was employed, since found unnecessary. On this job, which was poured during Christmas week, we provided 2-in. steam lines under the core. This also, later was found unnecessary.

CITY ICE AND FUEL COMPANY PLANT AT NILES

As usual, with an icing station, the season storage and daily storage houses are of different heights, and the forms are pulled simultaneously. When the top of the daily storage is reached, it is cut loose and only the season storage forms carried up. To make this cut-off, gates or panels are provided and at the proper time are inserted into the slots to receive them. Thus the concrete is held from going into the daily storage wall. The form itself is cut through at the walers and stays behind.

On this job, openings were provided for future extension of the season storage house. These openings were made, then sealed, the sealing process having 4 operations. By means of traveler scaffolds down from the finishers' scaffold, the 4 operations were performed as the work progressed.

CITY ICE AND FUEL COMPANY PLANT AT CLEVELAND

This plant consisted of a 6-story and basement cold storage house 200 by 200 ft., and an ice manufacturing room and an ice storage room for retail trade. On this job the group insert design, Fig. 11, was employed for anchoring canopy trusses. The grouping feature insures positive, correct relative spacing of inserts and eliminates looking for them and also puts the full thickness of the wall to work carrying the load as the threaded spud rod is removed and the permanent bolt inserted in the hole thus formed.

Screen wire back for floor slot boxes was also employed with success. The pocket and system of reinforcing dowels to produce a wall bracket or wall capital to take care of the negative movement occurring at the wall in a flat slab design was devised for use on this job but not used, as the engineers for the City of Cleveland did not consider wall capitals necessary.

CITY ICE AND FUEL COMPANY PLANT AT PITTSBURGH

This plant also consisted of ice manufacturing room, ice storage and cold storage house 200 x 197 ft., 7-stories high.

Complications due to physical conditions of the site were many. The 16th St. viaduct leading to the bridge over the Allegheny river ran at an angle to the building line and interfered with yoke ends for a section of the east wall of the ice house. It was necessary to design the yoke ends so that a portion could be removed in passing the bridge, then, as it was advisable to have the full runway, they were built out to standard length when the bridge rail was passed.

The ice house and ice manufacturing room was built independently of the cold storage house, but the east wall of the cold storage house later was to close in the west end of the ice house and manufacturing room. The structure had an open end, over which was built a bridge to provide a continuous runway for the concrete buggies. The ice manufacturing room was on the second story over the ice storage room, and also over the engine or compressor room. The walls of the ice storage room were double for a height of 30 ft., at which point the center wall, or south wall of the storage room was stopped. The north and east walls of the storage were carried up 27 ft. as single walls, together with the engine room walls, which were single walls, from the foundations up the full height of 57 ft.

It was decided to tie and brace the center wall forms to the other wall forms and also to carry up the 2 bridges the full height of 57 ft. When the 30-ft. elevation was poured, the center wall and the bridge ends were carried up on free standing jack rods, braced with false work. The operation was successful but caused a constant worry.

Adjoining the cold storage on the front half of the east elevation was a residence on the building line for a height of 60 ft. Panel forms with flattened walers were placed, but the pilaster face was on the line. Guide strips fastened to the adjoining walls with pipe rollers on the panel walers and outrigger jacks on the inside were used to maintain equilibrium until the adjoining building was passed, when standard size yokes were built on the east side producing a uniform face of wall and pilasters above.

SOUTHERN ICE AND UTILITIES COMPANY PLANT AT NASHVILLE

On this job a distance of 60 ft. between walls was bridged with three latticed trusses using 16 ft. plank for bridge deck. The bridge was carried entirely on the forms with no center support and caused no trouble.

Readers are referred to the JOURNAL *for June 1933 for discussion of this and the preceding report (January* JOURNAL*). Such discussion should reach the Secretary by April 1, 1933.*

Mass Concrete Research For Hoover Dam*

BY BYRAM W. STEELE†

INTRODUCTION

The design and construction of Hoover Dam has necessitated the solution of problems of greater variety and magnitude than any similar project ever built. Those pertaining to mass concrete construction occupy an important position.

