(c) The principles of economics and their application to industry and commerce;
(d) The principles that govern the relations between people, not only as applied to managers and men, but also as applied to governments and society;
(e) The history of nations;
(f) The art of clear and correct expression in speaking, writing, and drawing.

"The relative emphasis to be placed on each of these fundamentals is a matter to be determined for each engineering course."

In emphasizing the importance of training, one must studiously avoid withering the aspirations and stifling the ambition of the large numbers of men in railroad and industrial service who have not had the benefit of overmuch school or any college preparation. These men outnumber vastly the high school and college men, and to their credit be it said that the 65% of Chairmen and 81% of Presidents remaining after taking account of those who have risen from the ranks of engineers have been drawn largely from the men who have had none of the benefits of higher education. Without mentioning them, the names of a number of the ablest and most distinguished railroad Chairmen and Presidents in the United States, who have by sheer ability and pluck risen from lowly ranks and have actually built their own careers and builded admirably well, suggest themselves.

Again quoting from the report to the National Industrial Conference Board:

"Sympathetic guidance of both the college man and the non-college man presupposes a careful evaluation of the work of all employees and assurance to them that talent and effective work will be known to and appreciated by the management. Educators report a growing feeling among undergraduates that in most large corporations a young employee often is lost in a department and for many months may not come under the observation of the leading men of the organization. A large public utility company, the two largest manufacturers of electrical apparatus, and a few other large corporations which have unusual and enlightened personnel departments, in many cases are getting the pick of the young talent, because of their attention to this problem."

"These are some of the ways in which industry can supplement the work of the educators," and profiting by their example thus can the present generation help those who are to "carry on" when it shall have passed.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1584

MULTIPLE-ARCH DAM AT GEM LAKE ON RUSH CREEK, CALIFORNIA*

By Fred O. Dolson† and Walter L. Huber,‡ Members, Am. Soc. C. E.

With Discussion by Messrs. J. Y. Jewett, L. R. Jorgensen, Walter H. Wheeler, C. A. P. Turner, Thomas H. Wiggin, C. H. Howell, E. W. Lane, E. J. Waugh, Alfred D. Flinn, Luigi Luiggi, Thaddeus Merriman, M. M. O'Shaughnessy, J. B. Lippincott, Oren Reed, B. F. Jakobsen, J. D. Galloway, I. Oesterblom, B. C. Collier, Fred A. Noetzli, F. W. Scheidenhelm, Charles W. Comstock, George W. Howson, and Fred O. Dolson and Walter L. Huber.

Synopsis

This paper is submitted for the purpose of calling the attention of engineers to the necessity of giving serious consideration to the action of frost when designing dams for use in cold climates. The writers believe deterioration from frost action will occur in any thin concrete structure subjected to water pressure and extreme cold unless the concrete can be made 100% water-proof (or water-tight).

The results of frost action, therefore, have been pointed out in this paper, together with the expensive repairs necessary to safeguard the structure, and it is hoped the discussion will develop some positive and permanent method of water-proofing concrete.

Introduction

Much has been written in recent years concerning multiple-arch dams, but the writers believe that all the story is not yet told, and it is with the

* Presented at the meeting of October 7, 1925.
† Vice-Pres. and Asst. Gen. Mgr., Southern Sierras Power Co., Riverside, Calif.
‡ Cons. Engr., San Francisco, Calif.

hope of placing before the Engineering Profession another valuable chapter that this contribution is offered. Much of the material heretofore presented has dealt wholly, or almost entirely, with mathematical analyses. It is not intended to attempt an addition to the store of material available along these lines. Indeed, a mathematical analysis and a complete description of the structure which is the subject of this paper has already appeared in the publications of the Society.*

Gem Dam was built in 1915 and 1916, and at the time embodied all the best practice in the design of multiple-arch dams, as is evidenced by its designer, L. R. Jorgensen, M. Am. Soc. C. E., having been awarded the Norman Medal by the Society in 1917 for his paper entitled, "Multiple-Arch Dams on Rush Creek, California".* Eight years of subsequent operation of this structure, during which time the concrete has partly disintegrated by freezing, has afforded opportunities for observations and has necessitated remedial measures which, it is believed, cannot fail to be of interest.

Descriptions of engineering structures which have failed to function as intended are often very instructive. It is hoped this one will prove to be as interesting to those members of the profession who are concerned with similar structures as it has been to the several engineers who have had to do with remedial methods.

