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GURI DAM MASS CONCRETE STUDIES

BY
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FINAL REPORT TO
HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

DECEMBER 1976

STRUCTURAL MATERIALS LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

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GURI DAM MASS CONCRETE STUDIES

INTRODUCTION

Guri Dam, a concrete gravity dam on the Caroni River in Venezuela, is being constructed in stages. For the first stage, completed in 1968, the cement for the concrete was Vencemos Type II cement, produced at Pertigalete. Consideration was given to using Guayana Type IS cement for the second stage concrete, to consist of a 50-50 mixture of Type I cement from Pertigalete and a slag cement produced from steel mill wastes at Porto Ordaz. This report summarizes the results of studies undertaken at the University of California of the engineering properties of mass concretes utilizing these two different cements to check the compatibility of adjacent concretes from Stage I and Stage II.

The properties that have been studied included:

Strength
Elastic modulus
Poisson's ratio
Bleeding
Creep
Adiabatic temperature rise
Specific heat
Diffusivity
Coefficient of thermal expansion

Two progress reports have been submitted during the course of these studies. Progress Report No. 1, dated October 1974, covered the properties of concrete made with Guayana Type IS slag cement, and summarized minimum program of tests for checking the investigations being initiated at the Institute of Materials and Models of Central University of Venezuela at Caracas. Progress Report No. 2, dated June 1975, discussed tests of mass concrete made with Vencemos Type II cement. This final report combines material contained in the two progress reports with results of creep studies completed since the submittal of those reports.

MATERIALS

Cement

Two types of cement were used in these studies, corresponding to the types used in Phase I construction, and considered for Phase II construction. For Phase I, the cement was a Type IS slag cement called Guayana Cement blended at the C.A. Venezolana de Cementis plant at Puerta La Cruz from Type I Portland cement produced at Pertigalete with ground granulated slag produced as the waste product of the steel mill at Porto Ordaz, all in Venezuela. Table 1 shows the properties of this slag cement, as determined by the producer.

The cement considered for Phase II concrete was Vencemos Type II cement, a modified cement, produced at Pertigalete, Venezuela. Table 2 shows properties of the cement as used in these tests, together with typical properties reported in Harza Engineering Company Final Concrete Report No. 4. The cement analysis labeled UCB in Table 2 was performed at the laboratories of Kaiser Cement and Gypsum Corporation, Permanente, California, and shows that while the cement used in our tests was higher in C_3S and C_4AF, and lower in C_2S and C_3A than the cement referred to in the Guri final report, they are all in the range of Type II cements and should have somewhat similar heat and strength properties. The alkali content of the cement, expressed in terms of equivalent amount of Na_2O, was only 0.23 and thus this cement would be classified as a low-alkali cement. A low-alkali content cement is beneficial in minimizing any potential expansion of concrete due to the alkali-aggregate reaction.

Although the chemical composition of the Vencemos cement would be considered to be excellent for a Type II cement which is to be used for a mass concrete, its Blaine specific surface of 2950 cm^2/g is relatively low compared to the fineness of a typical Type II cement used for mass concrete in the United States, whose Blaine fineness would be about 3600. As shown later in this report the fineness of the cement has a significant influence on strength, especially during the first few weeks of hydration. The lower the fineness, the lower the strength. Also a coarse cement will produce concretes having higher bleeding characteristics than when using a finer cement.

Aggregate

The aggregate was received in five sizes, as follows: sand, 3/16 to 3/4 in., 3/4 to 1 1/2 in., 1 1/2 to 3 in., and 3 to 6 in. This aggregate was a crushed granitic gneiss from a quarry adjacent to Guri Dam, with some additions of river sand which was blended with the crushed sand at the aggregate plant. The aggregate, which was received dirty, was washed and rescreened before use in the laboratory mixes, corresponding to the treatment at the mixing plant at the job. Gradation and physical properties of the aggregate are given in Table 3.

Water and Admixtures

The mixing water used was regular laboratory tap water. Since the concrete for Guri dam is mixed using the rather colorful Caroni River water, a separate series of tests was carried out at the Guri Dam concrete laboratory comparing strengths of concrete made with river water and concrete made with distilled water. No significant difference in strengths was found at early age, but from age of 28-days on, the concrete made with distilled water was slightly stronger than that made with river water.

The water-reducing and retarding admixture used was PDA-25R Dual Purpose Water Reducing Admixture, manufactured by Protex Industries, Venezuela. The air-entraining admixture was Aerocrete. Both admixtures were taken directly from the supply at Guri Dam.

Concrete Mix Proportions

The basic concrete mix (Job Mix GWA-6) is shown on Table 4, all values being in terms of saturated surface-dry condition. This basic mix produced concrete with an air content averaging 5.5 percent, and a slump of about 2 inches as measured on 1 1/2 in. MSA wet-screened concrete. This mix exhibited an excessive amount of bleeding in comparison with other mass concrete mixes evaluated in the past in our laboratory.

The basic mix was used in the adiabatic temperature rise tests exactly as shown in Table 4. For the bleeding tests and comparative strength tests we chose, instead of wet-screening the full mass mix, to exclude all aggregates larger than 1 1/2 in. MSA from the mix, retaining the same proportions of all other materials. While this procedure is not exactly the same as wet-screening, it produces comparable results without the necessity of handling and rehandling large amounts of unused (and scarce) materials.

One other modification should be made to the concrete mix when used on the job. An air content of 6 percent determined on 1 1/2-in. MSA concrete wet-screened from 6-in. MSA concrete does not mean that there is 6 percent air in the full mass mix, because the air is mainly associated with the mortar. The true air content for the 6-in. MSA mix is about two-thirds that of the 1 1/2-in. MSA wet-screened concrete, or 4 percent. All material quantities therefore should be increased proportinately as shown in Table 4 in order to obtain full yield in the field.

Batching and Mixing

All batching was by weight except for the admixtures which were batched by volume. Except for the adiabatic temperature rise tests and two of the bleeding tests, all ingredients were batched and mixed at room temperature. Desired lower initial temperatures for the adiabatic temperature rise tests were obtained by storing materials at low temperature, and lowering the temperature of the mixing room. For the lower concrete temperature bleeding tests the materials were cooled prior to mixing, but the bleeding test was performed in a room controlled at 73 ± 3°F.

Concrete for the full mass mixes was mixed in a one-fifth cubic yard Essick Model 93 drum-type tilting mixer. Concrete for the 1 1/2 in. MSA mixes was mixed in a two cubic foot Lancaster No. 17-BX counter-current pan mixer.

Mixing time for the full mass mix was 4 1/2 minutes, with the 3 to 6 in. cobbles added to the concrete three minutes after start of mixing. Mixing cycle used for the 1 1/2 in. MSA mixes was that given in ASTM C192 which consists of an initial mixing for 3 minutes, followed by 3 minutes rest, followed by 2 minutes of final mixing.

Properties of the fresh concrete for the full mass mix are summarized on Table 5. Slump and air content were determined on concrete wet-screened to pass a 1 1/2 in sieve. Concrete had a slump of 2 ± 1/2 in. and an air content of 4.5 ± 0.8 percent. The unit weight of the full mass mix averaged 144 pcf. The water-cement ratio was 0.71. It was noted that there was considerable bleeding of the specimens as cast, amounting to about one percent by volume during a period of 90 minutes.

ADIABATIC TEMPERATURE RISE

Adiabatic temperature rise in concrete is the quantitative measurement of the total amount of heat generated by the hydrating cement in a particular concrete mixture, by periodically determining the temperature of the concrete specimen stored in a condition where no heat is lost. Four tests have now been completed using two cements and four initial temperatures, as follows:

Test	Cement Type	Initial Temp. °F
1	IS	68
2	IS	54
3	II	47
4	II	67

Hourly temperatures of these four tests up to age 24 hours are given in Table 6, and daily temperatures to age 28-days are given in Table 7.

Two figures have been prepared to show the details of the adiabatic temperature rise histories. Fig. 1 shows on an enlarged scale the first sixty hours of hydration. The inhibiting effect of low initial temperature on heat generation is shown clearly. All four mixes show an immediate rise of about 1°F during the first hour after mixing. It is believed this represents heat transfer from the cool paste to the warmer aggregates, the thermometer naturally measuring paste temperature. Thus it is believed the true initial temperature is 1°F above the first measurements, and the true temperature is the t_0 reported. Also, the retarder plus the low initial temperature appears to inhibit hydration for a period of from 6 to 9 hours after mixing, as shown by the flat initial slope of all the curves. It can also be seen that the lower the initial temperature, the longer it takes to reach maximum rate of hydration.

On Fig. 2, the total 28-day record of the four tests has been plotted. In addition to the effect of initial temperature, significant differences can be seen between the rates of hydration of concretes made with Type IS slag cement and Type II modified cement. For every 10°F that the initial temperature of Type II concrete is lowered, the temperature at 14 days is lowered 3.0°F, and the temperature at 28-days is lowered 3.1°F. For Type IS concrete, lowering the initial temperature by 10°F lowers the temperature at 14 days by 3.5°F, and at 28-days by 2.1°F. By studying the slope of these four curves, it can be seen that the slope is greater after 7 days for the slag-cement concretes. This indicates that the slag portion of the cement starts to hydrate at this age, increasing heat and strength, as will be shown later.

STRENGTH AND ELASTIC PROPERTIES OF CONCRETE

Tests Using Guayana Type IS Cement

Three 18 by 36 in. cylinders containing Guayana Type IS cement and made of the 6 in. MSA mass concrete mix GWA-6 were cast for determining the compressive strength, elastic modulus and Poisson's ratio of the mass concrete at the age of 28 days. These cylinders were cast in sheet metal molds, and covered after casting with moist sand and a pliofilm moisture barrier, thus approximating the curing conditions of the mass concrete in Guri dam. Immediately prior to testing, each cylinder was stripped and wrapped with Saran to prevent moisture loss during handling and testing, and then bonded to the 4,000,000 lb. testing machine with Hydrostone. Loading rate was 35 psi per second. Deformations under load were measured on a compressometer attached externally to the cylinders, for three cycles of load to about 40 percent of the estimated compressive strength. The transducers were linearly variable differential transformers transmitting to an XYY' recorder. Immediately after the elastic tests, the compressometer was removed and the cylinder was loaded to failure. At 28 days age, as shown on Table 8, the compressive strength averaged 2040 psi, elastic modulus was 4.4×10^6 psi, and Poisson's ratio was 0.15, excluding values that differed from the average by more than ten percent.

A number of 6 by 12 in. cylinders wet-screened to 1 1/2 in. MSA concrete were cast whenever there was opportunity, and tested in compression in groups of three at various ages from 2 to 90 days, with results shown in Table 9, and on Fig. 3. It can be seen that the concrete strength is quite low at early age, a fact that should be borne in mind if there is need for speed in concrete placement in the dam.

The average strength of the mass concrete shown by the 18 by 36 in. cylinder tests is slightly more than the average of all the 6 by 12 in.

cylinders tested here, a rather unusual situation, since normally the full mass mix has a strength about 85 percent of the wet-screened mix.

It is interesting to note that the modulus of elasticity of the mass concrete is about twice that predicted by the ACI equation for a 2000 psi concrete. It is quite evident that in mass concrete the large aggregate has a dominant role in the elastic modulus of the concrete, rather than the cement paste.

