 percent confidence interval was chosen around the regression line. For example, a sample having a normalized count of 600 between channels 62-74 would have a point estimate equal to 0.508 g of cement and a 95 percent confidence interval equal to $\pm$ 0.068 g. The point estimate for a sample recording a normalized cut of 1,800 per 5 min would equal 1.592 g of cement and would have 95 percent confidence interval of $\pm$ 0.066 g around this cement content.

Point estimates of cement content on mortar samples were made using Figure 11. A ratio of grams of cement per gram of mortar was then computed for the samples and

this information is contained in Tables 24, 26, 28, 30, and 32. The analysis of variance for the data is given in Tables 25, 27, 29 and 31.

For testing the hypothesis that the position of the concrete in the discharge stream has no effect on the cement content of a sample, the value of F was 14.69 in Table 29 and 12.97 in Table 31. Because these values exceed both $F_{0.05}$ and $F_{0.01}$ values, one can conclude that there is a highly significant difference in cement content of mortar among samples located in different positions in the discharge stream or its corresponding position in the mixer. Replication effect is also significant in Table 31 at the 5 percent level.

Referring to the other values of F in the various Tables 25 and 27, the main effects and interaction effects among the variables did not cause the cement content to differ significantly.

Visual Inspection

An objective evaluation was attempted to determine whether the authors could visually ascertain the degree of mixing by judging the uniformity of mixing of concrete discharged from the mixer. The samples used in the previously described tests were classified in one of three categories: well-mixed, fair, and poor.

Compressive strength, fineness modulus, and cement content of samples were used to correlate visual classification to degree of mixing. Although an analysis of variance can not be performed on these data, it may be concluded that the authors were unable to determine visually the degree of mixing uniformity.

For example, some samples were classified as being well mixed and exhibited values of strength, fineness modulus, and cement content of the mortar which indicated the opposite may be true. On the other hand some samples were classified as being poorly mixed but indicated some of the characteristics of a well-mixed material.

SUMMARY

The results obtained for fineness modulus, compressive strength, cement content, and visual evaluation of adequacy of mixing are as follows for the various mixers studied:

1. Fineness Modulus.—For the dual drum 34-E Mixer used on the MacDougald paving job exhibited significant effect on fineness modulus for the position-replication interaction term was observed. For the MacDougald Warren mixer used at a ready-mixed plant, replication of the experiment had significant effect on fineness modulus and position of the mix in the mixer had very significant effect on fineness modulus. All other main and interaction effects for all of the mixers studied were not significant.
2. Compressive Strength.—For the MacDougald Warren, Inc., mixer replication of the experiment had significant effect, and position of the mix in the mixer had very significant effect on compressive strength. All other main and interaction effects for the mixers studied were not significant.
3. Cement Content of the Mortar.—For the MacDougald Warren mixer position of the mix in the mixer had very significant effect on cement content of the mortar. For the Georgia Tech mixer, replication of the experiment exhibited significant effect and position of the mix in the mixer had very significant effect on cement content in the mortar. All other main and interaction terms for the mixers studied were not significant.
4. Visual Inspection of Concrete Mixing Adequacy.—Using fineness modulus, compressive strength and cement content as criteria for adequacy of mixing, it was not possible to determine the adequacy of mixing by visual observation for the mixers studied in this experiment.

CONCLUSIONS

The ease with which the sampling and testing program described in this report can be used in evaluating mixing efficiency justifies its application. Activation analysis appears to be a feasible method for determining the cement content of cast mortar samples. Although not equaling the accuracy obtained by chemical analysis, the cement

content could be predicted to within approximately 0.07 g of its true value 95 percent of the time for these experiments.

The principal advantages of activation analysis are the ease and speed of cement content determinations. The principal disadvantages are that a laboratory with trained personnel and equipped for irradiating samples and counting are required. This experiment may not be performed on concretes containing aggregates of limestone, marble, or other stone with an appreciable calcium content.

It may be concluded from the data collected that some of the mixers sampled did not produce a uniform concrete mixture. It is of interest to note that mixing time did not have significant effect on fineness modulus, compressive strength, or cement content of the mortar. Most mixing specifications for concrete require a minimum mixing time of 1 min. In these experiments, the analyses of data for the 30-sec mixes indicate no significant difference in quality of the mix for longer mixing times.