Selection of Multiple-Arch Type

Gem Dam, on the head-waters of Rush Creek in Mono County, California, is well up on the eastern slope of the Sierra Nevada Mountains at an elevation of 9 050 ft. (water-surface level) and in one of the most remote localities in the West. All materials necessary for its construction except lumber, which could be cut locally, and rock, must be moved long distances and under difficult conditions. Cement had to be shipped from the place of manufacture by broad-gauge railroad 336 miles, transhipped to a narrow-gauge railroad, and hauled 84 miles farther; then hauled over a sandy desert road, using engines or motor trucks of the caterpillar type, for 70 miles, to the power-house below the dam. Here, it was reloaded on tram cars and raised more than 1 250 ft. vertically on a 4 826-ft. tramway to Agnew Lake, where it was rehandled, loaded on barges, and towed across the lake to be again rehandled and raised an additional height of 550 ft. by another tramway, being finally placed on the dam site at a total cost, even under 1915 conditions, of $7.50 per bbl. In the high altitude of this site, the season during which construction work can be advantageously conducted is necessarily short, often only four months and seldom longer than five months.

The dam site is one of exposed, hard, blue limestone and igneous granite, still showing in many places the polish placed on it in the Glacial Age by the glacier which formerly extended down from the higher Sierra. No earth and very little sand is found in this locality.

Physical conditions governing the original construction of Gem Dam had much to do with the selection of the multiple-arch type. Materials for an

* *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), p. 850.

earth dam were not available. A masonry dam was thought, at the time, to have certain advantages over a rock-fill type. Because of the excessive cost of materials, the quantities required for a masonry dam of the gravity type had to be avoided. These considerations led to the selection of the multiple-arch type.

Description

Gem Dam was constructed in 1915 and 1916 at the outlet of Lower Gem Lake. The reservoir created by it has a storage capacity of 17 216 acre-ft., and is supplied by the run-off from a water-shed of 21.3 sq. miles, ranging in elevation from 9 000 ft. at the dam to 13 090 ft. at Mt. Lyell. The dam is composed of sixteen complete arches, of 40-ft. span, between centers of buttresses, and two fractional arches at the ends. The length at the crest is 688 ft. The maximum height of any individual arch is 84 ft., and the vertical distance from the crest to the deepest point in the foundation is 112 ft.

The arches vary in thickness from 1.0 ft. at the crest to 3.95 ft. at the deepest point, and the up-stream face is inclined at an angle of 50° from the horizontal. The buttresses vary in thickness from 1.85 ft. at their tops to 4.25 ft. at the deepest point, and are strengthened by counterforts, varying in total width from 4.5 ft. at their tops, which are 15 ft. below the crest of the dam, to 11.0 ft. at the deepest point. Two sets of double, horizontal, braced 12 by 30-in. struts extend between the buttresses, one set 15 ft. and one set 45 ft. below the crest. Spillway openings, which can be fitted with stop planks, have been left near the crest of the dam in the two southern arches, the five openings, 6 ft. long by 2 ft. deep, in the end arch being at Elevation 9 050, and the eight openings, 6 ft. long by 2 ft. deep, in the next arch at Elevation 9 048. A steel pipe line leads directly from the dam to the power-house, where a static head of 1 807 ft. is obtained.

This general description, together with the plans, Figs. 1, 2, and 3, and the photographic views, Figs. 4, 5, and 6, should give the reader a fair idea of the structure as it existed from its completion in 1916 until its repair in 1924. A more complete description, including details of reinforcement and an analysis of stresses, is given in Mr. Jorgensen's paper, previously mentioned. A review of this analysis will show that the stresses are within the limits prescribed by good engineering practice and that the design is more conservative than that of other multiple-arch dams which have been constructed to greater heights.

History of Operation

During the eight years of operation of the structure, very few cracks occurred in it. A horizontal crack developed in each of the arches immediately below its crest, due undoubtedly to the fact that the deflection of the walk along the crest, which acted as an arch between the tops of the buttresses, was less than the deflection of the thinner arches of the dam immediately below. This crack introduced no element of weakness and, because of its location and its very slight width, was not evident except to the critical observer. Its existence simply permitted the arches of the dam to resist all water pressure unaided, a function for which they were designed.