Strength and Elastic Properties of Aggregate

In an endeavor to explain the high elasticity of this essentially low-strength concrete, four 2 by 4 inch cores were cut from large aggregate particles, fitted with SR-4 strain gages, and tested in compression for strength and elasticity, with results as shown on Table 7. While there is some variation in the results of the individual tests, reflecting the variation in mineralization of the individual aggregate particles, the average strength is over 22 ksi, the elastic modulus is 11.5 x 10^6 psi, and Poisson's ratio averages 0.27. It can be seen that the aggregate is quite strong, in fact has strength and elastic properties like some metals.

Tests Using Vencemos Type II Cement

The basic mix used in the laboratory was Job Mix GWA-6, which was designed to produce a strength of 2000 psi (140 kg/cm^2) at 28 days. In the Harza Engineering Company Final Concrete Report No. 4, tests of 3836 28-day cylinders gave an average strength of 179 kg/cm^2 (2509 psi), or about 25 percent over requirements. It was thus a disappointment, to say the least, when tests in the Materials Laboratory in Venezuela Central University (IMME) indicated mass concrete strengths of 115 kg/cm^2 (1619 psi) at 28-days for concrete made of Type II cement. The 6 x 12 in. cylinders gave the same average strength as the 18 x 36 in. cylinders.

While we did not test any 18 x 36 in. mass concrete cylinders containing the full mix using Vencemos Type II cement in this phase of our work, we did test a number of 6 x 12 in. 1 1/2 in. MSA wet-screened concrete cylinders for strength. It will be recalled by referring to Fig. 3 that the average strength of 6 x 12 in. cylinders corresponds closely to the strength of the 18 x 36 in. cylinders. Hence we chose to work with the smaller cylinders, to use as little material as possible.

The water-cement ratio for Mix No. GWA-6 corrected to SSD conditions is 0.73. Five separate batches of concrete made with a water-cement ratio of 0.73 gave an average compressive strength of 1720 psi (122 kg/cm^2), slightly higher than the IMME tests, but about two-thirds the strength of the field tests. It was at this point that we started to check the Vencemos Type II cement that we had received.

Tests of Vencemos Type II Cement

The first test was the chemical analysis of the cement, with the results mentioned earlier, and shown on Table 2. There were slight differences in the quantities of the oxides, leading to differences of a few percentage points in the various compounds of the composition of the cement. These small differences, however, do not account for the large difference in strength of the field and laboratory concrete mixes.

We then checked in three ways to see if the cement had partially hydrated prior to its use. The crudest test was an inspection to see if there was an excess of lumps of partially-hydrated cement. The cement appeared normal. Next we checked loss on ignition since high loss would indicate cement hydration. The new value obtained checked the value reported in 1968. Finally, we performed an X-ray diffraction analysis, comparing the Vencemos Type II cement with another Type II cement we had in stock. We could find no significant differences in the compounds of the two cements. Thus all three tests supported the finding of no partial hydration of the cement.

Strength of Mortars

Next a series of strength tests on 2 in. mortar cubes (ASTM C109) was undertaken, to check out the strength of the cement itself, without the added complication of the Guri aggregate. In this evaluation of the strength-development potential of the cement, the Type II cement was tested in its as-received condition (Blaine of 3110 cm^2/g)* and after grinding to a higher fineness of 3700 and 4200 cm^2/g. Also evaluated was the effect of a 30 percent by volume replacement of the cement with slag. The strength results obtained for ages of 3, 7 and 28 days are given in Table 11. For comparison, we used the records of seven U.S. Type II cements tested recently in the University of California concrete laboratory, as shown on Table 11 and Fig. 4.

At all ages, Guri Type II cement had about two-thirds the strength of the average U.S. Type II cement tested in our laboratory. It should also be noted that the Guri Type II cement was much coarser than the U.S. cements. By grinding to a Blaine fineness of 3700 cm^2/g, the 28-day strength was increased by thirty percent to a value comparable with the weakest of the laboratory cements. Grinding further to a Blaine fineness of 4200 cm^2/g increased the strength another nine percent, which might be an uneconomical increment.

We then checked to see if slag had a significant effect on strength when combined 30/70 by volume with Vencemos Type II cement. While slag reduced the strength at early age, it increased the 28-day strength of the cement as received by 13 percent, and when combined with the Type II cement reground to a fineness of 3700, the strength was increased by 18

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* Determined at UCB on portion of cement used for regrinding.

percent. As shown on Fig. 4, the rate of strength gain of slag cement indicates still higher strengths at age 90 days. Clearly, a number of options are available for increasing the strength of Vencemos Type II cement as presently produced.

Design of 2400-psi Concrete Mix

Finally, after a number of trial mixes to determine the effect of water-cement ratio on the strength of concrete containing Vencemos Type II cement, a new mix was designed to give the required strength using the same amount of water as in field mix GWA-6. This mix is shown on Table 12 as Mix A, together with a modified mix, Mix B, in which 30 percent of the Type II cement is replaced with an equivalent volume of slag. Two 6 x 12 in. cylinders made from this Mix A, using only the 1 1/2 in. MSA portion, gave an average strength of 2430 psi.

BLEEDING

Introduction

Guri concrete, whether mixed in the laboratory or in the field, is characterized by the appearance of copious quantities of water on top of the concrete when placed, or even in the transporting buckets. This phenomenon is termed "bleeding," which has been defined as the emergence of mixing water from newly-placed concrete caused by the settlement of the solid materials within the mass. While bleeding--or "water gain" as it is sometimes termed--is characterized by the appearance of water at the top of the mass, the process involved is actually settlement, as the heavier aggregate, sand, and cement particles settle downward under the force of gravity and displace the lighter water which has a tendency to rise to the surface. It is generally understood that bleeding is increased by increases in the amount of mixing water, by an undersanded or an oversanded mix, by excess angularity of the aggregate particles, and by the use of materials that are coarser than average. A number of these factors were seen to be present in the Guri mix, and tests were performed to show the effects on bleeding of changing these conditions.

Bleeding Test

The test for bleeding follows ASTM C 232. A half-cubic-foot container is nearly filled with the test sample, and the free water which rises to the surface is removed periodically and its volume measured cumulatively. Bleeding is determined as the percentage of water removed with respect to the total water originally in the sample.

Since measures taken to change bleeding characteristics also affect a number of other properties of concrete, each batch of 1 1/2 in. MSA concrete tested was made large enough to include tests for initial temperature, slump, air content, unit weight, and 28-day compressive strength of a pair of 6 x 12 in. cylinders. Altogether, 24 batches were made and tested. These break down into a group of control mixes, in general one control mix for each new series tested, and six groups of tests evaluating the effect of slump, sand content, sand fineness, cement fineness, mixing temperature, and combinations of the above.

Table 13 summarizes the actual batch weights of each batch tested, and Table 14 summarizes the properties of each batch.

Bleeding of Controls

The control group was tested to determine as nearly as possible the bleeding characteristics of mix GWA-6, the production concrete used in the dam, with the material above 1 1/2 in. MSA removed. Since the slump measured at Guri averaged 2 1/2 in., laboratory slump was set at 3 in. to allow for cement paste that would have adhered to the wet-screened material.

Mixes E1A, E1B, and E1D constitute the control group, with average slump of just over 3 in. and air content of 5.4 percent. As shown on Fig. 5, the control mix bled rapidly for just over an hour, to a total average volume of 8.5 percent for these three controls. As shown by Mix E1C, increasing slump to 4.5 in. by increasing the air content to 8.2 percent increased bleeding to over 14 percent, and prolonged bleeding time to almost three hours. However, as shown by Mix E1, in which air content was increased to 15 percent, increasing slump to 5 1/2 in., reduced the bleeding somewhat to 10.7 percent, which still is higher than control.

Conclusion: Reduced slump will reduce bleeding.

Effect of Sand Content and Grading

The effects on bleeding of variations in sand content and grading are shown on Fig. 6. The percentage of sand to total aggregate in GWA-6 is 25.7 percent, with bleeding of 8.5 percent. When the sand content was increased to 30.7 percent in Mix E3, bleeding reduced to just under 7 percent, but at the expense of an oversanded mix. In Mix E6, which had a sand content of 27.7 percent, gap grading was used to replace all of the aggregate smaller than 3/8 in. with an equal weight of 3/4 - 1 1/2 in. aggregate. While there was some difference in detail, the end result was the same bleeding as the control, 8.5 percent. However, as shown by Mixes E5A and E5B, increasing the fineness of the sand reduced both the bleeding rate and amount. Changes in fineness were made by adding small quantities of a local fine river sand to give F.M. = 2.43 for Mix E5A, which had a bleeding of 6 percent and F.M. = 2.22 for Mix E5B, which had a bleeding of 6.5 percent.

Conclusion: Moderately increasing fineness of sand reduces bleeding more than increasing sand content.

Effect of Water Content and Temperature

Fig. 7 shows the effects on bleeding of two variables that are easily controlled at the mixing plant. Mix E2B has a lower water content than GWA-6, and a slump of 1 5/8 in., about half that of the control mix. While bleeding rate is much lower than the control, the final bleeding volume shows no reduction over that of the control. Mix E7A shows that a reduction of the initial temperature of the concrete from the normal 71°F to 51.5°F increased bleeding quantity to 10.5 percent.

Conclusion: Extra care will be needed to control bleeding in precooled concrete.

Effect of Fineness of Cement

The effect of fineness of cement on bleeding was the next property tested, as shown on Fig. 8. The control mix used Vencemos Type II cement, with a specific surface of 3110 cm^2/gm. Table 10 shows the specific gravity and fineness of the cements and of the pozzolanic materials used as partial replacement of the cement to increase its fineness. All additions replaced 30 percent of the volume of the cement, taking into account the difference in specific gravity of the two materials. In Mix E10, the replacement material was the slag used with the Guayana Type IS cement, which has a specific surface of about 3900 cm^2/g, giving an effective average specific surface of 3350 cm^2/g. This reduced the bleeding by about one percent below that of the control. Next, we tried a locally available pozzolan, "Airox," a very fine calcined shale with a specific surface of 11,550 cm^2/g, which gave an effective surface of 5640 cm^2/g. As shown by E10A, this reduced the rate of bleeding, and the total bleeding to 5.7 percent. Since this pozzolan is not at present available in Venezuela, we tried the effect of regrinding the SIDOR slag to a specific surface of 6940 cm^2/g, and using this as a replacement of 30 percent of the Type II cement, giving an average specific surface of 4260 cm^2/g. This, shown as Mix E11, had an intermediate effect between E10 and E10A, greatly reducing bleeding rate, but having only a minor effect on bleeding quantity. Mixes E15 and E16 were nearly identical in fineness and in bleeding properties. Mix E15 had a Blaine fineness of 3700 using fine ground Type II cement, and Mix E16 had a Blaine fineness of 3750 when 30 percent of fine ground cement was replaced by slag. Both gave intermediate bleeding rates as determined by fineness.

Conclusion: Increasing the fineness of the cement fraction by grinding or by pozzolanic replacement decreases bleeding.

Combined Effect of Fine Sand and Fine Cement

Since it had been shown that bleeding was decreased by increasing the fineness of either the sand or cement, one series of tests was run in which combinations of fine sand and fine cement were used, as shown on Fig. 9. Except for the control mix, the fineness modulus for the sand of all mixes shown was 2.43. Mix E5A, shown also on Fig. 5, used Type II cement with specific surface of 3110 cm^2/g. Mix E12 had a 30 percent replacement of Type II cement with slag, giving an effective fineness of 3350 cm^2/g. Thus small changes in fineness of the cement seems to have an insignificant effect on bleeding. However, when the effective fineness of the cement was increased to 4260 cm^2/g by replacement with fineground slab, bleeding was reduced to 4.3 percent, as shown by Mix E13.