Although no conclusions can be definitely drawn about other mixers, the results of this research may be an indication that some changes are needed in the blade angles, speed of rotation, capacity, etc., to insure the production of a uniform concrete mixture.

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Appendix A

TABLES OF RESULTS AND ANALYSIS OF VARIANCE

TABLE 6

AGGREGATE FINENESS MODULUS, WRIGHT PAVING JOB

Replication	Position in Mixer or Discharge Stream	Fineness Modulus for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	6.32	5.83	5.81	5.42	5.84
	2	5.86	5.67	5.62	5.27	5.77
	3	5.80	5.58	5.82	5.37	5.64
2	1	5.88	5.95	5.94	5.61	5.89
	2	5.77	5.61	5.97	5.89	5.93
	3	5.76	5.84	4.85	5.75	5.99

TABLE 7

ANALYSIS OF VARIANCE FOR FINENESS MODULUS, WRIGHT PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	0.0340	1	0.0340	0.37	7.71	21.2
Mix time	0.4583	4	0.1146	1.25	6.39	16.0
RT	0.3655	4	0.0914	—	—	—
Position	0.2189	2	0.1095	1.51	4.46	8.65
PR	0.0623	2	0.0312	0.43	4.46	8.65
PT	0.3177	8	0.0397	0.55	3.44	6.03
PRT	0.5805	8	0.0726	—	—	—
Total	2.0372	29				

TABLE 8

AGGREGATE FINENESS MODULUS, MACDOUGALD PAVING JOB

Replication	Position in Mixer or Discharge Stream	Fineness Modulus for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	6 11	5 96	5 76	5 95	5 94
	2	5 99	5 96	5 76	5 80	5 92
	3	5 84	5 80	5 85	5 75	5 68
2	1	5 79	5 97	5.98	5 89	5 69
	2	5 90	5 77	5 92	5 74	5 68
	3	6 10	6 35	6 34	5 91	5 78

TABLE 9

ANALYSIS OF VARIANCE FOR FINENESS MODULUS, MACDOUGALD PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	0.0182	1	0.0182	0.45	7.71	21.2
Mix time	0.1586	4	0.0397	0.99	6.39	16.0
RT	0.1602	4	0.0401	—	—	—
Position	0.0470	2	0.0235	3.13	4.46	8.65
PR	0.2588	2	0.1294	17.25[a]	4.46	8.65
PT	0.1066	8	1.0133	1.77	3.44	6.03
PRT	0.0597	8	0.0075	—	—	—
Total	0.8091	29				

[a]Significant at 1 and 5 percent levels.

TABLE 10

AGGREGATE FINENESS MODULUS, MACDOUGALD WARREN, INC

Replication	Position in Mixer or Discharge Stream	Fineness Modulus for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	4.61	4 78	4 72	5.03	5.09
	2	5 09	5.05	5.09	5.01	4 96
	3	5 22	4 98	5 09	5 17	5 09
2	1	4 76	4 49	4 76	4.99	4 31
	2	5.01	4 85	5 05	5.07	5.17
	3	5 07	4 96	4.78	4.96	5.30
3	1	4 73	4 69	4 68	4 32	4.96
	2	5 00	4 91	4 94	5.15	5.08
	3	5 16	4.81	5 00	5.27	4.97

TABLE 11

ANALYSIS OF VARIANCE FOR FINENESS MODULUS, MACDOUGALD WARREN, INC.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	0.0853	2	0.0427	7.91[a]	4.46	8.65
Mix time	0.1689	4	0.0422	7.81	3.84	7.01
RT	0.0428	8	0.0054	—	—	—
Position	0.9913	2	0.4957	9.80[b]	3.63	6.23
PR	0.0455	4	0.0114	0.23	3.01	4.77
PT	0.0509	8	0.0064	0.13	2.59	3.89
PRT	0.8090	16	0.0506	—	—	—
Total	2.1939	44				

[a]Significant at the 5 percent level.
[b]Significant at the 1 and 5 percent levels (highly significant).