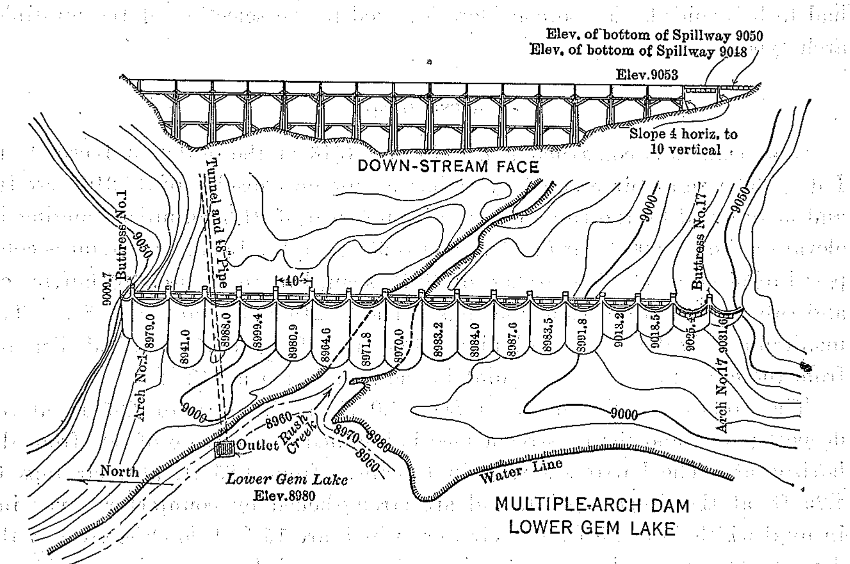

FIG. 1.

Very small diagonal cracks developed near the up-stream toes of three of the buttresses. They were similar to cracks which have developed in the buttresses of practically all the multiple-arch dams which have been constructed to date. The usual practice has been to provide but little reinforcement in buttresses or to omit it. It is believed that the introduction of a comparatively small amount of reinforcement would have eliminated these cracks in every instance.

Gem Dam has withstood some rather severe tests. In September, 1918, a very heavy rain on the upper water-shed occurred when the spillways were partly blocked with flash-boards, and before the flash-boards could be removed, the entire structure had been overtopped to a depth of 4 in. This overtopping lasted for 8 hours, but not to the maximum depth throughout. Although it was not designed as an overflow dam, no damage resulted.

When the structure was constructed, the up-stream faces of the arches of Gem Dam were covered with a 1 : 2 plaster coat of cement mortar, applied with a cement gun. This coat varied in thickness from $\frac{1}{4}$ in. at the top to $\frac{3}{4}$ in. at the bottom.

At first, the leakage was very small. Mr. Jorgensen* thus describes it:

"Some of the arches on the Gem Lake Dam are absolutely tight, some of them sweat in places, and a few drip in places. A few small springs have formed behind the dam, and a trickle of water comes under one arch; but, all told, the total leakage is very small."

* *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), p. 906.

