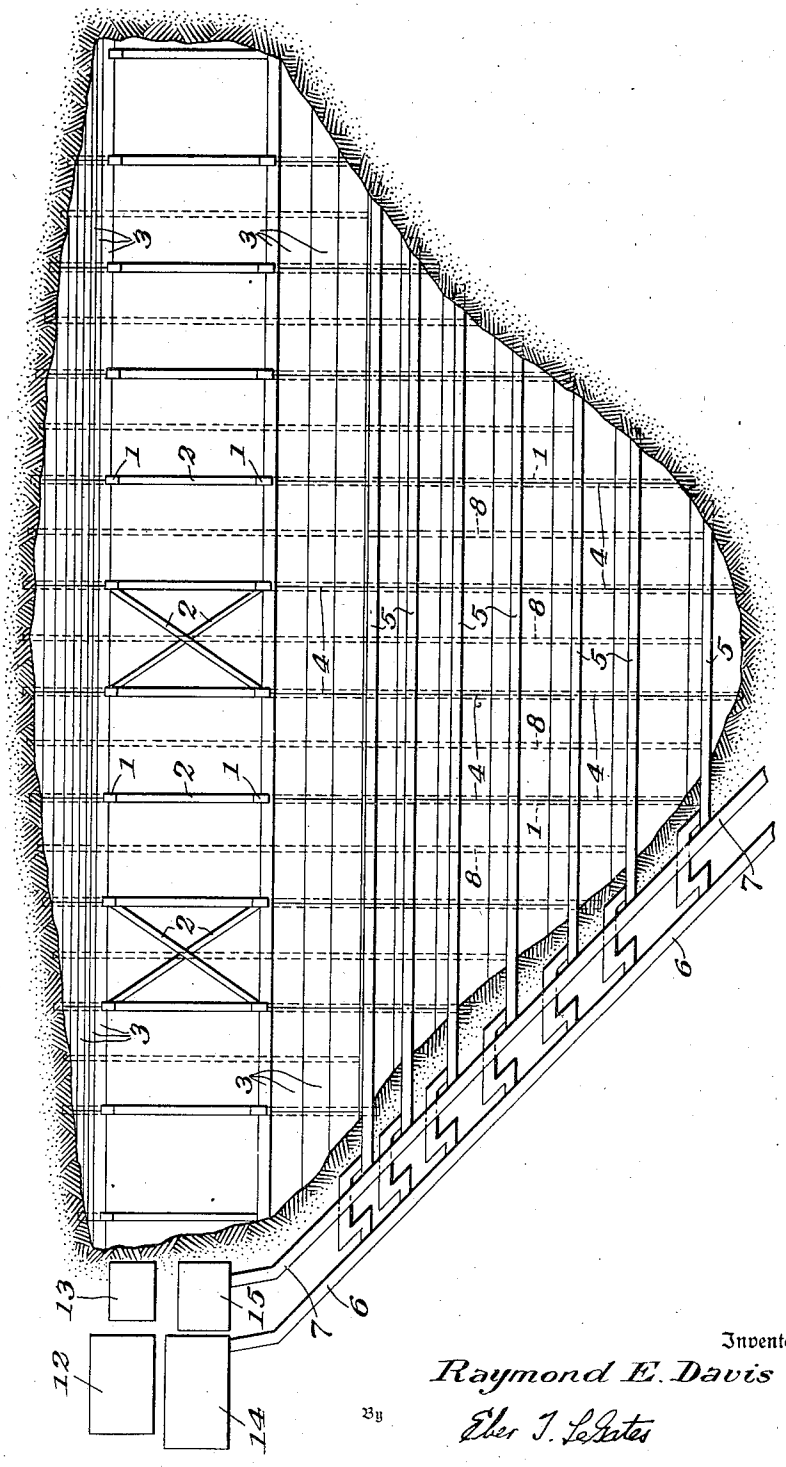
Oct. 12, 1943. R. E. DAVIS 2,331,311

CONCRETE CONSTRUCTION PROCESS

Filed Feb. 9, 1939 3 Sheets-Sheet 1

Fig. 1



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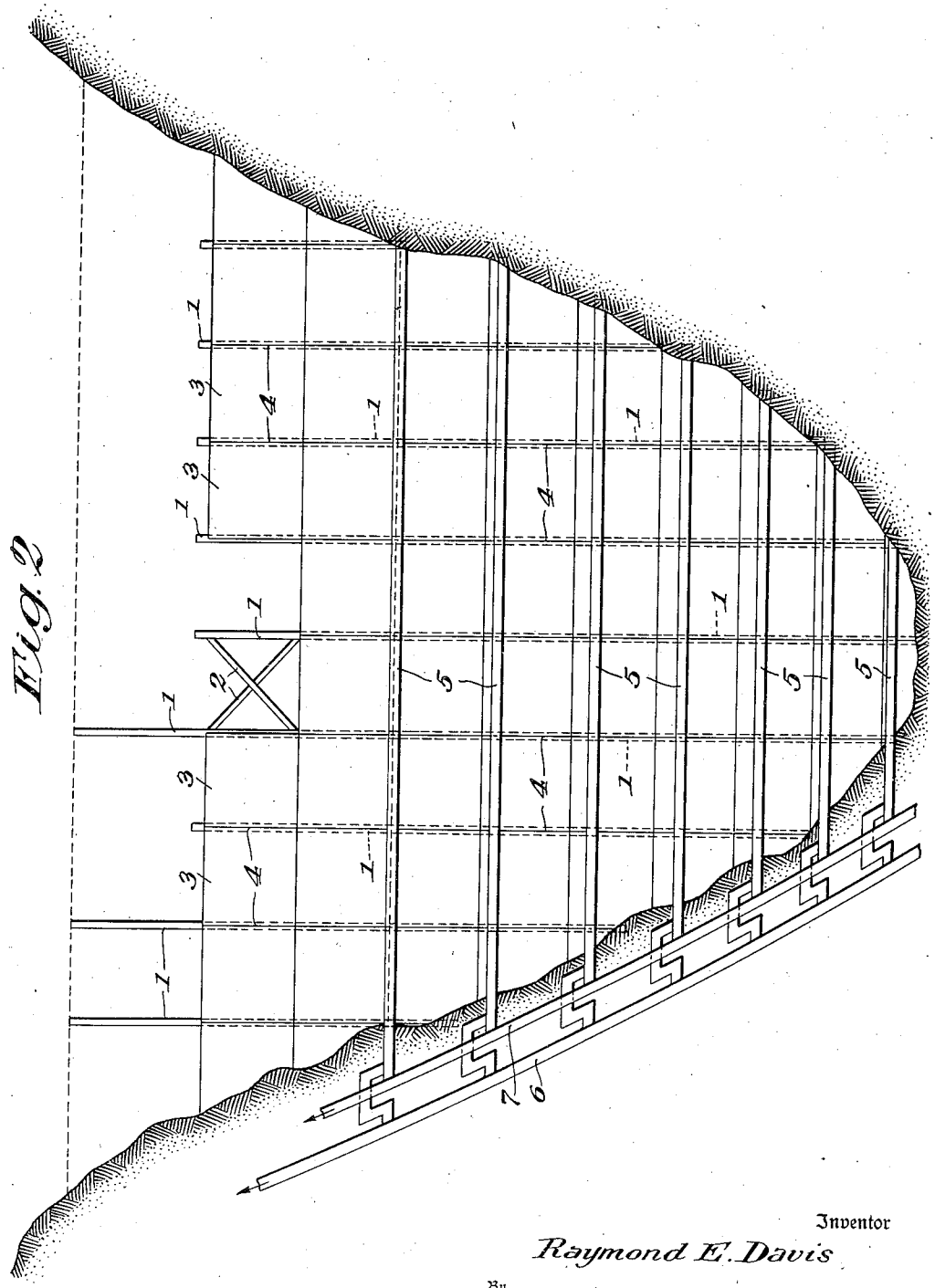