TABLE 12

AGGREGATE FINENESS MODULUS, GEORGIA TECH MIXER

Replication	Position in Mixer or Discharge Stream	Fineness Modulus for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	5 26	5 32	5 33	5.12	5 40
	2	5 39	5.34	5 23	5 25	5.43
	3	5.55	5.16	5.08	5.77	5.11
2	1	5 66	5 55	5.33	5.25	5.35
	2	5.78	5.82	5.30	5.32	5.35
	3	5.57	6.14	5 19	5.26	5.60
3	1	5.74	5.41	5.46	5.56	5.38
	2	5.45	5.38	5.41	5.58	5 39
	3	5.44	5.37	5.50	5 47	5.33

TABLE 13

ANALYSIS OF VARIANCE FOR FINENESS MODULUS, GEORGIA TECH MIXER

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	0.2745	2	0.1373	1 87	4 46	8.65
Mix time	0.3064	4	0.0766	1 04	3.84	7 01
RT	0.5886	8	0 0736	—	—	—
Position	0.0063	2	0.0032	0.09	3.63	6.23
PR	0.0621	4	0 0155	0 45	3 01	4.77
PT	0.1001	8	0.0125	0 37	2.59	3 89
PRT	0.5479	16	0.0342	—	—	—
Total	1.8859	44				

TABLE 14

AGGREGATE FINENESS MODULUS[a], CAMPBELL MATERIALS COMPANY

Replication	Position in Mixer or Discharge Stream	Fineness Modulus for Mixing Time			
		45 Sec	60 Sec	120 Sec	180 Sec
1	1	5.33	5 56	5.51	5.23
	2	5 33	5.64	5.52	5.18
	3	5 64	5.71	5.50	5.25
2	1	5 10	—	5.29	—
	2	5.21	—	5.28	—
	3	5.33	—	5.28	—

[a]Incomplete experiment.

TABLE 15

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH FOR WRIGHT PAVING JOB

Replication	Position in Mixer or Discharge Stream	Strength (psi) for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	3,360	3,900	2,460	4,520	3,290
	2	3,310	3,530	2,460	5,010	3,290
	3	2,420	3,690	3,290	4,270	3,400
2	1	3,100	2,840	2,870	2,830	2,910
	2	3,240	2,790	3,160	2,740	3,000
	3	2,840	2,960	3,010	2,240	3,080

TABLE 16

ANALYSIS OF VARIANCE FOR COMPRESSIVE STRENGTHS FOR WRIGHT PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	24,596 033	1	24,596 033	2 0216	7 71	21 2
Mixing time	17,968 797	4	4,492 199	0.3692	6 39	16.0
RT	48,667.467	4	12,166.866	—	—	—
Position	915.267	2	457.6335	0 6328	4.46	8 65
PR	56.867	2	28.4335	0 0393	4.46	8.65
PT	11,449 403	8	1,431 175	1 9791	3 44	6.03
PRT	5,785 133	8	723 142	—	—	—
Total	109,438 967	29				

TABLE 17

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH FOR MACDOUGALD PAVING JOB

Replication	Position in Mixer or Discharge Stream	Strength (psi) for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	4,030	5,390	4,120	2,780	3,340
	2	5,170	5,450	4,260	1,900	3,580
	3	3,330	5,550	4,140	3,140	3,530
2	1	3,000	4,040	4,650	4,420	4,760
	2	2,730	4,200	4,530	4,870	4,630
	3	3,050	3,940	3,980	4,640	4,430

TABLE 18

ANALYSIS OF VARIANCE FOR COMPRESSIVE STRENGTHS FOR MACDOUGALD PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0\ 05}$	$F_{0\ 01}$
Replication	1,555 203	1	1,555.203	0.0467	7 71	21 2
Mixing time	59,299 2	4	14,824 8	0 4450	6 39	16.0
RT	133,253 47	4	33,313 37	—	—	—
Position	1,264 07	2	632 04	0.2467	4 46	8 65
PR	391 4	2	195 7	0 0764	4 46	8 65
PT	8,860 6	8	1,107 57	0 4324	3 44	6 03
PRT	20,493.93	8	2,561 7	—	—	—
Total	225,117 87	29				

TABLE 19

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH OF CLASS "A" CONCRETE FOR MACDOUGALD WARREN, INC.