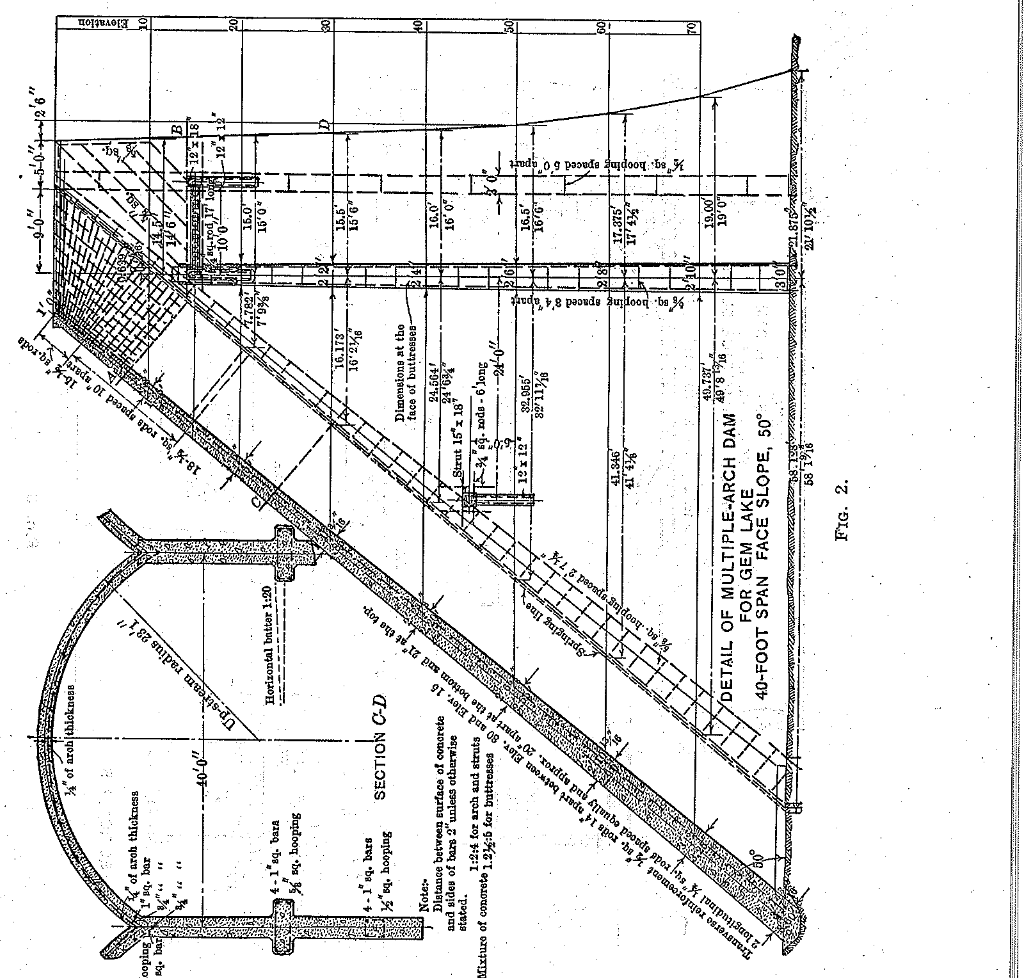

FIG. 2.

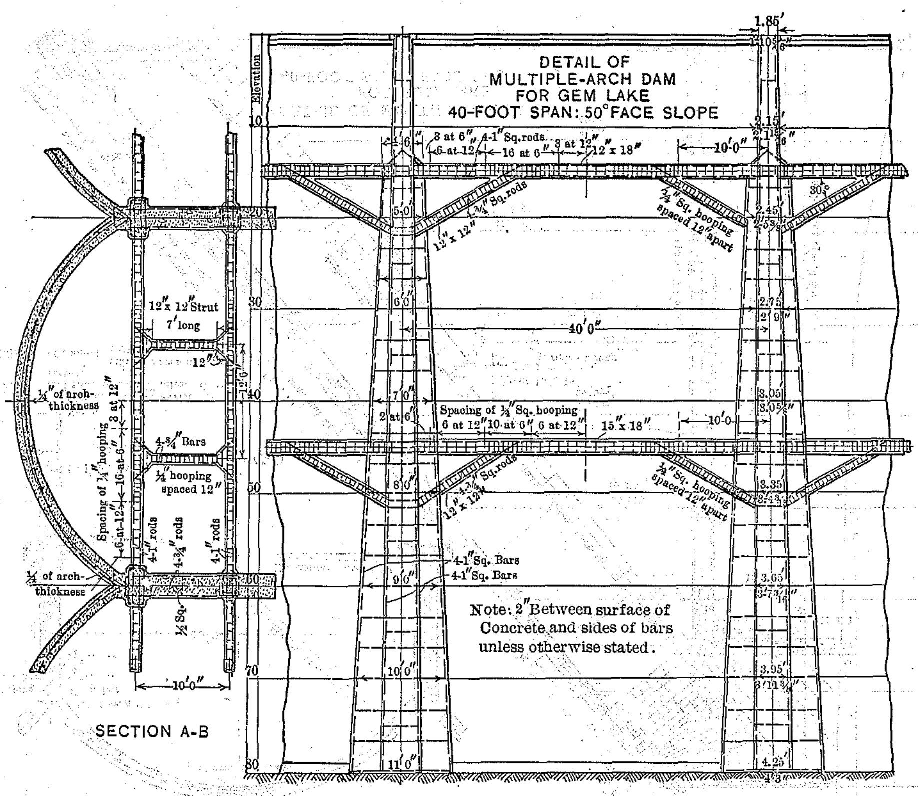

FIG. 3.