Attorney

Oct. 12, 1943. R. E. DAVIS 2,331,311

CONCRETE CONSTRUCTION PROCESS

Filed Feb. 9, 1939 3 Sheets-Sheet 2

Fig. 2



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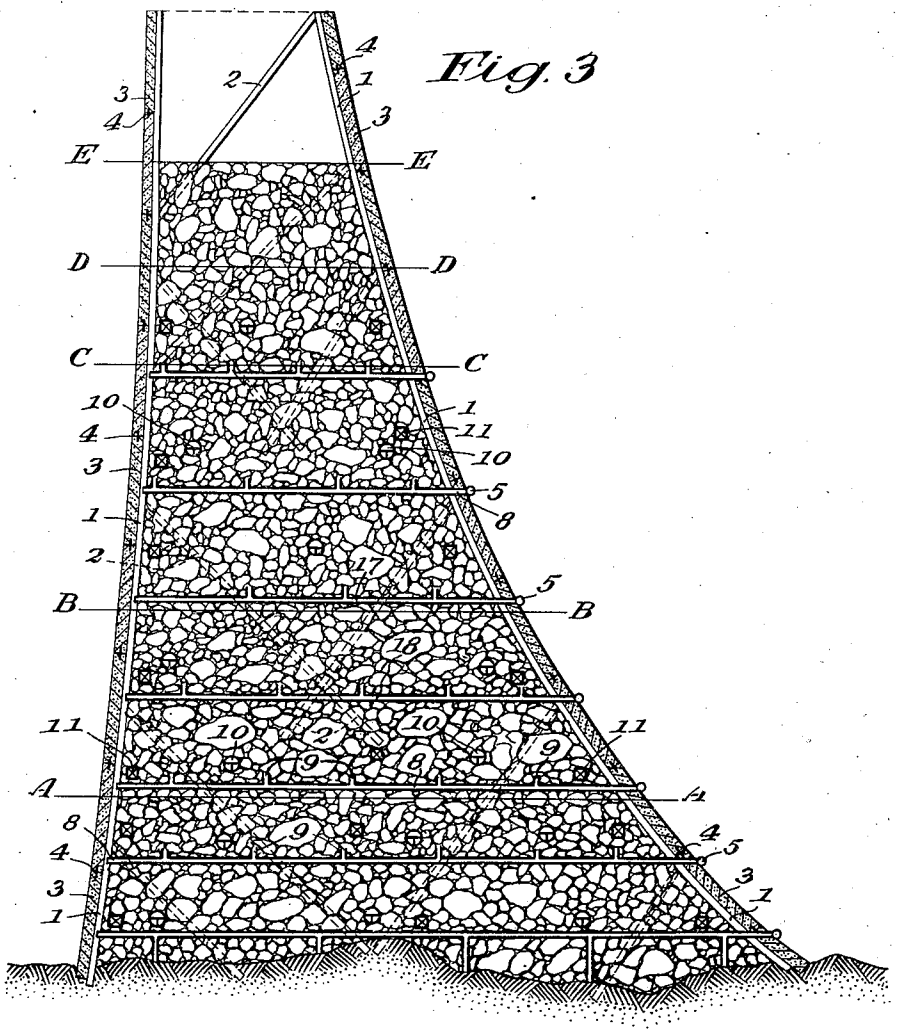
Attorney