Replication	Position in Mixer or Discharge Stream	Strength (psi) for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	5,850	5,210	6,230	5,180	4,730
	2	4,210	4,980	5,210	4,720	3,980
	3	2,650	4,360	3,880	3,890	4,330
2	1	5,420	5,050	5,040	3,830	3,570
	2	5,110	5,370	4,880	3,300	2,810
	3	3,230	4,220	3,760	3,600	3,000
3	1	5,390	6,170	3,220	3,750	3,270
	2	4,380	4,650	3,040	3,290	3,390
	3	2,190	3,250	3,220	2,560	3,000

TABLE 20

ANALYSIS OF VARIANCE FOR COMPRESSIVE STRENGTHS FOR MACDOUGALD WARREN, INC

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	71,448	2	35,724	5 28[a]	4 46	8 65
Mix time	83,942	4	20,986	3 10	3 84	7 01
RT	54,106	8	6,763	—	—	—
Position	145,230	2	72,615	12 23[b]	3 63	6 23
PR	6,061	4	1,515	0 25	3 01	4 77
PT	57,222	8	7,153	1 20	2 59	3 89
PRT	94,969	16	5,936	—	—	—
Total	512,978	44				

[a]Significant at the 5 percent level.
[b]Significant at the 1 and 5 percent levels (highly significant).

TABLE 21

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH OF CLASS "A" CONCRETE FOR GEORGIA TECH MIXER

Replication	Position in Mixer or Discharge Stream	Strength (psi) for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	3,630	2,820	3,420	3,410	3,870
	2	3,240	2,730	2,910	2,770	3,560
	3	3,430	2,820	3,000	2,820	3,330
2	1	2,810	3,230	3,310	2,580	3,470
	2	2,870	3,400	2,860	2,730	3,270
	3	3,760	2,060	3,220	2,640	3,470
3	1	3,110	3,750	2,800	3,270	3,310
	2	2,740	3,530	2,060	3,360	3,090
	3	3,450	3,520	3,280	2,090	3,170

TABLE 22

ANALYSIS OF VARIANCE FOR COMPRESSIVE STRENGTH FOR GEORGIA TECH MIXER

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	1,458 179	2	729 0895	0 2951	4 46	8 65
Mix time	15,867 912	4	3,966 978	1 6055	3 84	7 01
RT	19,767 154	8	2,470 894	—	—	—
Position	4,845 645	2	2,422 823	1 8696	3 63	6 23
PR	1,951 288	4	487 822	0 3764	3 01	4 77
PT	17,295.688	8	2,161 961	1 6683	2 59	3 89
PRT	20,734 046	16	1,295 878	—	—	—
Total	81,919 912	44				

TABLE 23

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH OF CLASS "A" CONCRETE[a] FOR CAMPBELL MATERIALS COMPANY

Replication	Position in Mixer or Discharge Stream	Strength (psi) for Mixing Time			
		45 Sec	60 Sec	120 Sec	180 Sec
1	1	6,540	5,830	4,130	4,010
	2	4,840	4,210	3,820	4,280
	3	4,850	4,030	3,730	4,250
2	1	6,640	—	4,890	—
	2	5,920	—	5,160	—
	3	4,620	—	4,590	—

[a]Incomplete experience.

TABLE 24

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR FROM WRIGHT PAVING JOB

Replication	Position in Mixer or Discharge Stream	Cement Content (g/g Mortar) for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	0 33	0 38	0 37	0.39	0.38
		0 32	0 43	0 38	0 41	0.32
	2	0 38	0 35	0 32	0.34	0 36
		0 39	0.42	0 32	0.41	0 42
	3	0 30	0.37	0.33	0.37	0.41
		0.34	0.37	0.38	0 41	0 40
2	1	0.40	0.38	0 36	0.40	0.36
		0.41	0.38	0.41	0.35	0.37
	2	0.35	0.39	0.38	0 38	0 41
		0.39	0.41	0 34	0 41	0 38
	3	0.39	0.40	0 40	0.39	0.40
		0 38	0.38	0.35	0 37	0 40