In the last 20 years the immense amount of research work on plain and reinforced concrete has been largely confined to investigations of concrete in which the maximum size of aggregate was about 1½ in., rather than to mass concrete containing aggregate of all sizes up to and including cobbles. Past research, while applicable to a large percentage of all concrete work, does not furnish adequate data for the solution of mass concrete problems such as will arise in the construction of Hoover Dam. While numerous mass concrete structures have been built regardless of this lack of information, the magnitude of the undertaking, which involves more concrete than has been placed by the bureau since its organization in 1902, seemed to warrant an investigation to secure the fundamental data required for the solution of these problems.

SCOPE OF INVESTIGATIONS

The program of investigations as originally outlined embodied such subjects as volume change, foundation and contraction joint grouting, portland cement, mass concrete strength and mix proportions, elastic properties of mass concrete, thermal properties of mass concrete, permeability, precooling concrete ingredients versus concrete refrigeration, action under axial, biaxial and triaxial loads, bond and sliding friction, shear, uplift, and durability.

In the beginning, certain tests were assigned to different organizations, but as the work progressed, some of the tests originally contemplated were dropped and others were postponed or transferred from one organization to another. The investigation of portland

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†Bureau of Reclamation, Denver.

cement started by the Bureau of Standards in Washington, was continued and greatly expanded by the University of California under cooperative arrangement with the Bureau of Reclamation, and will be concluded, insofar as Hoover Dam is affected, by what are termed "comparison of cements" tests on mass concrete now in progress at the Bureau of Reclamation laboratories in Denver.

The mixing of mass concrete was recently studied at Owyhee Dam during its construction. These studies are being continued at the Denver laboratories and at the concrete mixing plant at Hoover Dam. The studies on strength, thermal and elastic properties and permeability are now in progress in the laboratories in Denver. Tests of stress under axial, biaxial and triaxial loads remain to be considered. Some work has been done in Denver on shear, bond and sliding friction, and uplift. Volume change has received both field and laboratory consideration by the bureau. Durability is being studied at the University of California.

Thus it will be seen that the field covered by these investigations is fairly comprehensive. However, it should be pointed out that the Bureau of Reclamation has undertaken only such research as applies directly to concrete design and construction in structures of the type of Hoover Dam and related works, and particularly the former inasmuch as mass concrete conditions furnish the outstanding problems. Considerable pioneering in technique and development of testing apparatus have been necessary since much of the research is outside the range of standardized laboratory practice. More than a year was spent in preliminary testing in order that the final data would not be tainted with tests of the apparatus, but would represent a true story of the performance of the test specimen. The major subjects of the investigation will now be discussed in the order of their relative importance.

VOLUME CHANGE

Since volume change occurs in all concrete work, it is common practice to place contraction joints, or designed cracks at appropriate intervals to improve the appearance of the structure and to prevent cracking at undesirable locations. In a dam, either the contraction joints must not open or the opening must be sufficient to permit a satisfactory job of grouting if a monolithic structure is to be obtained.

Foremost of the mass concrete problems is the control of this volume change. But back of all this is the underlying reason for desiring to control this change. As the dam shrinks, due to loss of heat, the particles which make up the cantilever elements are held in intimate contact by gravity and consequently when the water load is applied the minimum of deformation takes place. With the arch elements, however, the condition is entirely different. As the dam shrinks gravity does not assist in holding the arch element particles in intimate contact and as a result the vertical contraction joints open up and arch action is prevented until they are again closed. This closing can be accomplished in two ways; (1) by deflection of the cantilever elements downstream in a radial direction until the arch voussoirs again come into contact, or (2) by grouting the contraction joints so that the water load will be distributed to both the arch and cantilever elements with the minimum of deflection and in the proportions assumed in the design. Obviously the latter is preferable, and it is the principal reason for considering accelerated shrinkage of the concrete in the dam and grouting of the contraction joints.

Shrinkage in a massive concrete dam is normally distributed over a long period of years and is due principally to two causes: (1) the loss of chemical heat generated during the hardening process, and (2) the loss of initial heat, which is the heat due to temperature in excess of mean annual at the time the concrete is placed. The impracticability of regulating the rate of heat dissipation was the controlling factor in determining that the concrete in Hoover Dam would need to be artificially cooled if the contraction joints were to be grouted before the dam was subjected to water load. Were it economically practicable to construct Hoover Dam at a rate such as to allow all, or nearly all, of the heat to dissipate under natural conditions during the construction period; or, to construct it only during the cooler parts of the year when the difference between the initial concrete temperature and mean annual was equal to the temperature rise due to the heat of hardening, then all problems of future volume change of any moment would disappear, since the final temperature of the concrete would be at or below mean annual and no shrinkage would occur. Such a condition would obtain if for example the temperature of the concrete at the time of placing was 40°, and the temperature rise due to generation of heat during the hardening process was 32°, making the resulting temperature in the concrete 72°, which is approximately mean annual for that locality.