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CONCRETE CONSTRUCTION PROCESS

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Fig. 3



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2,331,311

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2,331,311

CONCRETE CONSTRUCTION PROCESS

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Application February 9, 1939, Serial No. 255,455

10 Claims. (Cl. 61—30)

The present invention relates to the construction of large concrete structures and more particularly to such structures which it is desired should behave as monoliths when completed and in service such as arch dams, gravity dams, bridge piers and large masses of concrete in general. For simplicity of description the invention will be described as applied to the construction of a gravity dam although it is understood that the invention is not limited to this particular type of structure.

In the design and construction of concrete gravity dams primary objectives have been to rapidly build a structure which, after completion, would behave as a monolith, would be watertight and would, over a long period of years, resist the action of weather and erosion.

In an effort to accomplish the first of these objectives, it has been customary practice to build a concrete gravity dam as a series of interlocking blocks or columns, vertically separated by joints called "contraction" joints, which permit the mass of any block to contract horizontally without restraining effect from neighboring blocks.

Each block is ordinarily constructed as a series of horizontal or slightly inclined layers termed "lifts," and the top of each lift is left exposed for a few days in order that a portion of the heat of hydration of the cement in the lift may be dissipated to the air, thus reducing the maximum temperature below that which would obtain if construction were made continuous. Also, for the same reason the thickness of lift is limited to a few feet. Quite customarily it is specified that the thickness of lift shall not exceed 5 feet and that the interval of time between the completion of one lift and the beginning of the succeeding lift shall not be less than three days. The top of each lift is substantially a plane surface and the junction between lifts is called a "construction joint plane" or a "day's work plane."

As the concrete in each block is placed and the process of hardening begins, the hydration of the cement is accompanied by the evolution of heat which raises the temperature of the mass. Under the prevailing construction practices, this temperature rise in the center of a thick mass may be 40° F. or more above the temperature of the freshly placed concrete, and the maximum temperature may not be reached for a month or more after the concrete is placed. Subsequently with the gradual dissipation of heat to the surrounding media, the mass gradually cools until after a period of years it reaches an equilibrium temperature corresponding to the mean annual temperature of the region in which the dam is located. As the mass cools, each block contracts and the joints between blocks open. Attempt is then made to fill the small spaces formed by the joint openings by forcing under high pressure a mixture of cement and water, called "neat cement grout," into the joints through pipes which were placed in the dam during construction. When this grout hardens, if the joints are thus filled, each block, through interlocking keys or through natural bond, is assumed to be locked to its neighboring blocks, and if there are no cracks in the blocks between contraction joints, the dam will act as a monolith.

In an effort to accomplish the second of the above objectives, namely that of water-tightness, and also to make secure against the tendency of the mass above, when subjected to water pressure, to slide along the construction joint planes, it has been the customary practice to clean the top of each lift so that there will be no surface film of inert material and so that the aggregates will be exposed. This is usually done with a high pressure air and water jet after the cement has stiffened but before it has hardened to a point where it cannot be removed from the surface aggregate by this process. And just before the next lift is started, this preliminary "clean-up" is followed by a final "clean-up" for which, in addition to the air-water jet, there may also be employed, for the removal of calcium-carbonate deposits and vegetable growths, a sand blast. The beginning of the new lift is a thin layer of sand-cement mortar which is brushed by hand with brooms into the top of the preceding lift.

In an effort to accomplish the third objective, namely that of resistance to erosion and weather, it has been customary practice to employ in the concrete placed next to the upstream and downstream faces of a dam a higher cement content than for the body of the mass and to exercise a much greater degree of care in tamping and spading these exterior layers than for the mass as a whole, in order to secure homogeneity. The higher cement content naturally produces a stronger, less yielding, more brittle concrete, as well as a concrete which is more resistant to erosion and weather.