TABLE 25

ANALYSIS OF VARIANCE FOR CEMENT CONTENT OF MORTAR SAMPLES FROM WRIGHT PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	0 0014	1	0 0014	2 33	7 71	21 2
Mix time	0 0042	4	0 00105	1.75	6 39	16 0
RT	0.0024	4	0 0006	—	—	—
Position	0 0000	2	0.0000	0.00	4 46	8 65
PR	0.0001	2	0 00005	0 11	4 46	8.65
PT	0.0043	8	0.0005375	1 23	3 44	6 03
PRT	0.0035	8	0.0004375	—	—	—
Total	0.0159	29				

TABLE 26

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR FROM MACDOUGALD PAVING JOB

Replication	Position in Mixer or Discharge Stream	Cement Content (g/g Mortar) for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	0.16	0 18	0 18	0 22	0.17
		0.16	0 16	0.24	0.19	0.20
	2	0.19	0 14	0.19	0.20	0.20
		0.21	0.19	0.20	0.23	0.19
	3	0 21	0.18	0.18	0.22	0.20
		0 19	0 14	0.23	0 23	0 19
2	1	0 21	0 14	0 18	0 18	0 19
		0 22	0.10	0.17	0.21	0.18
	2	0.20	0.17	0 15	0 20	0.17
		0.19	0.18	0.17	0.21	0.20
	3	0 22	0 18	0 17	0.21	0 21
		0 17	0 19	0.19	0.18	0.17

TABLE 27

ANALYSIS OF VARIANCE FOR CEMENT CONTENT OF MORTAR SAMPLES FROM MACDOUGALD PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	0.00066	1	0.00066	1.97	7 71	21.2
Mix time	0.00586	4	0.00142	4.24	6.39	16.0
RT	0.00134	4	0.000335	—	—	—
Position	0.00061	2	0.000305	0.84	4.46	8.65
PR	0.00000	2	0.00000	0.00	4.46	8.65
PT	0.00076	8	0.000095	0.26	3.44	6.03
PRT	0.00290	8	0.0003625	—	—	—
Total	0.01195	29				

TABLE 28

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR FROM MACDOUGALD WARREN, INC

Replication	Position in Mixer or Discharge Stream	Cement Content (g/g Mortar) for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	0.22	0.20	0.32	0.27	0 32
		0.22	0.22	0 36	0.33	0.30
	2	0.12	0.28	0.20	0.26	0.23
		0.22	0.21	0.23	0.29	0.29
	3	0.16	0.20	0.18	0.25	0.20
		0.18	0.21	0.26	0.18	0 28
2	1	0.35	0.33	0.25	0.21	0 21
		0.33	0.33	0.23	0.24	0.28
	2	0.27	0.21	0.25	0.21	0.21
		0.32	0 30	0.29	0.25	0.25
	3	0.24	0.19	0.19	0.18	0.14
		0.32	0.31	0.21	0.23	0.21
3	1	0.35	0.43	0.29	0.32	0.27
		0.34	0.36	0 32	0.32	0.13
	2	0.18	0.16	0.20	0.23	0.15
		0.25	0.19	0.24	0.20	0.20
	3	0.20	0.21	0.22	0.23	0.22
		0.20	0.24	0.28	0.18	0.23

TABLE 29

ANALYSIS OF VARIANCE FOR CEMENT CONTENT OF MORTAR SAMPLES FROM MACDOUGALD WARREN, INC.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	0.0013	2	0.000650	0.14	4.46	8.65
Mix time	0.0033	4	0.000825	0.18	3.84	7.01
RT	0.0367	8	0.004587	—	—	—
Position	0.0435	2	0.02175	14.69[a]	3.63	6.23
PR	0.0128	4	0.0032	2.16	3.01	4.77
PT	0.0049	8	0.000612	0.41	2.59	3.89
PRT	0.0237	16	0.001481	—	—	—
Total	0.1262	44				

[a]Significant at the 1 and 5 percent levels (highly significant).