To obtain data on volume change in mass concrete under actual working conditions in the field, a test was made during the construction of Owyhee Dam, in which a pipe cooling system similar to that proposed for Hoover Dam was embedded in two adjacent panels or blocks near the top of the dam. This experimental section was roughly 100 ft. long, 82 ft. high, and had an average thickness of 35 ft. (Fig. 1). Suitable devices of three different types for measuring the joint opening between panels 3 and 4, and the volume change or shrinkage within each panel were installed, 90 of these devices being mounted across the contraction joint and 70 within the mass at various points.

Fig. 2 shows an elevation of the contraction joint between panels 3 and 4, on which is imposed an isometric drawing of the contraction joint opening. The diagonal lines represent, in accordance with the scale shown at the side of the section, the amount of the contraction joint opening after river water had been pumped through the section for 40 days. Attention is directed to the shape of a horizontal section through the contraction joint—wide in the center and narrow at either side. If this joint is not grouted before the reservoir is filled, when the water load comes on the dam the arch load instead of being distributed across the entire arch section will be concentrated on either side, thereby increasing materially the unit stresses in the arch concrete.

The reason the lower part of the joint opened more than the upper is that water was pumped through the lower section longer and the temperature difference between river water and concrete was greater early in the experimental period, pumping being started May 13 before the river water had warmed up much. Pumping was continued both in the upper and lower parts of the experimental section until the rising temperature of the river water and the falling temperature of the concrete did not permit any further extraction of heat. The wider joint opening at the center, as compared with the edges, was due to the fact that more heat was available near the center for extraction by artificial cooling, whereas at the edges or corners of the blocks considerable heat was lost to the air. Panel 3 being placed first and exposed on all four sides lost more heat to the air than panel 4 which was poured last and exposed on two sides only.

Fig. 3 gives part of the numerical values used in plotting the joint opening shown in Fig. 2. The upper figure in each circle is the temperature drop of the concrete surrounding the joint measuring device. The central figure is the joint opening in inches at the location of the circle. The lower figure is the significant part of the temperature shrinkage coefficient as computed from the figures above. The average temperature drop for the lower two-thirds of the joint was 30° F., the average joint opening was .044 inches, and the temperature shrinkage coefficient, as computed from these averages, was .0000025. The difference between this value and that obtained in the laboratory for the coefficient of expansion was apparently due largely to restraint of