From a critical inspection of a large number of dams, I have found that in no single instance have the objectives previously mentioned been completely attained by prevailing practices. Even where the methods of design and construc-

tion represented the best in modern practice, dams are not water-tight and do contain cracks of a magnitude which makes it apparent that they cannot behave as monolithic structures. Because of these conditions, it seems evident that the stress distribution in these structures is considerably different from that calculated in design and that their stability is less than has commonly been assumed. Moreover, most dams that have been in service for any considerable period in severe climates exhibit exposed surfaces that have to a degree disintegrated under the action of weather.

The major cracks, which are all due to thermal changes as the mass cooled from the relatively high temperature reached during hydration of the cement, are generally vertical and are both normal to and parallel with the dam axis. They are largest and most frequent near the foundation. They indicate that no economically practical spacing between contraction joints could be made sufficiently small to eliminate such cracks. There are also quite generally smaller horizontal cracks at construction joint planes in both upstream and downstream faces, due also to temperature changes, which cracks apparently extend only a few feet into the mass. There is also, of course, the usual surface crazing, due to drying shrinkage, which is of no particular significance so far as the behavior of a dam is concerned.

Quite generally where contraction joints have been grouted, leakage is manifest in galleries and in the downstream face of dams at vertical cracks between contraction joints, but more particularly at horizontal construction planes. Just below these planes in the downstream face is where the most severe disintegration usually takes place.

A principal object of the invention is to provide a large concrete structure, the principal mass of which is truly monolithic and without contraction and expansion joints and at the same time substantially free from stresses or cracks due to thermal changes resulting from hydration of the cement. A further object of the invention is to provide a large concrete structure which will remain water-tight. A further object of the invention is to provide a large concrete structure which will resist the action of weather and erosion over a long period of years. A further object of the invention is to devise a construction process for large concrete structures which will make possible the use of larger sizes of aggregate than can be used in known processes.

An illustrative embodiment of the invention is shown in the accompanying drawings in which,

Fig. 1 is a plan view;

Fig. 2 is an elevation; and

Fig. 3 is a typical section of a dam in process of construction showing the dam at various stages of construction.

I have found that there can be produced at low cost a concrete of adequate strength for large structures by forcing sand-cement grout into a properly graded mixture of aggregate if an agent for increasing the plasticity of the grout, such as a cement dispersing agent, is added to the grout. I have also discovered that by using a cement of the proper water-retaining characteristics and of the proper composition, preferably a finely ground Portland-pozzuolan cement for which the Portland cement constituent has a low heat of hydration and the pozzuolan is of a type which makes for water-tightness and low water gain, and to which cement there is added a special dispersing agent, the grout can be forced for long distances through the graded aggregate without appreciable separation of the water from the cement and sand, and that the adiabatic temperature rise of concrete produced by forcing such grout into the graded gravel does not exceed 25° or 30° F. from a starting temperature of 35° to 40° F.

From what has gone before, I reasoned that for the mass of the dam, if the aggregates could first be placed and then be cooled to a sufficiently low temperature, say 32° to 40° F., and if the spaces between the aggregates could then be filled with a sand-cement grout of an appropriately low temperature, the temperature of the resulting mass would slowly rise to a temperature at or near the mean annual temperature. Thereafter, there would be no substantial temperature change. For this reason, contraction joints would not be required and there would be no opportunity for cracks to develop. This procedure would also make possible a continuous construction operation, with no horizontal construction joints. Hence, the expensive operation of construction joint clean-up required by the ordinary methods of construction would be eliminated. I found by experiment that grouts at these low temperatures retained their mobility much longer than corresponding grouts at normal temperatures. I also found that the resulting concretes ultimately developed higher strengths than similar concretes manufactured at normal temperatures.

When this method of construction is followed, it will usually be desirable to first build an outer shell to serve as a form in which the graded aggregates for the mass of the structure may be deposited. This shell may be constructed in any manner and of any material suitable to the purpose the completed structure is to serve. Thus, it may be of a temporary or permanent nature, may be of unitary construction or made up in several parts, or may take the form of a caisson. The shell may be composed of thin, articulated slabs of highly impervious reinforced concrete precast and cured, and then placed in position on a frame to act as a form for the mass. These face slabs can be joined together with flexible strips of copper or other ductile and corrosion-proof metal, so that there could be small movement of one slab with respect to adjacent slabs, yet the joints at all times would be perfectly sealed against the passage of water to the interior. In this way the face slabs can expand or contract with changes in temperature of the surrounding air, and when joined together in the manner just indicated produce a form in which the graded aggregates for the mass or core of the dam can be deposited.