TABLE 30

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR FROM GEORGIA TECH MIXER

Replication	Position in Mixer or Discharge Stream	Cement Content (g/g Mortar) for Mixing Time				
		30 Sec	45 Sec	60 Sec	120 Sec	180 Sec
1	1	0 21	0 22	0 19	0 23	0 23
		0 19	0 21	0 26	0 21	0.21
	2	0.18	0 25	0.22	0 19	0.19
		0.22	0 23	0 23	0.20	0 20
	3	0 21	0 18	0 16	0 24	0.22
		0 22	0 23	0.19	0 23	0 22
2	1	0 19	0.16	0 17	0 18	0 19
		0 18	0 20	0 19	0 21	0 21
	2	0 16	0 20	0 17	0 20	0.20
		0 18	0 17	0 17	0 19	0 17
	3	0 20	0 18	0 16	0 18	0.20
		0 17	0.18	0.18	0 18	0 20
3	1	0 20	0 19	0.20	0.21	0 22
		0.23	0 21	0 16	0 20	0 19
	2	0.23	0 20	0 17	0 19	0 22
		0 18	0 19	0 17	0 21	0 15
	3	0 20	0.19	0 18	0 19	0.17
		0 18	0 21	0 21	0 19	0 22

TABLE 31

ANALYSIS OF VARIANCE FOR CEMENT CONTENT OF MORTAR SAMPLES FROM GEORGIA TECH MIXER

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests	
					$F_{0.05}$	$F_{0.01}$
Replication	0.00569	2	0.002845	7.7701[a]	7 71	21.2
Mix time	0 00109	4	0 0002725	2 5057	6 39	16.0
RT	0 00087	8	0 00010875	—	—	—
Position	0 00245	2	0.001225	12.97[b]	4.46	8.65
PR	0 00007	4	0.0000775	0 18538	4 46	8 65
PT	0 00124	8	0 000155	1 6419	3.44	6 03
PRT	0 00151	16	0 0000944	—	—	—
Total	0.01292					

[a]Significant at the 5 percent level.
[b]Significant at the 1 and 5 percent levels (highly significant).

TABLE 32

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR FROM CAMPBELL MATERIALS COMPANY[a]

Replication	Position in Mixer or Discharge Stream	Cement Content (g/g Mortar) for Mixing Time			
		45 Sec	60 Sec	120 Sec	180 Sec
1	1	0 27	0 32	0.25	0 30
		0 32	0 31	0.29	0 24
	2	0 21	0 27	0.28	0.28
		0 17	0 27	0.33	0.27
	3	—	0 29	0.23	0 24
		0 23	0 21	0 29	0 25
2	1	0 31	—	0 26	—
		0 31	—	0 27	—
	2	0 24	—	0 26	—
		0 34	—	0 26	—
	3	0 25	—	0 26	—
		0 32	—	0 28	—

[a]Incomplete experiment.

Appendix B

CONCRETE MIXER SPECIFICATIONS

Figure 13. Specifications of mixers for Wright Contracting Company and MacDougald Construction Company.