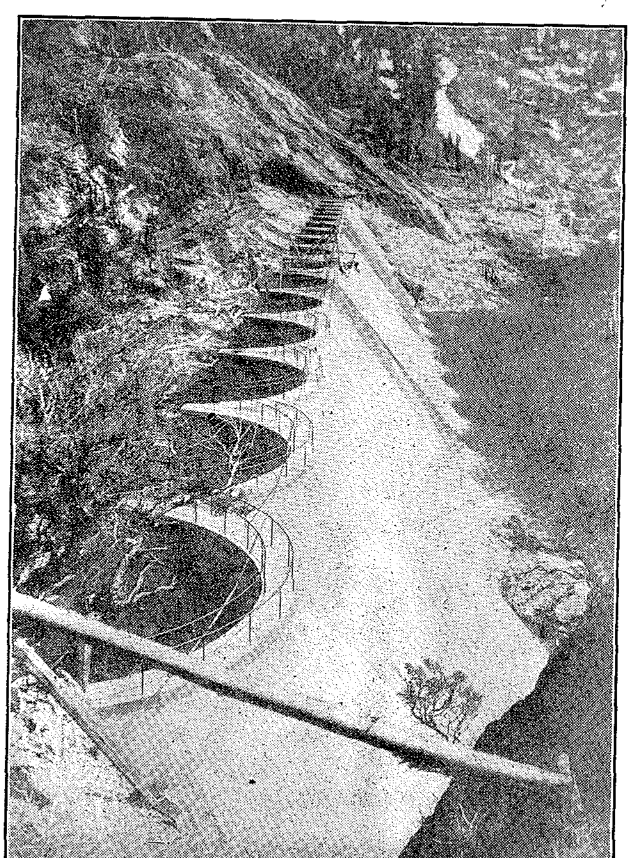

FIG. 4.—GENERAL VIEW OF GEM DAM.

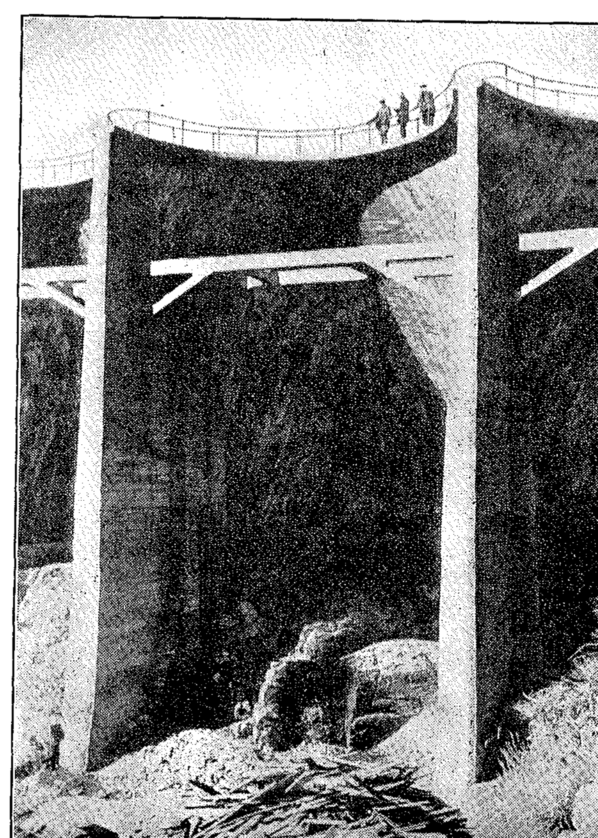

FIG. 5.—DETAILED VIEW OF REAR FACE OF ARCH NO. 3, GEM DAM.