I have discovered by experiment that when water pressure is applied to a surface of concrete, there are developed within the mass pressures of intensity varying directly with time and inversely with distance from the pressure face and size of pore spaces. I have also found that the size of pore space can be greatly reduced by the use of very fine cements and dry concrete mixes. Most especially, I found that through the use of certain Portland-pozzuolan cements treated with a special dispersing agent there can be produced by a combination of vibration during casting, pressure after casting, and steam curing subsequent thereto, a concrete in which the pore pressures at a few inches from the pres-

sure face, due to external water pressures will be small even after a considerable period of time. I also discovered by experiment that when a thin slab of such concrete is bonded to a thick mass of ordinary concrete of the type now employed in dams or of the type produced by grouting as hereinbefore described, no appreciable pore pressure was developed in the ordinary concrete even when high pressures were applied to the face of the slab for a long period of time. I found that the concrete slabs thus produced were of exceedingly high strength, several times the strength of ordinary concrete, exhibited a vary small shrinkage due to drying, and were highly resistant to freezing and thawing and to erosion.

When the aggregates have been placed, in any desired amount, up to the full height of the dam, they can then be cooled to any desired low temperature above freezing by the simple expedient of running cold water over the top of the mass and allowing the water to flow downward by gravity through the interstices between the pieces of aggregate, and to escape from the mass through openings left in the form at the base of the dam, or at other levels above the base or through pipe openings at various levels and at various locations in the mass; or by circulating cold water through the mass between pipe or other openings at various levels and at various locations. In winter the natural temperatures of water supplies would usually be sufficiently low to cool the aggregate to the desired low temperature; in summer it will usually be necessary to cool the water artificially.

An alternate method of cooling which may be used when the humidity of the air is low consists in moistening the aggregates by sprinkling with water at temperature higher than that required to cool the aggregates to the desired low temperatures and by blowing air through pipe openings at lower levels in the aggregate mass. The air thus introduced evaporates the water, and thus produces the desired lowering in the temperature of the aggregates.

After the aggregates for any desired portion of the dam above the base or foundation up to the full height have been cooled to the desired low temperature, the grout, consisting of a mixture of cement treated with a special dispersing agent, sand and water of a required fluidity or consistency and of a desired temperature is pumped under a low pressure through pipes with openings in the mass at desired locations and elevations, and the grout forced from these openings under pressure fills the interstices between the pieces of aggregate, displacing air and also, because of its relatively high specific gravity, displacing water. Later as the cement hydrates, the grout will harden and the individual pieces of aggregate will be bound together to form a monolith having properties essentially the same as that of concrete mixed, placed and cured by ordinary methods, but having a uniform temperature, regardless of the season of the year, which when the hardening process has been completed will approximate that of the mean annual temperature of the region in which the dam is located.

Referring to the drawings, 1 indicates frames which serve to support the precast concrete slabs 3. These frames are held in position by struts and ties 2. The joints between adjacent slabs 3 are closed by conventional contraction joints with water-tight seals 4. A system of pipes 5, 6, 7, and 8 which were used during the construction to supply and withdraw water or air for cooling the aggregate and for introducing the grout remains in position in the completed structure. Electrical resistance thermometers 10 and gauges 11 which were used during construction for measuring water and grout pressures are distributed at critical points throughout the core of the dam.

The process of construction will be best understood by reference to Fig. 3. In the dam shown in this figure the outer shell is in place up to the level EE and has been filled with aggregate to this level. At the lowest level, below the line AA, the dam is completed, the aggregate having been cooled and the grout run in and hardened. Between the levels AA and BB grouting may be in progress. The grout is introduced through one or more of the distributor pipes 8 in this level, and as it rises displaces any cooling water present in this level upwardly within the aggregate to a higher level. In this higher level, for example between BB and CC, the operation of cooling the aggregate is in progress. This may be accomplished by running in small quantities of water through a distributor pipe 17, and blowing in cooling air through a distributor pipe 18 which is preferably near the bottom of the level. When a cold water supply is available it may be preferable to introduce cooling water through one set of distributor pipes and withdraw it through another. It will usually be found desirable to lead the grout main 6 to a central grout plant 14, where the grout for the entire operation can be prepared and from which it can be pumped under pressure. Similarly the water main 7 can be led to a central pumping station 15. A refrigeration plant 12 for cooling the water if necessary may be located in the vicinity of the pumping station. The leads from the electrical resistance thermometers 10 and from the pressure cells 11 run to a general control station 13 at which the operations of cooling and grouting can be controlled.

At a higher level between DD and EE placing of aggregate may be in progress and simultaneously at a still higher level, above EE, the operations of placing the framework 1 with its struts and ties 2 and placing of the slabs 3 may be carried on without interference with the work at other levels.

There will thus be produced a dam with a highly imprevious outer shell in which there are joints permitting expansions or contractions due to day-by-day or month-by-month changes in temperature, and a truly monolithic inner mass, without contraction joints, for which the temperature will not gradually decline from the maximum reached during hydration of the cement and thus produce tensile stresses and cracks, as is the case with ordinary construction, but which after the mass has hardened, will remain at a substantially constant temperature and will, therefore, remain forever substantially free from stresses due to thermal changes.

The construction procedure to be followed in building a dam by this new method will naturally depend upon the size of the dam and upon other conditions. For a low dam the entire outer shell may be constructed or erected, the entire mass of the aggregate may be placed and this mass may all be cooled to the desired low temperature before the operation of grouting is begun.