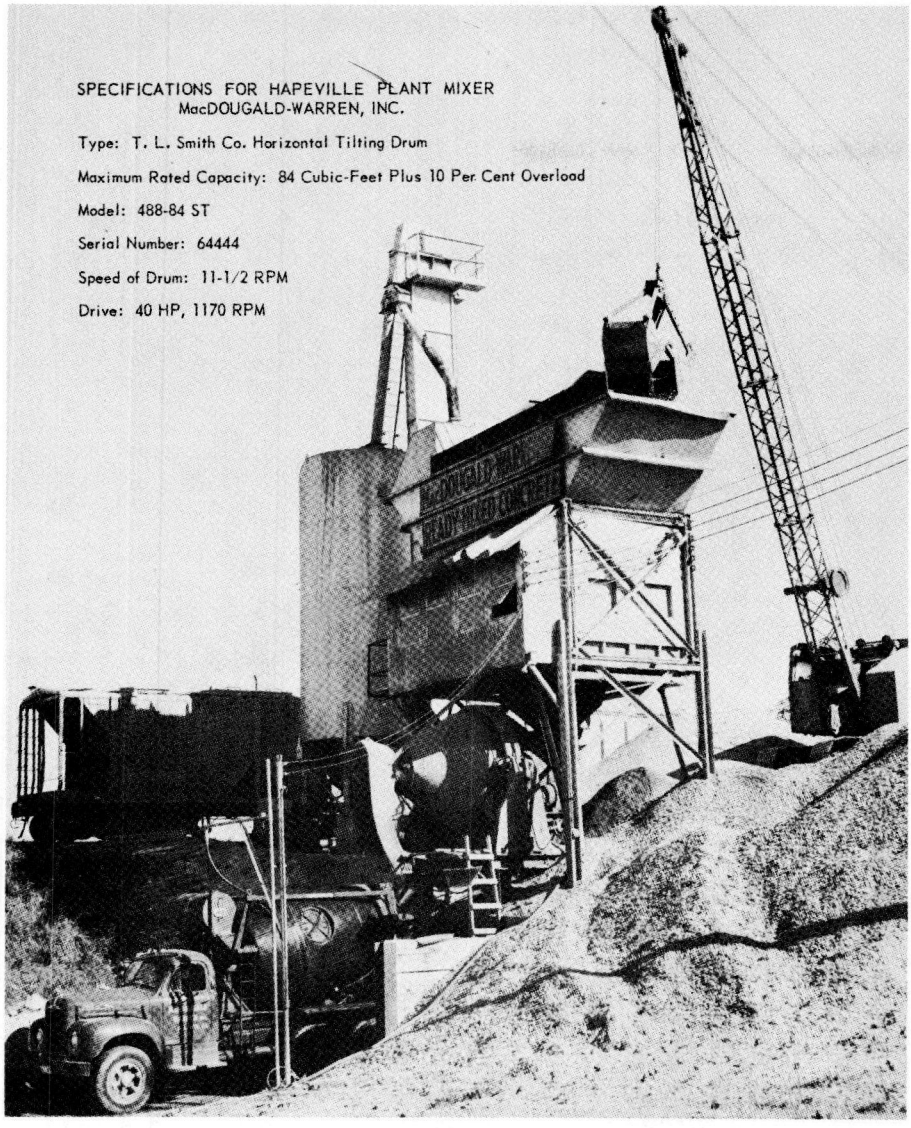

Figure 14. Specifications for Hapeville Plant mixer, MacDougald Warren, Inc.

SPECIFICATIONS FOR GEORGIA TECH LABORATORY MIXER

Type: Worthington

Maximum Rated Capacity: 6 Cubic-Feet Pulus 10% Overload

Model: 6S–2A

Serial No.: W59644

Speed of Drum: 18 RPM

Drive: 16 HP, 1750 RPM

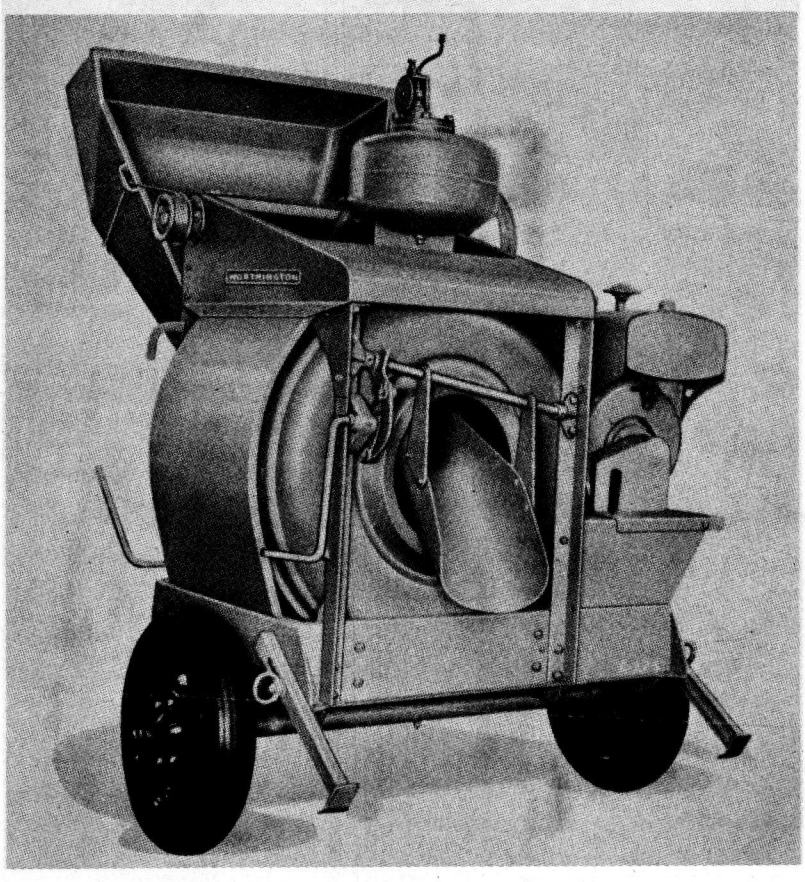

Figure 15. Georgia Tech's concrete laboratory mixer.