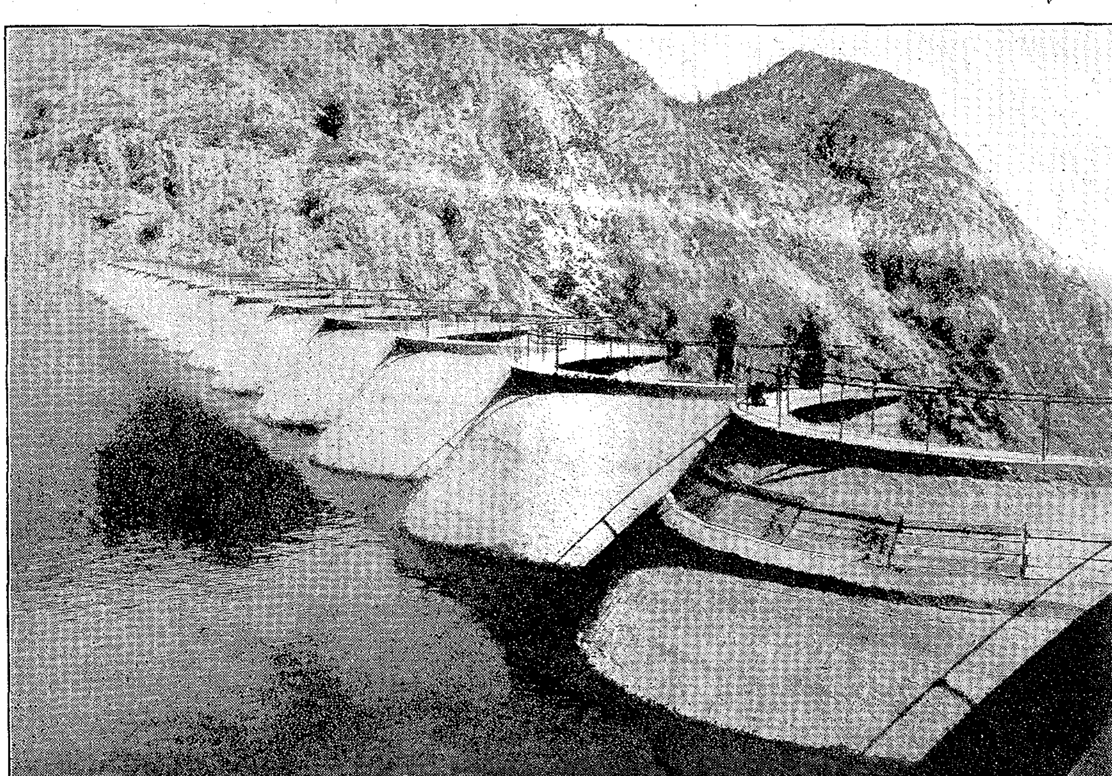

Fig. 6.—Water Face of Gem Dam After Completion of Gunite Coat. Note Operation of Spillway with Stop Planks in Place.

It remained small for two years after the completion of the dam and the filling of the reservoir, and during this time no change in the structure was apparent. During the third year some leakage developed and a white deposit was noticeable on the rear faces of the arches. At first, this condition was not considered serious, as a small amount of leakage through a concrete structure is not necessarily a cause for alarm. After chemical analyses, it was concluded that the white deposit was laitance which was being washed out of construction joints.

During the next two years serious disintegration started on the face of the dam, apparently due to the concrete freezing in thin layers on the face and disintegrating by frost action. This action which was slow at first, increased very rapidly with each additional year of age. It was originally believed that the damage had resulted from ice which formed on the surface of the water in the reservoir to a thickness of 30 or 40 in. This ice adhered to the surface of the dam and, as the water was lowered and the ice thus left overhanging, it would tear loose, presumably taking the gunite coating with it. However, this theory was partly disproved by cutting a hole through the ice near the dam and examining the water face immediately below. It was found that, for 8 or 10 ft. under the reservoir surface, this face was covered with a thin layer of ice, thus proving that the freezing was through the thin concrete section of the dam and that the ice on the surface of the reservoir was not the entire cause of the damage.

It was believed that the condition could be remedied if the water face of the structure could be effectively and permanently water-proofed. A careful and detailed study of possible methods of accomplishing this result was made. This study included laboratory tests by J. Y. Jewett, Assoc. M. Am. Soc. C. E., of twelve brands of water-proofing compounds, all of which failed to meet the requirements of the tests.*

The study of water-proofing compounds led to the selection of the so-called "Ironite" treatment. Before applying this treatment, all concrete that showed any signs of disintegration was chipped from the face of the dam. This proved to be quite a task. In places, the concrete over large areas was chipped to a depth of as much as 8 in. Concrete was very carefully replaced in these areas to insure a good bond, and the ends or corners of such areas were chipped out square in an attempt to preserve arch action. After the application of the "Ironite" treatment, the dam was practically water-tight for a short time. However, the "Ironite" coating soon developed hair-line cracks, probably due to expansion and contraction of the arches, and thereafter, with the return of low temperatures, deterioration began again. It was then apparent that more heroic remedial measures must be adopted.