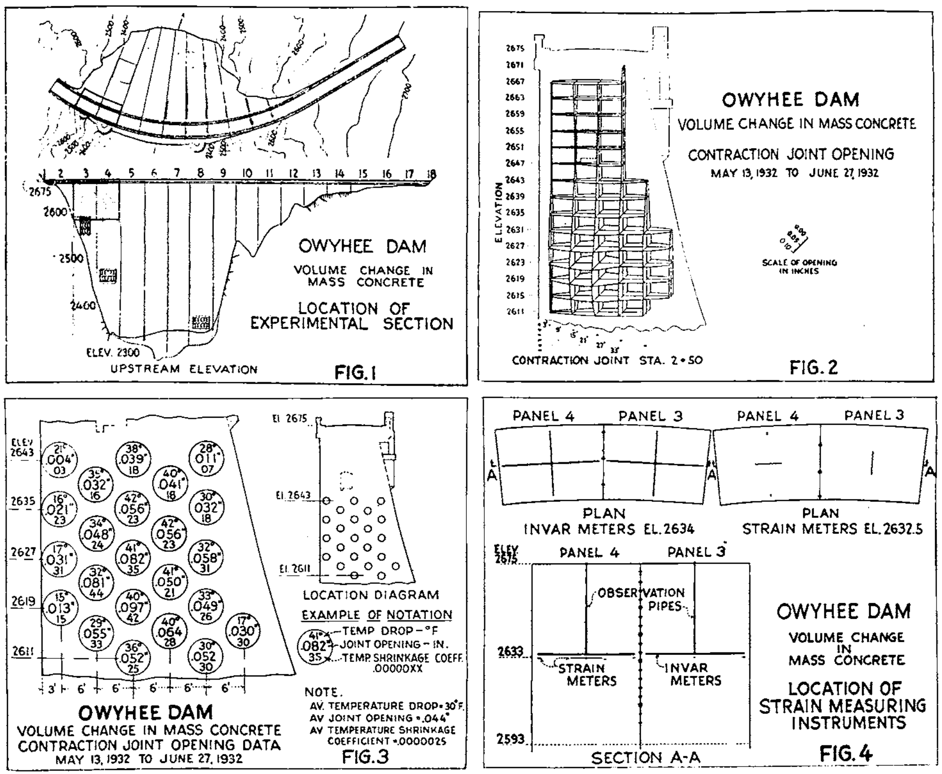


FIG. 1-4—VOLUME CHANGE IN MASS CONCRETE

one form or another and, in a limited measure, to the relief of residual compression in the concrete at the time cooling was started.

For the measurement of shrinkage in the mass, long invar rods were suitably mounted in embedded pipes, both radially and circumferentially, in the concrete of both panels as shown in the sectional plan views in the upper part of Fig. 4. Just below the invar rods were embedded strings of strain meters bolted together as shown in section AA, which is a vertical circumferential section taken at the cross in the invar meters.

Fig. 5 gives a comparison of the mass concrete shrinkage measurements. The upper curve is the average temperature of the concrete surrounding the instruments plotted against time. In the lower part of the figure are shown smooth dotted curves which are theoretical openings of the contraction joint according to the time temperature curve above, and are placed there solely as guide lines for the interpretation of the other curves shown. The smooth solid curve is the average shrinkage value of the 22 strain meters located under the circumferential invar meters. The solid jagged curve is the average shrinkage of the two circumferential invar meters. The dotted jagged curve is the contraction joint opening between panels 3 and 4 indicated by the contraction joint meter located across the joint between the two circumferential invar meters. Thus there is combined in this figure a comparison of three radically different types of volume change measuring devices. The gage length of the circumferential invar meters is roughly 45 ft. whereas the gage length of the strain meters is 10 in., and yet the shrinkage of the entire mass as indicated by both instruments is very close. The contraction joint opening, while not necessarily the same as the indicated shrinkage of the mass, is a very good check on the performance of the other instruments. Thus it appears that a temperature shrinkage coefficient of .000003, or less, is justified for use in estimating contraction joint openings. These five figures give the high-lights from nearly 100,000 individual observations and 150 drawings which were made in connection with this volume change experiment.

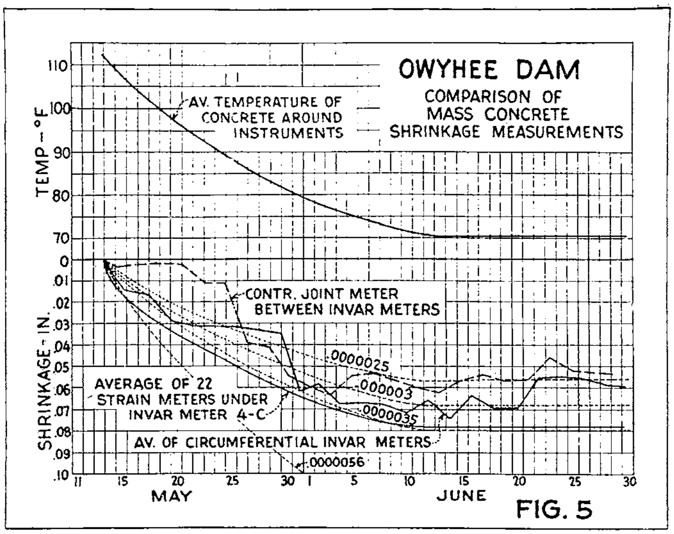
After the contraction joints in Gibson Dam had been grouted, 45 cores were diamond-drilled from across the contraction joints in various parts of the dam to determine the thickness of grout film and also its quality. The average thickness of film obtained from these cores was found to check the results obtained at Owyhee. In other words, the average temperature shrinkage coefficient obtained in the field is, by virtue of restraint and other field conditions, appreciably less than the coefficient of expansion (or contraction) obtained in the laboratory where the test specimen is free to move in response to temperature changes.