In a high dam the operations of erecting the outer shell, of depositing the aggregate, of cooling and of grouting may be carried on simultane-

ously. That is, at any time during construction grouting may be in progress at a lower level, cooling may be in progress at an intermediate level, deposition of aggregates at a higher level, and shell erection at a still higher level.

Also, when the outer shell is formed of concrete slabs the thickness of the slabs, the quality of concrete of which they are composed, the amount and position of steel reinforcement, the size and arrangement of slabs, the manner in which they are connected to their supporting frames, and the nature and size of the supporting frames, and the manner of anchoring the slabs and frame to the mass will naturally depend on the size of the dam, the rapidity with which construction is to be carried out, and other conditions. In a small dam it will generally be more economical to cast the slabs in place, at the time the supporting frame is being constructed. In a large dam there would be an advantage in precasting the slabs in a central casting plant. The slabs and their supporting frames, with their anchors or ties, should be designed to safely carry the loads calculated to come upon them during the construction operation, including lateral pressures from the mass of aggregate, from cooling water and from grouting.

Ordinarily, for this new method of dam construction the operations of preparing the foundation rock are the same as those customarily employed, and a plant for crushing, washing and screening the sand, gravel or stone into various sizes is required as in the customary practice.

In dams built by the present method the maximum size of aggregate is limited only by the economics of handling and placing and the larger pieces may have a least dimension of several feet inasmuch as the aggregate need not be run through a concrete mixer. In ordinary concrete dams the maximum size of aggregate is such as will pass a six-inch opening. The larger maximum aggregate size obtainable by following the teaching of the present specification results in a reduction in the void space considerably below that obtained in conventional practice.

Inasmuch as the operations of crushing the rock to reduce it to sizes suitable for the aggregate result in progressively reducing the strength of the rock by weakening the rock along cleavage planes, the use of larger sizes of aggregate results also in increased strength in the aggregate.

When the aggregates are placed in the dam, it is desirable that the total void space which is later to be filled with grout be a minimum but that the sizes of voids be sufficiently large that the grout will readily flow into the voids under low pressures. By large-scale experiments I have found that these two objectives are attained when the minimum size of aggregate is such as will barely be retained on a screen having ½" openings, where the maximum size is as large as is practicable economically to handle and place, and where there is a uniform gradation of sizes from small to large. Where the aggregates are thus properly graded and the maximum size is of the order of 12 inches, I have found that by properly regulating the amounts of aggregate of various sizes, the void spaces may be reduced to 20% or less of the total overall volume.

I have also found that best results are achieved when the aggregates are deposited in the form in substantially horizontal layers, for each layer first placing the larger stones of size 12 inches or greater, then placing thereon material of smaller sizes. In this way, the aggregates of smaller sizes find their way by gravity into the interstices between the larger pieces. The consolidation of the aggregates of a layer so as to give minimum void space is most efficiently performed if the aggregates are mechanically vibrated with implements such as are generally used for the compaction of concrete in the forms.

To fill most completely the voids, I have found it desirable to start grouting at low areas in the foundation rock when these low areas have been drained free from standing water but are not dry. At levels above the foundation it is best not to begin grouting until the grout from below has risen above the grout outlets at the level in question. The grouting should be carried out in such manner as to maintain the free surface of the grout approximately horizontal. Once grouting has proceeded to the point where irregularities in the foundation rock at the base of the dam have been covered with grout, it has been found that equally good results are achieved when the operations of grouting and cooling with water are carried out simultaneously, provided the operation of grouting is made continuous. The special grout is not diluted by the water except at the surface of contact, and since the specific gravity of the grout is double that of water, as the grout level rises, it displaces water with which the voids may be filled.

While for the grout any cement may be employed, through large-scale experiments I have found that best results are obtained with a finely ground Portland-pozzuolan cement, treated with a plasticity increasing agent, for which the Portland cement constituent is of a composition low in tricalcium aluminate, say less than 6 percent and moderately low in tricalcium silicate, say about 25 percent, and for which the pozzuolan is high in silica of a form which under moist conditions most readily combines with calcium hydroxide. The percentage of the pozzuolan in terms of the weight of the entire cement preferably should not be less than 30 but may for certain pozzuolans be as high as 50. The advantages in the use of a cement of this type are (1) that its heat of hydration is very low, perhaps as low as 60 calories per gram, which makes for a very low temperature rise in the concrete, (2) that at the low grouting temperatures, the cement hydrates very slowly and the grout will retain its fluidity for a period as long as 24 hours, (3) that there will be practically no tendency under pressure for the water to be forced out of the grout, and (4) that the hardened grout will be exceedingly water-tight.

As the plasticity increasing agent, any of the known plasticizers for cement, such as bentonite, alkylated naphthalene sulfonic acids, the soaps or the diatomaceous earths may be used but since these materials, unless carefully controlled, tend to adversely affect the strength or other properties of the concrete I prefer to increase the plasticity by the addition of a dispersing agent for cement.