Conclusion: Combinations of effects that reduce bleeding will be needed to bring the bleeding of Guri concrete under control.

Bleeding of Redesigned 2400-psi Mix

It had become apparent that the Vencemos Type II cement sent to us would never give the desired 28-day strength of 2000 psi in the proportions of the GWA-5 mix. Study of all strength data from the twenty bleeding tests showed that a reduction of water-cement ratio from 0.73 to 0.63 should give a strength of 2400 psi at 28-days, which approximates the average strength achieved during construction of the first stage of Guri dam. A new mix was designed to give the required strength with the same workability as before. Practically, this meant using the same amount of water as in Mix GWA-6, and increasing the cement content of 279 lb. The mix design of this concrete is shown as Mix A on Table 12. To decrease bleeding, we further replaced 10 percent of the cement with 30 percent slag (Mix B, Table 12), based on information available at that time showing that the early strength of slag was only one-third that of the cement it replaced. This later proved to be a fact only at very early ages, as discussed in the section on Compressive Strength.

Mix E14, based on Mix Design A, with no pozzolan replacement, was tested for bleeding, as shown on Fig. 10, together with a new control mix E2C. Both gave nearly identical bleeding curves, with bleeding of 10 percent, or 1.5 percent higher than the E1 control series bleeding. This served to show that a slight increase in cement content is nowhere nearly as efficacious in reducing bleeding as increasing the fineness of the cement and sand fractions.

Conclusion: More grinding is needed, at the cement mill and at the sand plant.

Conclusions

It is evident that improvement in strength and bleeding characteristics of Guri concrete can be made easily with minor changes in the characteristics of some of its ingredients.

More cement is needed, and this cement should be more finely ground. Slag, ground to a finer degree than at present, can be mixed with the Type II cement with advantage in strength and in bleeding. The sand fraction should be slightly finer, to a fineness modulus of about 2.43.

In this connection, two items from Harza Final Report No. 4 - Concrete - are cited:

Page 4 - "It was generally necessary to use cement in excess of strength requirements to produce workable mixes. In spite of the excess cement, concrete bleed water was a continuous problem."

Exhibit B-5 - Evidently there has always been a coarse sand and a fine sand available. It is suggested that only the fine sand be used from now on.

THERMAL DIFFUSIVITY

Diffusivity is an index of the facility with which a material will undergo temperature change. Thermal diffusivity was determined on two 9 1/2 by 19 in. cylindrical speciemsn which were cast in thin sheet metal molds at the same time as the adiabatic temperature rise specimens, and utilizing the same concrete except that cobbles greater than 4 1/2 in. were replaced with an equal volume of 3 to 4 1/2 in. aggregate. The sealed specimens were cast at 54°F, cured at 73°F, and tested at age 28 days.

The test procedure consisted of transferring the 100°F specimen into 40°F water in a room maintained at 40°F, and reading the temperature at the center of the specimen at regular time intervals. The specimen was tested without removing the metal mold. Thermal diffusivity for the two specimens was 0.040 and 0.041, averaging 0.041 sq. ft. per hour at an average temperature of 70°F.

SPECIFIC HEAT

The specific heat of concrete is the amount of heat required to raise the temperature of a unit mass of concrete one degree fahrenheit, usually expressed in units of Btu/lb/° F. The test specimen was a hollow cylinder, 16 in. long, 1 1/2 in. inside diameter, 8 in. outside diameter, made of 3 in. MSA concrete cast in a thin sheet copper mold with a brass inner tube, and all sealed by silicon sealer. Two specimens were cast at 54°F, and cured at 73°F for 28 days after which the tests for specific heat were initiated.

A carefully weighed quantity of water is circulated through and around the test specimen in an insulated chamber in which air is circulated. The amount of electricity needed to energize a heater-stirrer in the central chamber of the specimen is measured on a watt-hour meter. Adiabatic conditions are maintained by increasing the heat input to the air in the outer chamber so that air and water temperature are matched. Temperatures are carefully monitored to 0.1°F by means of thermopiles consisting of four thermocouples. The test is normally run for 2 1/2 hours of heater time plus 45 minutes of stirring with the heater shut off to bring specimen and water to the same temperatures. Allowance must be made for heat losses in the insulation. The values of specific heat found in the two specimens were 0.225 and 0.239 , giving an average value of 0.232 Btu/lb/° F.

THERMAL EXPANSION

Coefficient of thermal expansion is the unit length change of an unconfined concrete specimen due to a unit temperature change, usually expressed as microstrains per °F.

Three 12 by 36 in. cylindrical specimens were cast in 24-gage galvanized steel molds for determining the coefficient of thermal expansion. Each specimen was instrumented with two 10-in. Carlson strainmeters on its major axis, and sealed after casting. Similarly to the diffusivity test specimens, cobbles larger than 4 1/2 in. were replaced with an equal volume of 3 to 4 1/2 in. aggregate. The use of this smaller size aggregate eliminated difficulties in placing concrete around the strainmeter.

The specimens were cast and stored at 73°F to the age of 28 days. Two complete cycles of temperature were then run, each cycle consisting of storage at nominal temperatures of 70-110-70-40-70°F. Each storage period lasted about five days, long enough for the internal temperatures to reach equilibrium, as measured on the strainmeter.

The average coefficient of thermal expansion of the mass concrete was 4.3×10^{-6} per °F.

CREEP

Like most materials, concrete deforms when loaded, and the relationship of load and deformation at the low load range is termed the elastic modulus. In addition, if load is maintained on concrete, it continues to deform, at a varying rate depending on its age when initially loaded, and on the duration of the load. This continued deformation is termed creep. It has been found that creep can be defined by a logarithmic equation of the form

$$\varepsilon = \frac{1}{E} + f(K) \log_e (t + 1)$$

where

ε = total deformation, per psi of load

E = elastic modulus

$f(K)$ = creep rate for age of loading

t = time, days

The creep rate must be determined by test for each individual concrete and at a number of different ages of loadings, to establish the variation of f(K) with age of concrete.

In order to study the behavior of mass concrete at the interface between Phase I and Phase II construction, it was necessary to make a comparative study of creep of mass concrete using Guayana Type IS cement against mass concrete using Vencemos Type II cement.

Six 16 by 44 in. cylinders were cast in butyl rubber jackets and sheet metal molds--three using each cement. Each specimen was fitted with three 10-in. Carlson strainmeters, two longitudinal on the axis, and one lateral at mid height of the specimen. One specimen of each set of three was loaded to 300 psi at seven days age, one each was loaded to 600 psi at 28 days, and one each was loaded to 600 psi at 90 days age. All loads are maintained for at least a year.

A typical creep history plotted on a semi-logarithmic scale is shown as Fig. 11. This is the record of the specimen made with Vencemos Type II cement and loaded at age 90 days. The two dashed curves are the individual records from the top and bottom strainmeter and the full line is the average of the two dashed lines. This behavior was found in all six specimens and shows that bleeding in each specimen, and presumably in each lift of concrete, modifies concrete properties with height in each pour.

The six creep curves were analyzed, and yielded the six creep equations shown in Table 16, and sketched on Fig. 12. It can be seen from the drawing that while the curves differ at early age, they are practically duplicates by age 90 days. This means that in view of the slow rate of loading in dam construction, concretes in Phase I and Phase II construction will not differ markedly in their elastic and creep behavior.

CONCLUSIONS

Mass concretes made of Guayana Type IS cement or of Vencemos Type II cement have similar deformation characteristics after 90 days age.

Two modifications are needed in the basic Job Mix GWA-6. Cement content must be increased slightly to get desired strength and all material quantitites must be increased slightly to obtain full yield.

If Vencemos Type II cement is to be used in Phase II of Guri Dam, consideration should be given to finer grinding to increase strength and decrease bleeding.

ACKNOWLEDGEMENTS

The studies of Guri Dam mass concrete reported here extended over a period of three years. In addition to Professors Raphael, Pirtz and Polivka, the Principal Investigators of the project, much credit must be given to James Axley, Charles Mercer, and Anton Pirtz, Research Assistants at the University of California who were responsible for individual parts of the complete investigation.

TABLES

TABLE 1

PROPERTIES OF GUAYANA TYPE IS CEMENT

Brand - Guayana   Type of Cement IS - Slag Cement
Cement Plant - Pertigalete   Blending Plant - Port Ordaz, Venezuela

Chemical Properties

SiO_2	28.02
Al_2O_3	9.12
Fe_2O_3	2.04
CaO	52.69
MgO	5.03
SO_3	1.64
Na_2O	0.20
K_2O	0.23
S	0.35
Loss on Ignition	0.68
Total	100.00
Insoluble Residue	0.94

Physical Properties

Blaine Fineness, cm^2/g	3325
Autoclave Expansion,%	0.008
Setting Time, Vicat Needle	
Initial, min	206
Final, min	288
Compressive Strength, kg/cm^2	
3 days	123
7 days	199
28 days	386
Heat of Hydration, Cal/g	
7 days	59.0
28 days	71.8

TABLE 2

Chemical Analyses of Vencemos Type II Cement

	Mill Certificate No.			UCB *
	1276	1277	1278	Sample
SiO_2	23.94	23.84	23.88	23.44
Fe_2O_3	3.71	3.79	3.79	4.19
Al_2O_3	4.37	4.35	4.25	3.89
CaO	64.53	64.64	64.42	64.00
MgO	0.92	0.80	0.86	0.76
SO_3	1.53	1.67	1.63	1.72
Na_2O				0.14
K_2O				0.13
LOI				1.40
C_3S	41.7	42.5	42.2	45.6
C_2S	37.2	36.3	36.6	32.9
C_3A	5.3	5.1	4.9	3.2
C_4AF	11.3	11.5	11.5	12.7
$CaSO_4$	2.7	2.8	2.8	-
Alkalies as Na_2O	-	-	-	0.23
Blaine Sp. Surf.	2950	3140	3140	2950

* Tested at Permanente Cement Plant, California

TABLE 3

Properties of Aggregates

U. S. Std Sieve Size	Cummulative Precent Retained				
	3-6 in.	1 1/2-3 in.	3/4 - 1 1/2 in.	3/16-3/4 in.	Sand
6 in.	4				
3 in.	95	15			
1 1/2 in.	100	98	7		
3/4 in.	100	100	92	1	
3/8 in.	100	100	100	77	0
No. 4	100	100	100	99	0
No. 8	100	100	100	100	11
No. 16	100	100	100	100	33
No. 30	100	100	100	100	56
No. 50	100	100	100	100	75
No. 100	100	100	100	100	90
Fineness Modulus	-	-	-	-	2.65
Material Passing No. 200 Seive					2.0
Bulk Sp. Gravity	2.75	2.69	2.68	2.68	2.71
Absorption Capacity	0.13	0.21	0.27	0.37	0.42