Condition of Dam in 1924

A careful examination showed the upper portion of all arches, extending down approximately 30 ft. from their tops, to be in perfect condition and undoubtedly as strong as at any time in their history. Likewise, a section

* See p. 737.

of the bottom of each arch was little affected. In the intervening middle belt, the concrete had become a dead, inert material with little strength. All concrete in the buttresses was in perfect condition.

Holes were dug into the affected parts of the arches from their rear faces. A blow from a pick produced no ringing effect. Instead, the effect was such as would result from striking hard clay. The concrete was easily displaced, and, with little effort, holes were dug beyond the surface of the reinforcing steel to depths of approximately 18 in. (see Fig. 7), as far, in fact, as it was believed to be safe to carry such exploration, considering that at the time some water was in storage in the reservoir.

A review of conditions convinced all the engineers who made investigations that the damage was due to water from the reservoir percolating into the concrete and there freezing. Temperatures as low as − 25° Fahr. had been recorded during winter months. A review of records showed that when extremely low temperatures had occurred, the water level, in the natural operation of the reservoir, had always been drawn down 30 ft. or more from the crest of the dam, which accounted for the good condition of the concrete in the upper portion of the arches. The flood stages of Rush Creek, which are due almost entirely to melting snow, occur in May, June, and July; consequently, the reservoir is drawn down before the low temperatures of the following winter occur. The buttresses, not being subjected to water pressure at any point, were unaffected. Those parts of the bottoms of the arches which were but little affected, were undoubtedly protected from extreme low temperatures by a snow blanket drifted against their rear faces. This conclusion is substantiated by a similar experience of The Nevada California Power Company with a simple intake dam on Bishop Creek built of thin sections which were similarly affected by low temperatures until the sections back of the concrete water face were filled with earth.

Because of the developments just described, it becomes of particular interest to inquire into the history and quality of the concrete which was affected. As noted by Mr. Jorgensen,* the arches were of 1 : 2 : 4 concrete, the actual ratio of sand to cement being varied with the size of the aggregates, but in all cases $1\frac{1}{2}$ bbl. of cement per cu. yd. of aggregates were used. The rock was crushed in a gyratory crusher and separated into three sizes by a revolving screen having $1\frac{1}{2}$, $\frac{3}{4}$, and $\frac{1}{4}$-in. meshes. The rejects from the screen went into a jaw crusher set to give a maximum size of 2 in. A sand deposit along the shore of Gem Lake was used. Mr. Jorgensen describes the sand, as follows:

"This sand was first pumped, and later shoveled, from the lake, and transported to a storage pile near the mixing plant. This lake sand, which contained $3\frac{1}{2}\%$ of clay and 1% of dirt, was mixed with the sand from the rock crusher (all particles being less than $\frac{1}{4}$ in. in diameter) in the proportion of about three-fourths of lake sand to one-fourth of crushed rock sand. This gave a very good combination, both as to strength and water-tightness."

Compression tests on 6-in. cylinder specimens, made as the work progressed, showed an average strength of approximately 900 lb. per sq. in. for crushing

* *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), p. 879.