By the term "dispersing agent" is meant any material which produces a more nearly uniform distribution of the cement particles throughout their water-sand environment by rendering the particles mutually repellent. These materials increase the number of discrete particles available for hydration and increase the plasticity of the mix by preventing the formation of clumps or aggregations of cement particles. The most satisfactory materials for this purpose known to me

at the present time are: the formaldehyde condensation products of the naphthalene sulfonic acids and the water soluble derivatives of lignin, such as sodium lignin sulfonate, calcium lignin sulfonate, sodium lignate, and the glycol lignins (preparation described by Brauns and Hibbert, Journal of the American Chemical Society, 1933, vol. 55, page 4720).

Experiments have shown that where the minimum size of aggregate is not less than ½", a grout composed of a mixture of one part of cement of the type hereinbefore described and not to exceed three parts of a properly graded sand of maximum size such as will barely pass a screen having 14 meshes to the inch and with not less than 15% passing a screen having 100 meshes to the inch, with water sufficient to produce a pastelike fluidity or consistency, may be made to flow for long distances through graded aggregates and for all practical purposes to fill the voids even when the pressures under which the grouting is performed are but a few pounds per square inch.

Normally as the work of placing the aggregates proceeds, distributor pipes 8, electrical resistance thermometers 10, and pressure cells 11 should be placed at various levels and at various locations. The operation of cooling the aggregate which has been placed may be carried out by pumping cold water through certain portions of the system of distributor pipes, while at the same time other portions of the system may act as drains, or air may be forced through certain portions of the system for the purpose of evaporating moisture from aggregates, which moisture is supplied by sprinkling the layers of aggregate above. The resistance thermometers 10 will be used to control the operations of cooling the aggregate to the desired low temperature and will later be used to determine the temperatures of the concrete mass as the grout hardens and heat is liberated by the cement. The pressure cells 11 will be used to determine and regulate pressures, and hence heads, of cooling water when a circulating cooling system is employed, and to determine and regulate grout pressures in order that form pressures will not be excessive and in order to make sure that all areas are grouted.

Preliminary to the construction of a dam by this method, experiments would be made to determine for the aggregate, the proportions of various sizes which are likely to result in a minimum void space when they are placed in the dam and also likely to produce a void structure which the grout under pressure will with certainty penetrate. Experiments should also be made to determine the grading and amount of fine sand which may be employed with a cement paste of fixed maximum water-cement ratio to produce a grout which will readily flow under small pressures into the interstices of the graded aggregates, and from which the water will not readily separate.

The approximate temperature rise of the grouted mass can be calculated for any given starting temperature from the specific heat of the aggregate, the volume of void space and the rate and amount of heat of hydration of the cement. The mean annual temperature of the locality can be closely determined by the temperature of the underlying rock at the dam site. Given the temperature rise of the grouted mass and the mean annual temperature, it is a simple operation to calculate the temperature to which the aggregate and grout must be cooled in order that the temperature of the hardened mass will approximately equal the mean annual temperature. The calculated value can be experimentally verified by placing in an adiabatic calorimeter a sealed test specimen of freshly grouted aggregate and observing the temperature rise. And at the same time there may be determined the strength at various ages of grouted specimens cured adiabatically from the calculated low temperature. It is true that adiabatic conditions will not exactly obtain within the mass of the dam. Heat transfer through the outer shell will to some extent raise or lower the temperatures of layers of grouted aggregate adjacent to the shell and the temperatures of these layers will be somewhat above the adiabatic temperature in summer and below in winter. Also, if cooling water is circulated over the top of a grouted layer in which the cement has partially hydrated and which is, therefore, warmer than the cooling water, heat will flow to the latter and the temperature rise of the grouted mass will be less than the adiabatic. However, I have found that allowances can be made for the amounts of heat thus transferred. Moreover, it is not essential that the final temperature of the hardened mass be exactly equal to the mean annual temperature; a few degrees greater or less is of no consequence.

After the work is started, it is desirable that the grouting operation be a continuous process, so that the top layer of grout is always in a plastic condition, and it is also desirable that the open ends of grout pipes be buried in a grout layer, raised from below, before they are placed in operation. In this way the upper layer of grout is always being pushed upward by fresh grout from below and no appreciable amount of water is trapped in the voids. With a special grout of the proper cohesiveness, cooling water may slowly flow over its top surface without appreciably diluting the grout and without removing any appreciable amount of cement.

In the appended claims the term "mechanically cooling" is to be interpreted as applying to a controlled cooling of at least one of the components of the final mass by mechanical means.

I claim as my invention:

1. The method of constructing a monolithic gravity dam which comprises erecting a relatively thin outer shell of weather resistant concrete slabs separated by expansion and contraction joints, filling the lower part of the space inside the shell with graded aggregate, placing a system of pipes leading from a central station outside the shell to points at different levels inside the shell, cooling the lower levels of aggregate by flowing water through the aggregate from certain of the pipes, and then filling the voids in the lower levels of aggregate with a mixture of cement, sand, water and a cement dispersing agent by forcing said mixture into the mass of aggregate through pipes below the upper surface of the mixture in the dam, while simultaneously cooling the mass of aggregate at intermediate levels by flowing water through it from other pipes, placing graded aggregate inside the shell at higher levels and adding to the height of the shell at still higher levels.