TABLE 4

CONCRETE MIX DESIGN

Item	GWA-6		Proposed	
	Lbs.	c.f.	Lbs.	c.f.
Cement	242	1.22	250	1.26
Water	165	2.64	169	2.70
Sand	945	5.59	950	5.62
3/4	548	3.26	561	3.34
1 1/2	670	3.98	690	4.11
3	730	4.34	750	4.46
6	745	4.33	766	4.45
TOTAL	4045		4136	
Yield c.f.		25.36		25.94
Computed Air c.f.		1.64		1.06
Computed Air %		6.1		3.9
Density, pcf		149.8		153.2*
w/c		0.68		0.68

*observed also

TABLE 5

PROPERTIES OF FRESH CONCRETE FOR FULL MASS MIX

	Batch 1	Batch 2
W/C by weight	0.76	0.76
Temperature of Concrete, °F		
End of Mixing	68	54
End of Casting	67	55
Slump, in. (1 1/2" MSA)	2 1/2	2 1/4
Air Content,% (1 1/2" MSA)	4.1	5.4
Unit Weight, pcf		
1 1/2" MSA	144	143
6" MSA	156	153

TABLE 6

Adiabatic Temperature Rise - First 24 hours

Time hrs.	Temperature - °F Type IS	Type IS	Type II	Type II
0	66.3	54.6	45.7	65.4
1	66.9	55.4	46.2	66.2
2	67.1	55.7	46.4	66.4
3	67.3	55.9	46.6	66.6
4	67.5	56.0	46.7	66.8
5	67.6	56.2	46.8	67.0
6	67.9	56.4	46.9	67.2
7	68.4	56.6	47.1	67.5
8	68.9	56.7	47.3	67.9
9	69.4	56.8	47.4	68.3
10	70.2	57.1	47.6	68.9
11	70.8	57.4	47.8	69.3
12	71.6	57.7	48.0	70.2
13	72.4	58.0	48.2	71.1
14	73.4	58.4	48.3	72.1
15	74.5	58.6	48.6	73.1
16	75.7	59.0	48.8	74.2
17	76.6	59.5	49.1	75.4
18	77.3	60.0	49.3	76.4
19	77.8	60.5	49.6	77.9
20	78.3	60.9	49.9	79.0
21	78.7	61.5	50.2	80.1
22	79.1	62.2	50.5	81.0
23	79.3	62.9	50.9	81.8
24	79.7	63.7	51.3	82.5

TABLE 7

Adiabatic Temperature Rise - 28 Days

Time days	Temperature - °F			
	Type IS	Type IS	Type II	Type II
0	66.3	54.6	45.7	65.4
1	79.7	63.7	51.3	82.6
2	87.1	70.4	61.4	90.5
3	92.1	74.9	66.1	94.3
4	95.5	78.1	69.0	96.6
5	97.9	80.6	71.4	98.2
6	99.7	82.6	73.0	99.4
7	101.4	84.2	74.2	100.3
8	102.6	85.6	75.3	101.1
9	103.7	86.6	76.1	101.7
10	104.7	87.7	76.8	102.4
11	105.5	88.6	77.5	103.0
12	106.3	89.4	78.0	103.5
13	106.9	90.1	78.5	104.0
14	107.4	90.8	78.9	104.5
15	107.8	91.3	79.3	104.9
16	108.2	91.8	79.7	105.3
17	108.6	92.4	80.0	105.7
18	108.9	92.8	80.3	106.1
19	109.2	93.2	80.6	106.4
20	108.9	93.6	80.8	106.8
21	109.8	94.0	81.0	107.1
22	109.9	94.3	81.2	104.3
23	--	94.6	81.4	107.6
24	109.4	94.9	81.6	107.8
25	110.0	95.2	81.8	108.0
26	110.2	95.5	82.0	108.3
27	110.4	95.7	82.2	108.4
28	--	95.9	82.3	108.6

TABLE 8

COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES OF 18 by 36 in. SPECIMENS

Specimen	fc' psi	Elastic Modulus psi x 10^6	Poisson's Ratio
1	2050	4.45	.153
2	2000	3.37*	.095*
3	2075	4.30	.149
Average	2040	4.4	.15

*Note - not used in average.

TABLE 9

COMPRESSIVE STRENGTH OF 6 BY 12 IN. SPECIMENS

	Age - days	Strength* - psi
Trial Batch		
	7	940
	14	1540
	28	2140
	90	2900
1st Production Batch		
	7	950
	14	1300
	28	1740
	90	2750
2nd Production Batch		
	2	375
	28	1890
	90	2750

* Note - each value is average of three cylinders.

TABLE 10

STRENGTH AND ELASTIC PROPERTIES OF GURI AGGREGATE

Specimen Number	Compressive Strength psi	Elastic Modulus psi x 10^{-6}	Poisson's Ratio
1	21,490	11.2	0.23
3	28,010	11.0	0.23
4	23,940	11.7	0.27
5	16,010	12.2	0.39
Average	22,360	11.5	0.27

TABLE 11

COMPRESSIVE STRENGTH OF 2-INCH MORTAR CUBES

Cement	Blaine Fineness**	Strength-psi at age (days) 1	3	7	28
A	3700	1580	2570	3370	5230
B	4055	1183	2750	3408	--
C	3870	--	2527	3556	5183
D	3053	777	1938	2900	4250
E	3730	1250	2490	3512	--
F	3295	1075	2575	--	--
G	3434	1267	2480	4133	5844
Average	3590	1200	2470	3460	5180
Guri-Type II	3110	--	1620	2130	3360
"	3700	--	2080	2800	4380
"	4200	--	2160	2790	4650
Guri-Type IIS	3410*	--	1275	2080	3790
"	3820*	--	1410	2030	3950

* Effective Fineness with 30% Slag Replacement

** cm^2/gm

TABLE 12

2400 PSI MIXES - VENCEMOS TYPE II CEMENT

Item	1 Cubic Yard Batch SSD Weight - lbs. Mix A	Mix B
Type II cement	279	251
Slag	--	80
Water	176	176
Sand	965	952
3/16 - 3/4	741	732
3/4 - 1 1/2	467	461
1 1/2 - 3	769	759
3 - 6	769	759
Density - pcf	154.3	154.4
28 day Comp. Strength of 1 1/2 in. MSA mix, psi	2430	--

TABLE 13 - BLEEDING TEST BATCH QUANTITIES

BATCH NO.	CEMENT	REPL.*	BATCH WEIGHTS - LBS - SSD WATER	SAND	3/8 - 3/4	3/4 - 1 1/2	AGA**	WRA**
E1	13.63	--	9.91	52.26	30.64	37.56	4.5	17.12
E1A	13.63	--	9.91	52.25	30.64	37.56	1.5	17.12
E1B	13.63	--	9.91	52.26	30.64	37.56	2.5	17.12
E1C	13.63	--	9.91	52.26	30.64	37.56	2.5	17.12
E1D	13.63	--	9.91	52.23	30.64	37.56	1.5	17.12
E2	13.63	--	10.21	52.26	30.64	37.56	2.0	17.12
E2A	13.63	--	9.36	52.23	30.64	37.57	2.0	17.12
E2B	13.63	--	8.93	52.23	30.64	37.57	2.0	17.12
E2C	13.63	--	8.93	52.23	30.64	37.57	2.0	17.12
E3	13.63	--	11.01	62.42	28.57	35.03	1.8	17.12
E4	14.63	--	9.60	55.30	32.88	40.31	3.0	17.12
E5A	13.63	--	10.20	52.26[1]	30.64	37.56	2.5	17.12
E5B	13.63	--	11.23	52.26[2]	30.64	37.56	1.8	17.12
E6	14.83	--	10.16	56.32	3.96	62.45	2.5	17.12
E7	13.63	--	9.44	52.26	30.64	37.56	2.5	17.12
E7A	13.63	--	9.38	52.23	30.64	37.57	1.5	17.12
E10	9.54	3.86[3]	9.29	52.26	30.64	37.56	2.2	17.12
E10A	9.54	3.27[4]	10.28	52.26	30.64	37.56	2.2	17.12
E11	9.54	3.86[5]	9.91	52.26	30.64	37.56	2.5	17.12
E12	9.54	3.86[3]	9.91	52.26[1]	30.64	37.56	2.5	17.12
E13	9.54	3.86[5]	10.79	52.26[1]	30.64	37.56	2.5	17.12
E14	15.56	--	9.80	53.74	41.33	26.04	2.3	19.69
E15	7.50	--	5.33	28.73	16.85	20.66	0.8	9.42
E16	5.25	2.25[3]	5.33	28.73	16.85	20.66	1.0	9.42

* Replacement: [1] 20% Fine Sand [2] 40% Fine Sand [3] Slag [4] Pozzolan [5] Fine Slag ** grams

TABLE 14 - PROPERTIES OF BLEEDING TEST BATCHES

No.	Unit Wt. pcf	Temp of	W/C	% Air	Slump in.	Max Bleeding %	Remarks	28-day Compr. Str. psi
E1	134	70	0.73	1.50	5 1/4	10.72	Control	1540
E1A	147	70	0.73	4.7	3	7.39	Control	1680
E1B	144	70	0.73	6.5	4	8.88	Control	1770
E1C	140	71	0.73	8.2	4 1/2	14.35	Control	1630
E1D	146	71	0.73	5.0	3	9.45	Control	1960
E2	145	70	0.70	5.7	3	7.76	Control	2140
E2A	145	71.5	0.69	6.1	2 7/8	8.15	Control	2010
E2B	145	70	0.66	5.3	1 5/8	8.67	Control	2230
E2C	146	71	0.66	4.6	1 5/8	10.15	Reduced Slump	2050
E3	143	70	0.81	6.0	3	6.96	+5% Sand	1600
E4	144	70	0.66	7.2	3 3/4	8.59	-.5% Sand	2000
E5A	144	70	0.75	6.1	2 3/4	6.06	20/80 Replc.	1790
E5B	145	71	0.82	4.5	2 3/4	6.46	40/60 Replc.	1420
E6	143	72	0.68	6.0	3 1/2	8.57	gap graded	2010
E7	136	56	0.69	12.0	4 3/4	10.82	Control	1820
E7A	145	51.5	0.69	5.2	2 3/4	10.43	Control	2320
E10	145.5	71	0.60	5.6	3 1/4	7.43	30% Slag Replc.	1870
E10A	146	71	0.80	4.3	2 3/4	5.69	30% Pozz. Replc.	1770
E11	148	71.5	0.74	4.0	2 1/2	7.25	Fine Slag Replc.	2310
E12	144	71.5	0.74	6.0	2 3/4	7.02	20/80 + Slag	1430
E13	148	71	0.81	3.8	2 3/4	4.24	20/80 + Fine Slag	1700
E14	144	70	0.63	5.8	2 3/4	10.30	Increased Cement	2430
E15	149	70	0.71	3.4	2 1/8	7.27	Reground Cement (3700)	----
E16	148	80	0.71	3.9	1 1/2	7.50	Fine Cement (3700) +30% Slag	----

TABLE 15

SPECIFIC GRAVITY AND FINENESS OF CEMENTITIOUS MATERIALS

	Guayana Type IS Cement	Vencemos Type II Cement	SIDOR Slag	Fine SIDOR Slag	Pozzolan (AIROX)
Specific Gravity	3.18	3.18	3.00	3.00	2.54
Fineness (cm^2/g)	3060	3110	3900	6940	11550