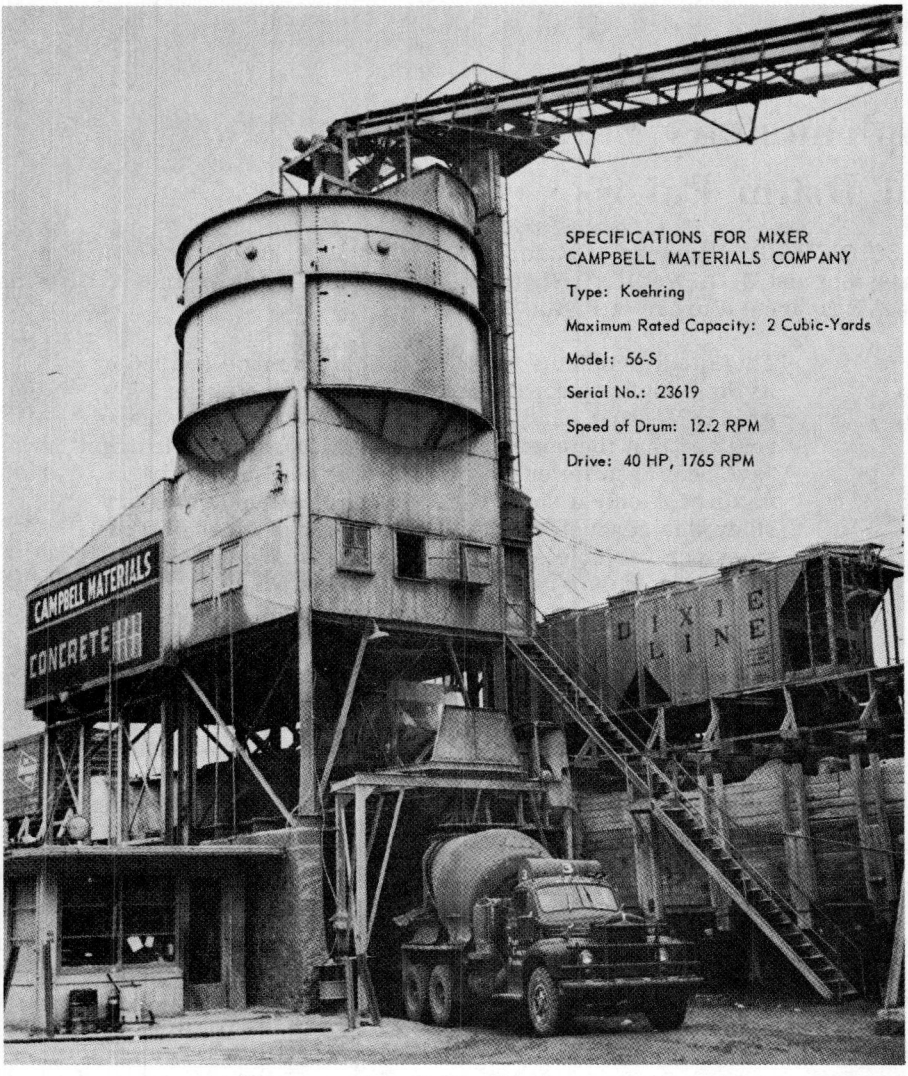

Figure 16. Specifications for mixer, Campbell Materials Company.

Appendix C

EXAMPLE CALCULATION FOR DETERMINING CEMENT CONTENT OF MORTAR SAMPLES

Sample Number	Indium Foil Data					Mortar Sample Data						
	Foil Count		True Count (N_t)	Foil Weight (mg)	N_t per 20 mg	Sample Count Channels 62-74	Sample Count for N_t = 300	Sample Weight (g)	Container Weight (g)	Net Sample Weight (g)	Weight Cement[a] (g)	Cement Content (g cement per g mortar)
	Per 5 Min	Per Sec										
334	77,039	257	299	201	298	1,301	1,310	5.18	0.94	4.24	1.14	0.27

[a]See Figure 12.