2. The method of constructing a large monolithic concrete structure substantially free from stresses or cracks due to thermal changes resulting from hydration of the cement comprising erecting a relatively thin outer shell of slabs of highly impervious and weather-resistant con-

crete joined together by contraction and expansion joints, placing a mass of graded aggregate within the shell, cooling the mass of aggregate by wetting it with water and blowing air through it and then, before the aggregate has warmed up to atmospheric temperature, filling the voids in the aggregate with an hydraulic cement composition.

3. The method of constructing a monolithic gravity concrete dam substantially free from stresses or cracks due to thermal changes resulting from hydration of the cement which comprises erecting a relatively thin outer shell of weather resistant concrete slabs on a supporting framework providing for expansion and contraction of the shell, placing graded aggregate inside the shell, placing a system of pipes leading from a central station to points at different levels inside the shell, cooling the aggregate by flowing water through it by means of the piping system, draining the water from the aggregate, and then filling the voids in the aggregate with a mixture of sand, cement, water and a cement dispersing agent by flowing the mixture into the aggregate through said pipes.

4. The method of building a large weather-resistant monolithic concrete structure substantially free from cracks due to cooling of the structure from the maximum temperature developed by hydration of the cement which comprises erecting a relatively thin outer shell of slabs of highly impervious and weather-resistant concrete joined together by expansion and contraction joints, placing a system of pipes leading from a central station outside the shell to a plurality of points at different elevations within the shell, placing a mass of graded aggregate within the shell, cooling the aggregate by flowing water therethrough from pipes of said system and filling the voids in the aggregate with a cement grout containing a cement dispersing agent by forcing the grout into the mass of aggregate through pipes of said system.

5. The method of constructing a large weather-resistant monolithic concrete structure which comprises erecting a relatively thin outer shell of weather resistant concrete slabs separated by contraction and expansion joints, placing a plurality of pipes leading to a plurality of points at different elevations within the shell, placing a mass of graded aggregate within the shell, cooling the aggregate by flowing water therethrough from said pipes, and filling the voids in the aggregate with a cement grout progressively from the bottom upwardly by forcing the grout into the mass of aggregate first through the lowermost of said pipes and then through said pipes at successively higher levels.

6. The method of building a large weather-resistant monolithic concrete structure substantially free from cracks due to cooling of the structure from the maximum temperature developed by hydration of the cement which comprises erecting a relatively thin outer shell of slabs of highly impervious and weather-resistant concrete joined together by expansion and contraction joints, placing a system of pipes leading from a central station outside the shell to a plurality of points at different elevations within the shell, placing a mass of graded aggregate within the shell, cooling the aggregate by flowing water therethrough from pipes of said system and filling the voids in the aggregate with a cement grout by forcing the grout into the mass of aggregate through pipes of said system.

7. The method of building a large weather-resistant monolithic concrete structure substantially free from cracks due to cooling of the structure from the maximum temperature developed by hydration of the cement which comprises erecting a relatively thin outer shell of slabs of highly impervious and weather-resistant concrete joined together by expansion and contraction joints, placing a system of pipes leading from a central station outside the shell to a plurality of points at different elevations within the shell, placing a mass of graded aggregate within the shell, cooling the aggregate by flowing water therethrough from pipes of said system and filling the voids in the aggregate with a cement grout containing a plasticizing agent by forcing the grout into the mass of aggregate through pipes of said system.

8. The method of constructing a large monolithic concrete structure substantially free from stresses or cracks due to thermal changes resulting from hydration of the cement which comprises erecting a relatively thin outer shell, filling the shell with a concrete mass formed from independently placed components comprising graded aggregate and a fluid cement grout by placing the aggregate within the shell, mechanically cooling a component to such a low temperature that the heat liberated by hydration of the cement cannot raise the temperature of the final mass substantially above the mean annual temperature of the locality, and while the cooled component is at a low temperature filling the voids in the aggregate with the fluid cement grout.

9. The method of constructing a large monolithic concrete structure substantially free from stresses or cracks due to thermal changes resulting from hydration of the cement which comprises erecting a relatively thin outer shell, placing graded aggregate within the shell, mechanically cooling the aggregate to such a low temperature that the heat liberated by hydration of the cement cannot raise the temperature of the final mass substantially above the mean annual temperature of the locality, and while the aggregate is at a low temperature filling the voids in the aggregate with a cement grout.

10. The method of constructing a large monolithic concrete structure substantially free from stresses or cracks due to thermal changes resulting from hydration of the cement which comprises erecting a relatively thin outer shell, placing graded aggregate within the shell, cooling the aggregate by forcing through the voids in the aggregate a cooling fluid to reduce the temperature of the aggregate to such a low temperature that the heat liberated by hydration of the cement cannot raise the temperature of the final mass substantially above the mean annual temperature of the locality, and then filling the voids in the aggregate with a cement grout.

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