TABLE 16

CREEP EQUATIONS

Guayana Type IS Cement

7 day $\varepsilon_{7} = .350 + .0419 \log_{e} (t + 1)$

28 day $\varepsilon_{28} = .275 + .0332 \log_{e} (t + 1)$

90 day $\varepsilon_{90} = .217 + .0192 \log_{e} (t + 1)$

Vencemos Type II Cement

7 day $\varepsilon_{7} = .283 + .0397 \log_{e} (t + 1)$

28 day $\varepsilon_{28} = .262 + .0282 \log_{e} (t + 1)$

90 day $\varepsilon_{90} = .212 + .0199 \log_{e} (t + 1)$

FIGURES

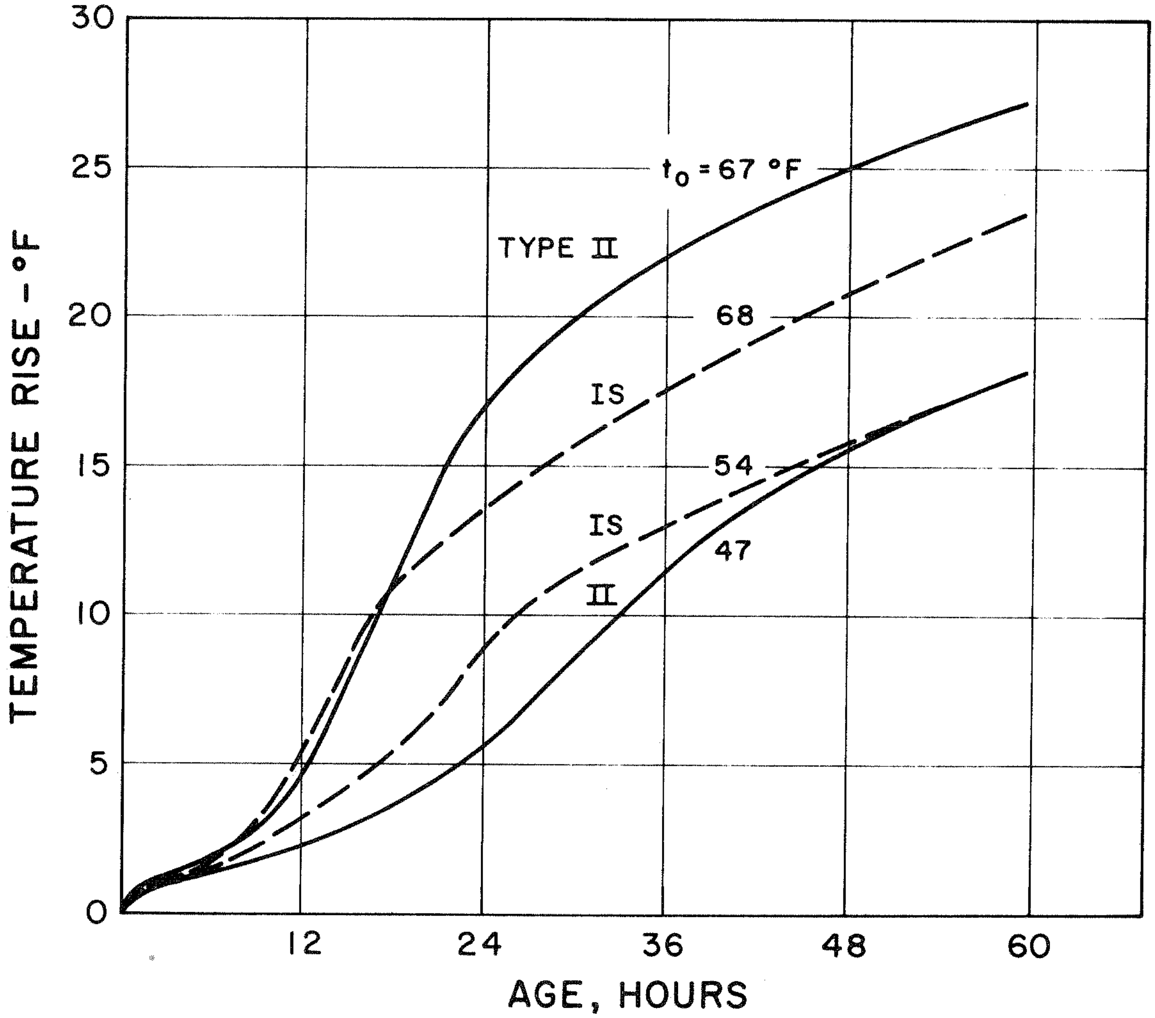

FIG. I INITIAL ADIABATIC TEMPERATURE RISE

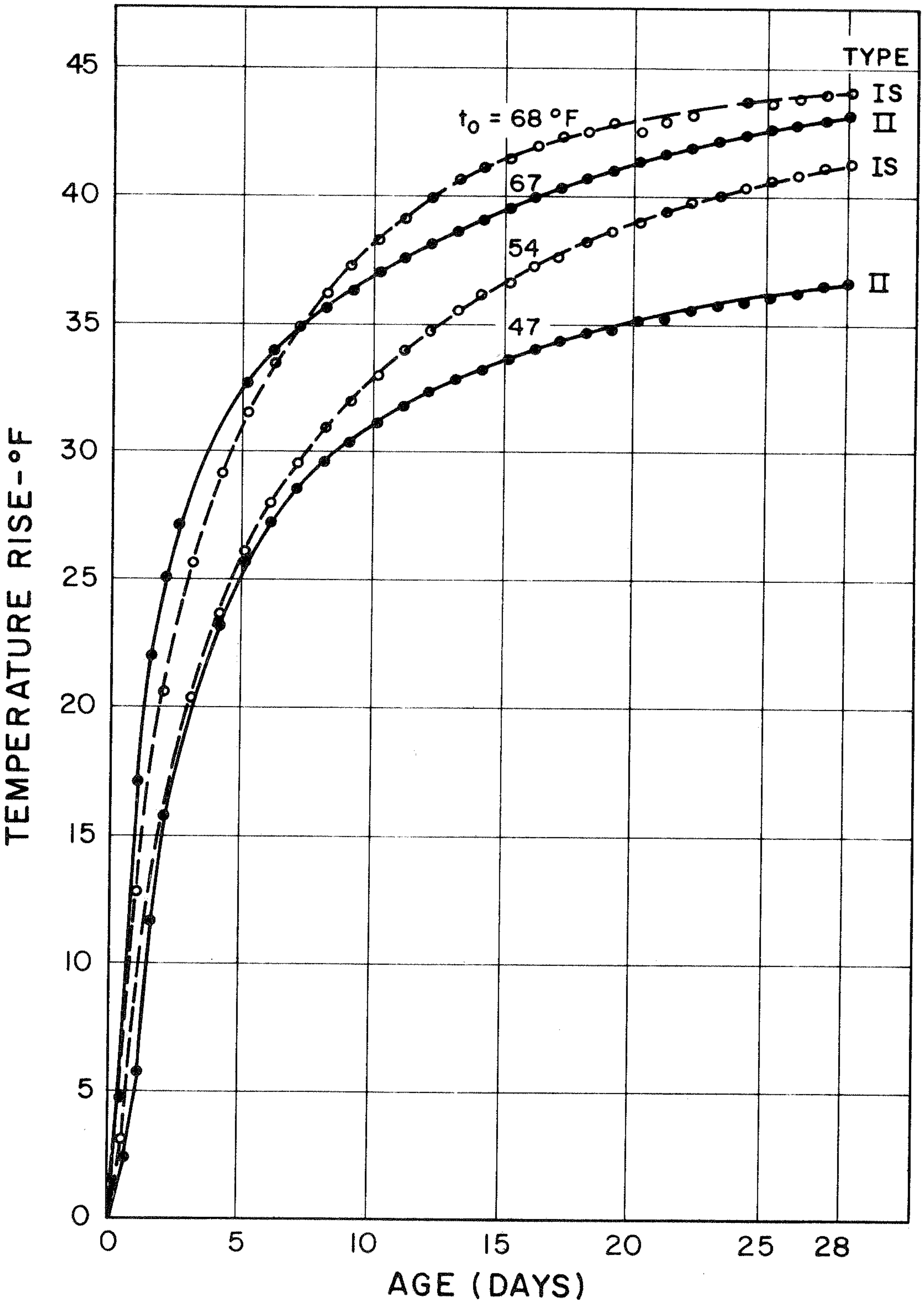

FIG. 2 28-DAY ADIABATIC TEMPERATURE RISE

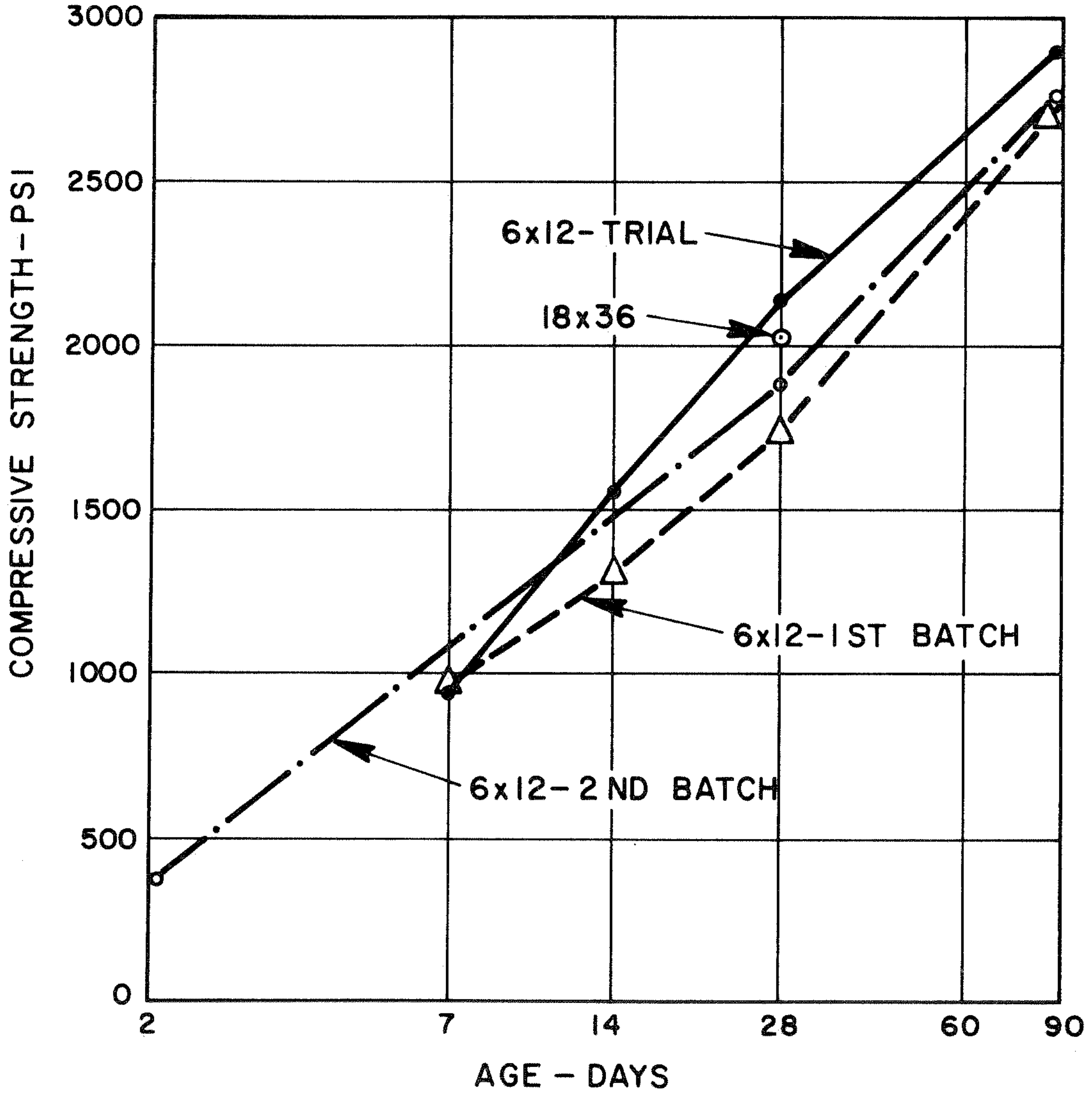

FIG. 3 COMPRESSIVE STRENGTH OF CONCRETE USING GUAYANA TYPE IS CEMENT

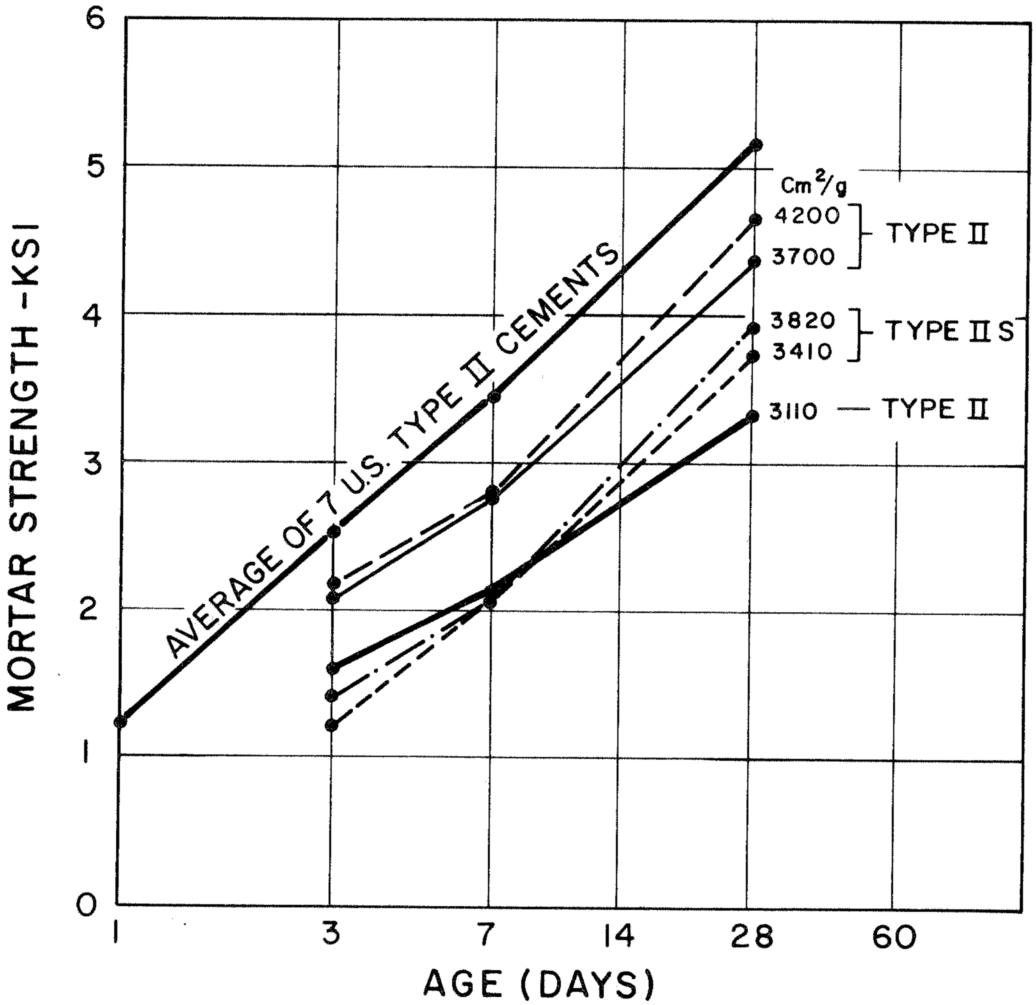

FIG. 4 EFFECT OF FINENESS ON STRENGTH