CONTRACTION JOINT GROUTING

For a better understanding of the flow of cement grout during the grouting of a contraction joint in a dam it was decided to conduct a series of grout experiments on a laboratory specimen in which the joint opening and all surrounding conditions could be closely controlled. In these grouting experiments, conducted in the Denver laboratories, fineness of the cement, water-cement ratio of the grout, width of contraction joint opening, grout pressure within the joint and shearing strength of the grout film have been studied. For this investigation a split cylinder of mass concrete 5 ft. in diameter by 7 ft. high, cast to simulate a contraction joint in a dam, was so constructed that the thickness of grout film could be easily and accurately controlled.

Fig. 6 shows the split cylinder, one half of which is slung from a trolley beam in such a manner that the halves of the cylinder may be spread apart to view the results of the grouting of the joint. The same pipe and fittings were used for this experimental specimen that are used in grouting the joints in a dam. However, a removable rubber grout stop was used in this experiment in place of the copper stop to prevent leakage of the grout from the joint. Metal shims spotted at various points on the joint face were used to control the thickness of the grout film.

To confine the grout within the contraction joint copper grout seals or stops, are embedded across the contraction joint near the faces of the dam. Some difficulty has been experienced in obtaining good bond between the copper and the concrete so as to prevent leakage around the grout stop. Fig. 7 shows the type of specimen used in the study of a grout stop that is more efficient and easier to install than the one which has always been used. On all dams grouted to date the bureau has used a copper stop so formed as to permit bending of the copper loop as the joint opens and closes. The grout stop shown in the figure is a straight piece of copper extending 3 in. into the concrete on each side of the joint, and is coated with an emulsified asphalt preparation. This coating is about 1/16 in. thick. When the joint opens the asphalt coating yields without breaking the bond either with the copper or the concrete. Grout pressures up to 400 p. s. i. have been introduced into these specimens, in which the joint opening was gradually increased to 1/4 in. without any leakage around the stop although leakage did


OWYHEE DAM
COMPARISON OF MASS CONCRETE SHRINKAGE MEASUREMENTS
TEMP – °F
SHRINKAGE – IN.
AV. TEMPERATURE OF CONCRETE AROUND INSTRUMENTS
CONTR. JOINT METER BETWEEN INVAR METERS
AVERAGE OF 22 STRAIN METERS UNDER INVAR METER 4-C
AV. OF CIRCUMFERENTIAL INVAR METERS
.0000025
.000003
.0000035
.0000056
MAY
JUNE
FIG. 5

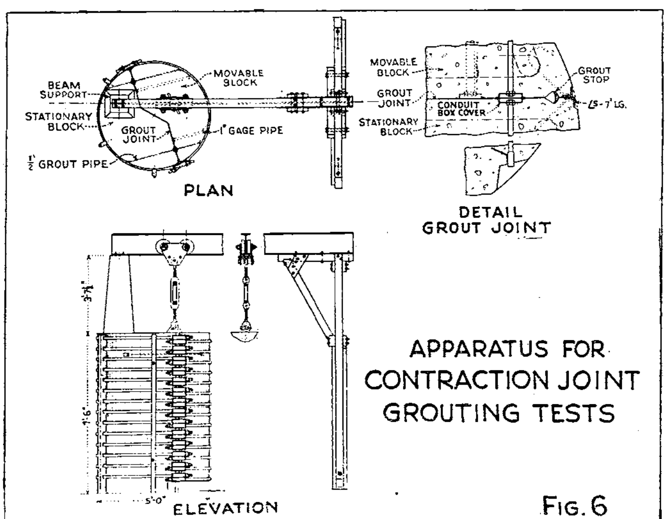

BEAM SUPPORT
STATIONARY BLOCK
MOVABLE BLOCK
GROUT JOINT
1" GAGE PIPE
½" GROUT PIPE
PLAN
MOVABLE BLOCK
GROUT JOINT
STATIONARY BLOCK
CONDUIT BOX COVER
GROUT STOP
DETAIL GROUT JOINT
ELEVATION
APPARATUS FOR CONTRACTION JOINT GROUTING TESTS
FIG. 6

FIG. 5-6