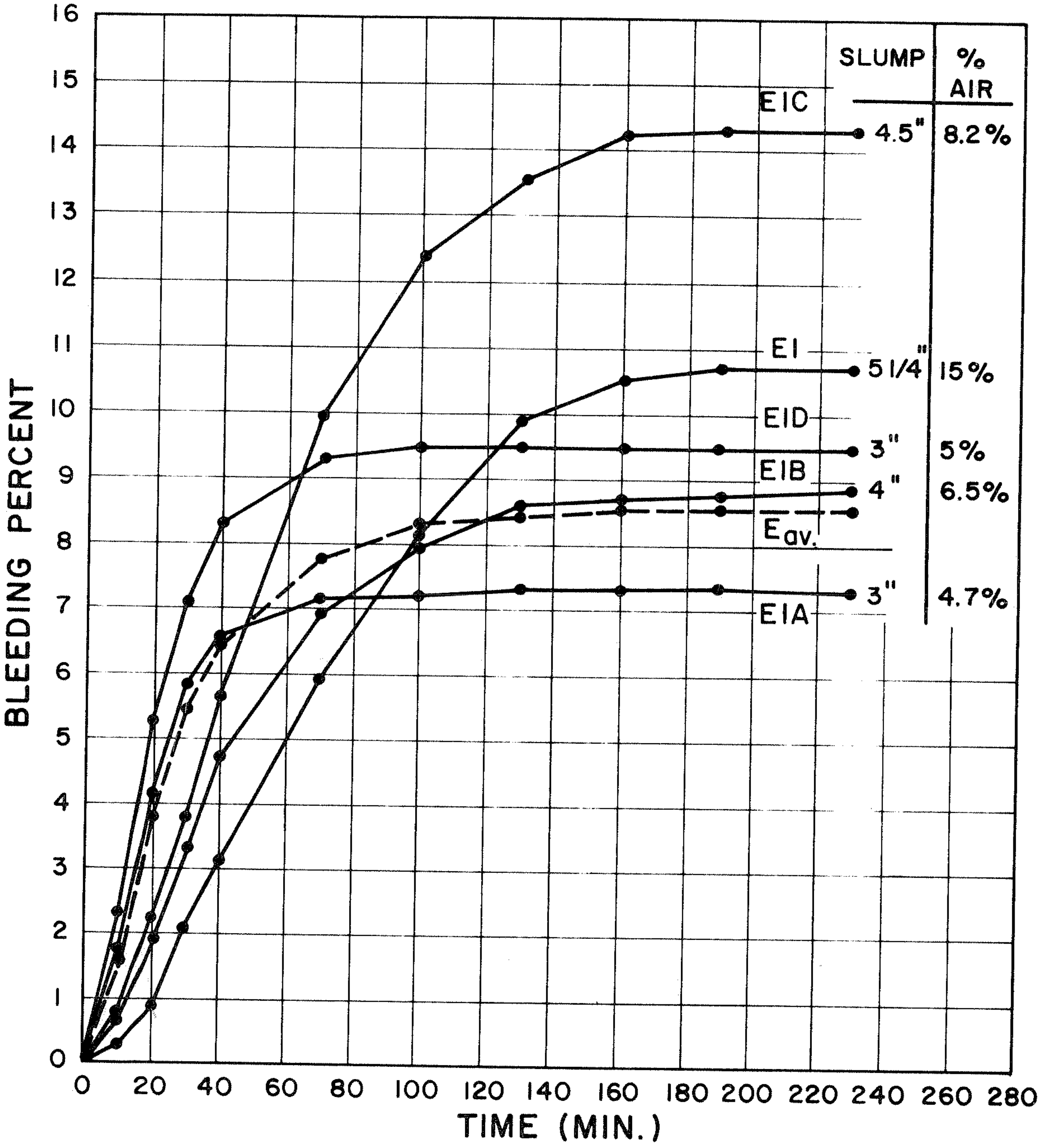

FIG. 5 BLEEDING OF CONTROL GROUP

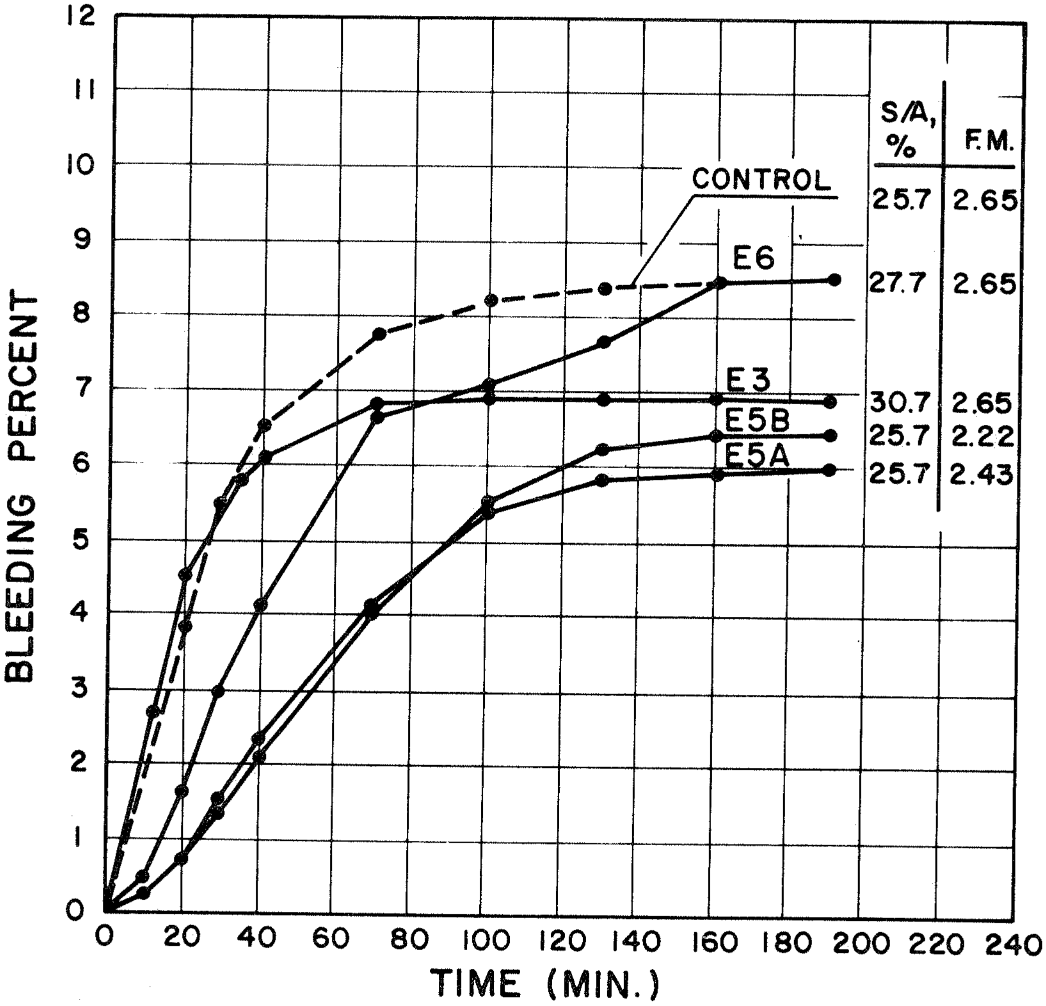

FIG. 6 EFFECT OF SAND CONTENT AND FINENESS ON BLEEDING

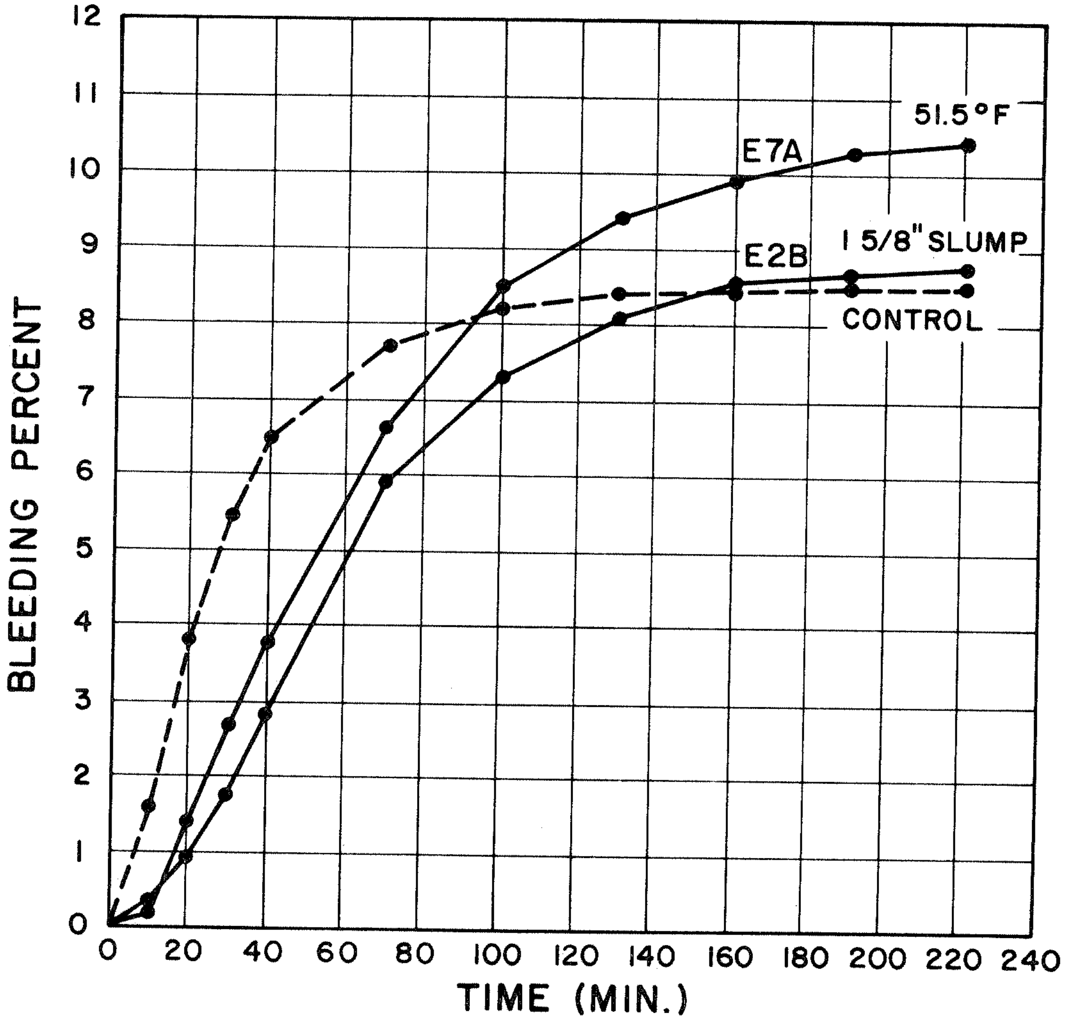

FIG. 7 EFFECT OF LOW SLUMP AND COLD MIXING ON BLEEDING

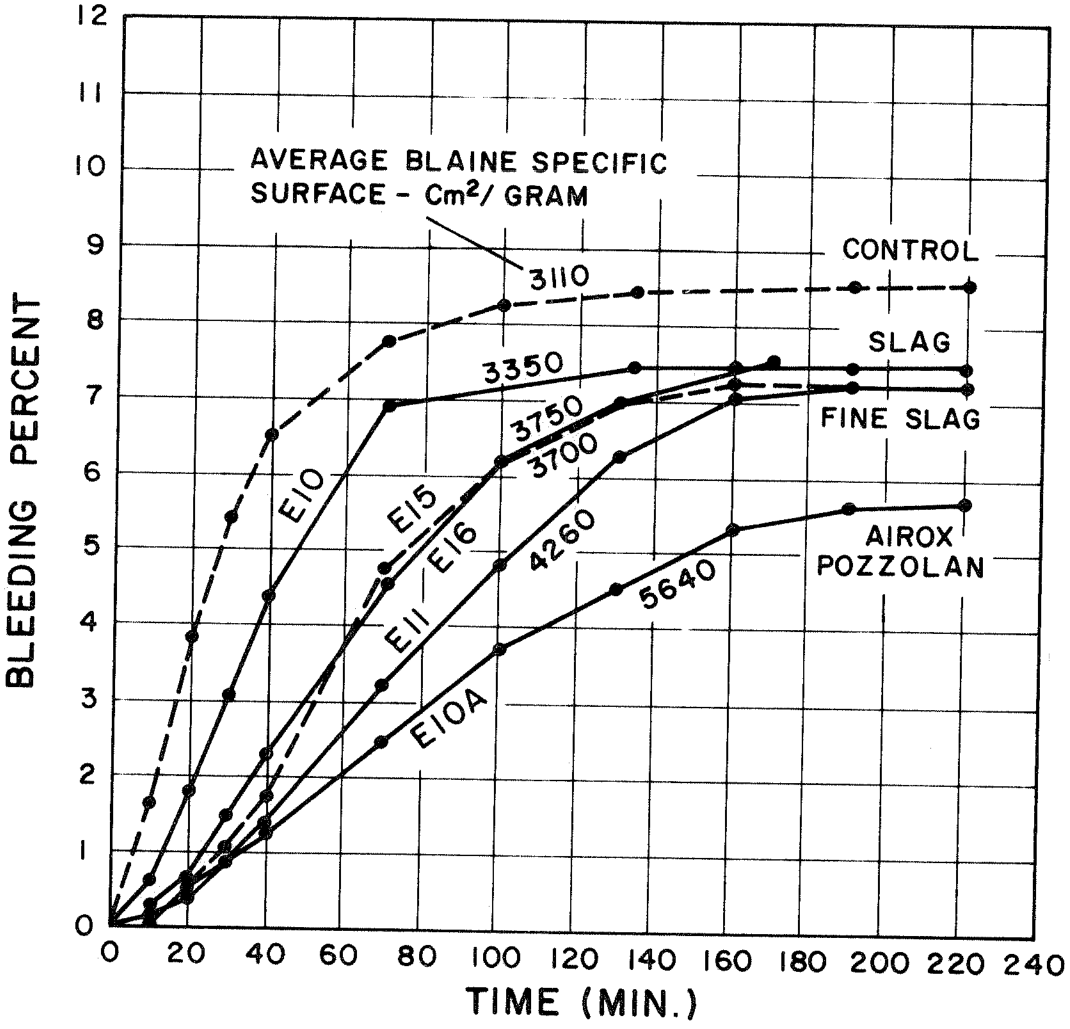

FIG. 8 EFFECT OF CEMENT FINENESS ON BLEEDING

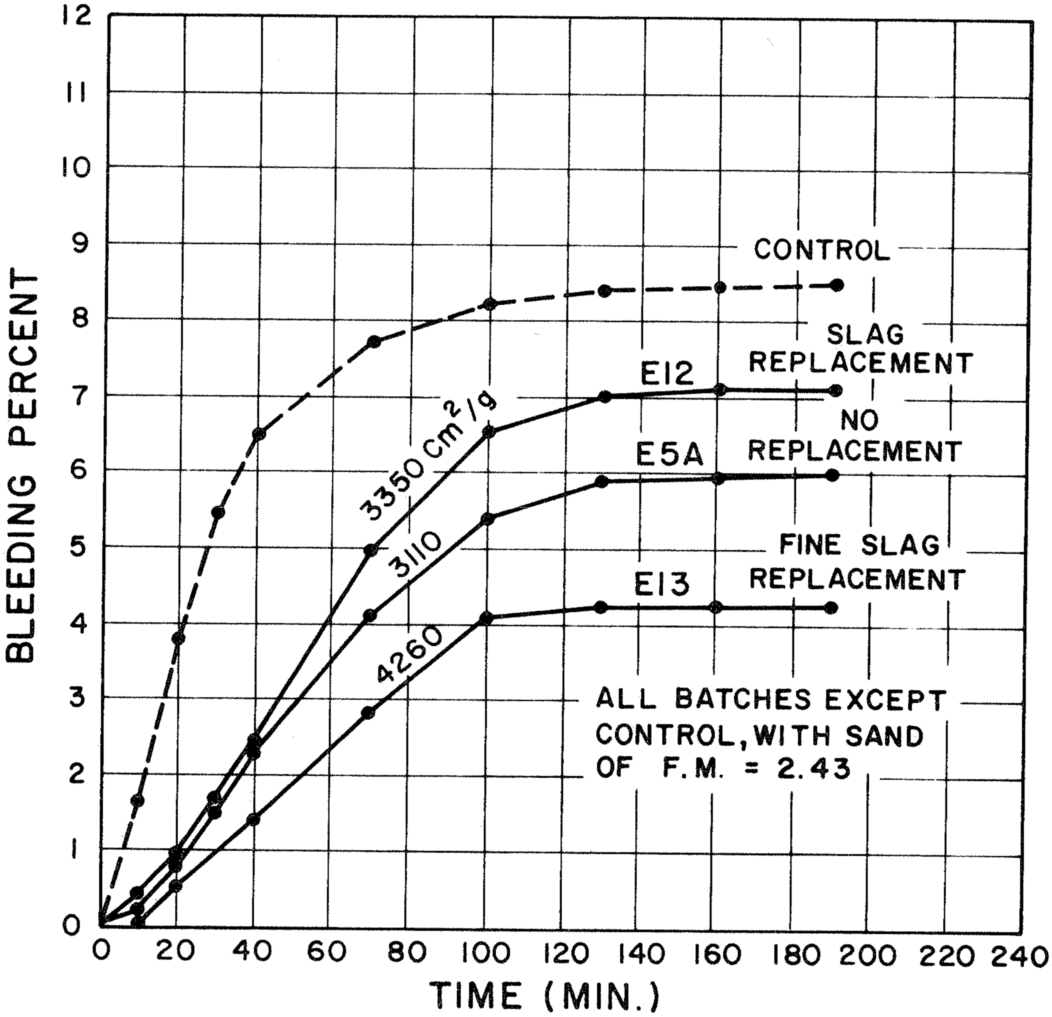

FIG. 9 EFFECT OF FINE SAND PLUS FINE CEMENT ON BLEEDING

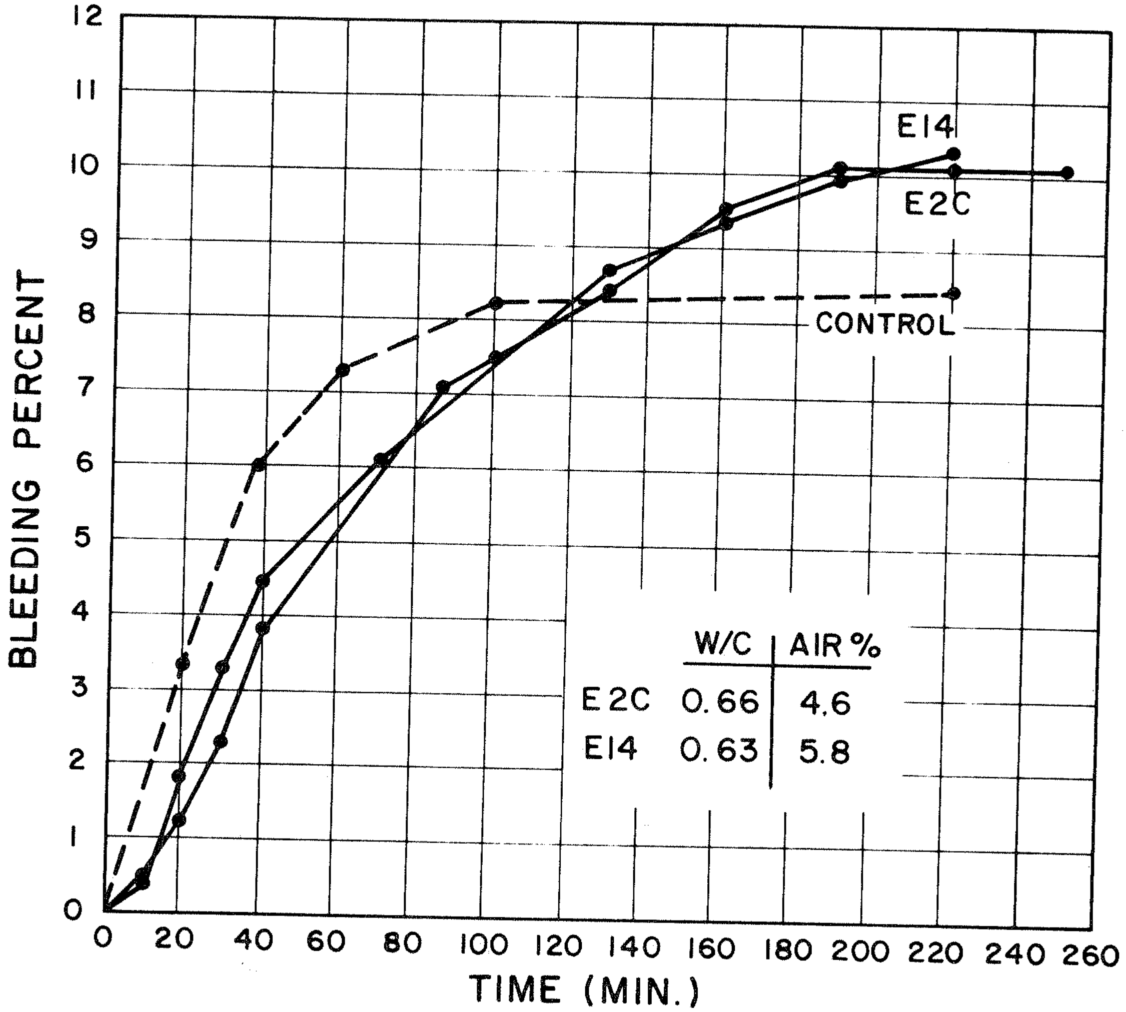

FIG. 10 BLEEDING OF TRIAL MIX DESIGNED FOR STRENGTH

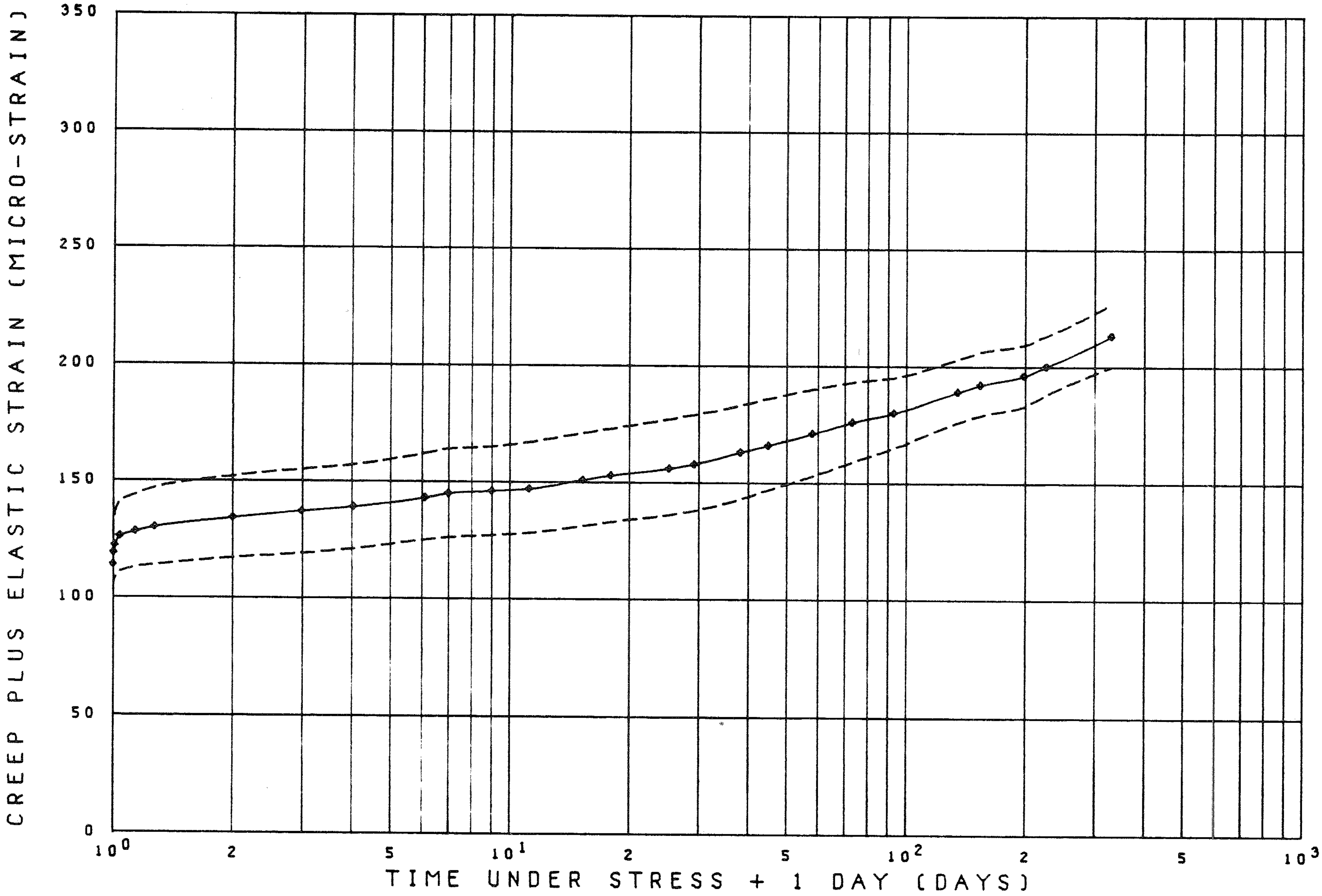

FIG. 11 ELASTIC AND CREEP STRAINS OF GURI DAM CONCRETE LOADED AT 90 DAYS TO 600 PSI --TYPE 2 CEMENT

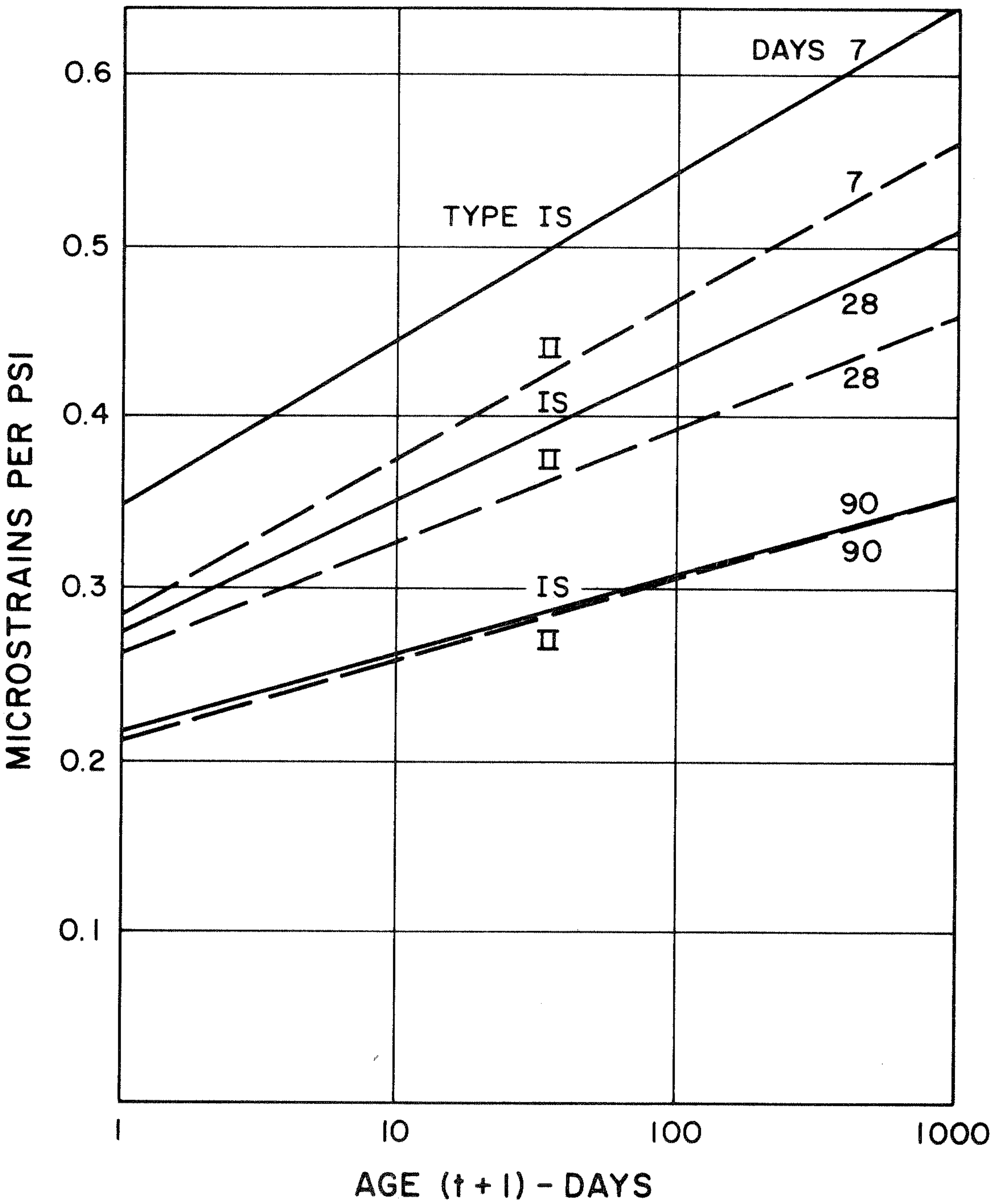

FIG. 12 MASS CONCRETE CREEP CURVES