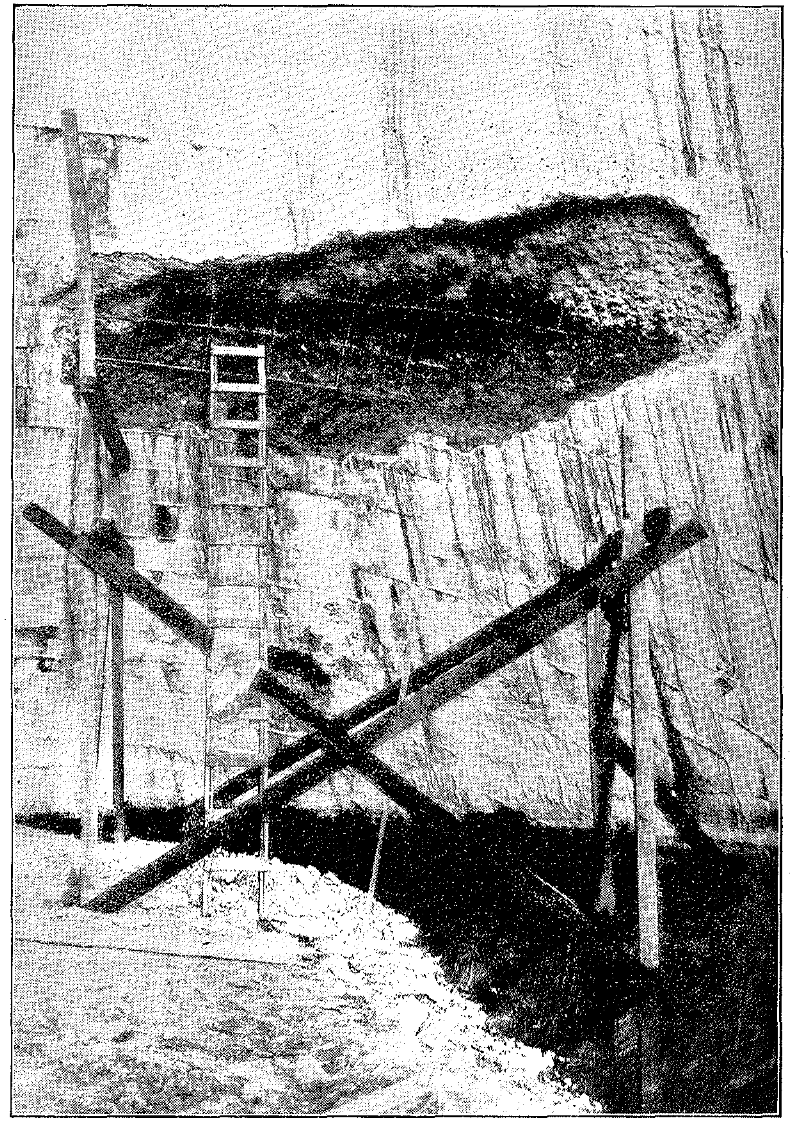

FIG. 7.—EXPLORATION IN REAR FACE OF GEM DAM EXPOSING REINFORCEMENT.

at the age of 14 days. Concrete was distributed to the different arches and buttresses with two-wheeled push carts and short chutes with the minimum opportunity for separation.

Before construction was begun, the design was reviewed by the J. G. White Engineering Corporation, and a representative of this Corporation also later reviewed and favorably commented on the work in the field.

Remedial Methods

The conditions described had developed by the spring of 1924. The preceding winter had been one of almost record low precipitation. It was evident that the run-off would not be sufficient to fill the reservoir and that repairs, if carried out during this one field season, could be completed without the loss of any stored water. On the other hand, repairs extending through two seasons might necessitate wasting considerable water and thus result in a financial loss which should be directly added to the cost of repairs. It should be noted that 1 acre-ft. of water stored in this reservoir is capable of producing 1 200 kw-hr.

Serious consideration was given to the problem of providing a rock-fill back of the concrete structure and utilizing the existing concrete arches as the water-tight face of the rock-fill dam to be thus constructed. Although a rock-fill dam, with its ready drainage, is very desirable at a location such as this, two objections to this method of repair were at once evident. The great quantity of rock necessary could not be placed in a single season, possibly not in two seasons, but, even more important, it was hardly probable that such rock-fill could be placed by any practicable methods so that it would not settle away from the concrete arches and allow them to continue to withstand the full pressure of the water until after they had actually failed.

It was finally decided that the best method of repair would be to pour a concrete gravity section back of each of the arches, extending it up to within 30 ft. of their tops. The section adopted is shown in Fig. 8. To have carried the section higher would have required greater quantities than could have been poured in a single field season. The upper 30 ft. of the existing arches and the buttresses supporting them appeared to be in perfect condition and to need no reinforcement. To clear up all doubts concerning the condition of the upper 30 ft. of the existing arches, they were drilled and tested for hardness. Two samples were cut from what appeared to be the poorest sections and were tested for strength in compression. The tests showed results of 1 880 and 2 170 lb. per sq. in., respectively. The normal operation of the reservoir during eight years had not subjected this part of the dam to water pressure during seasons of extremely low temperature, and it is not probable that future operating conditions will require that they be so exposed. It is not improbable that a horizontal crack will develop in the existing arches opposite the top of the gravity section, due to difference in rigidity of the two types, but it is not believed that any serious results will be occasioned. The two types will simply act independently and without serious leakage.

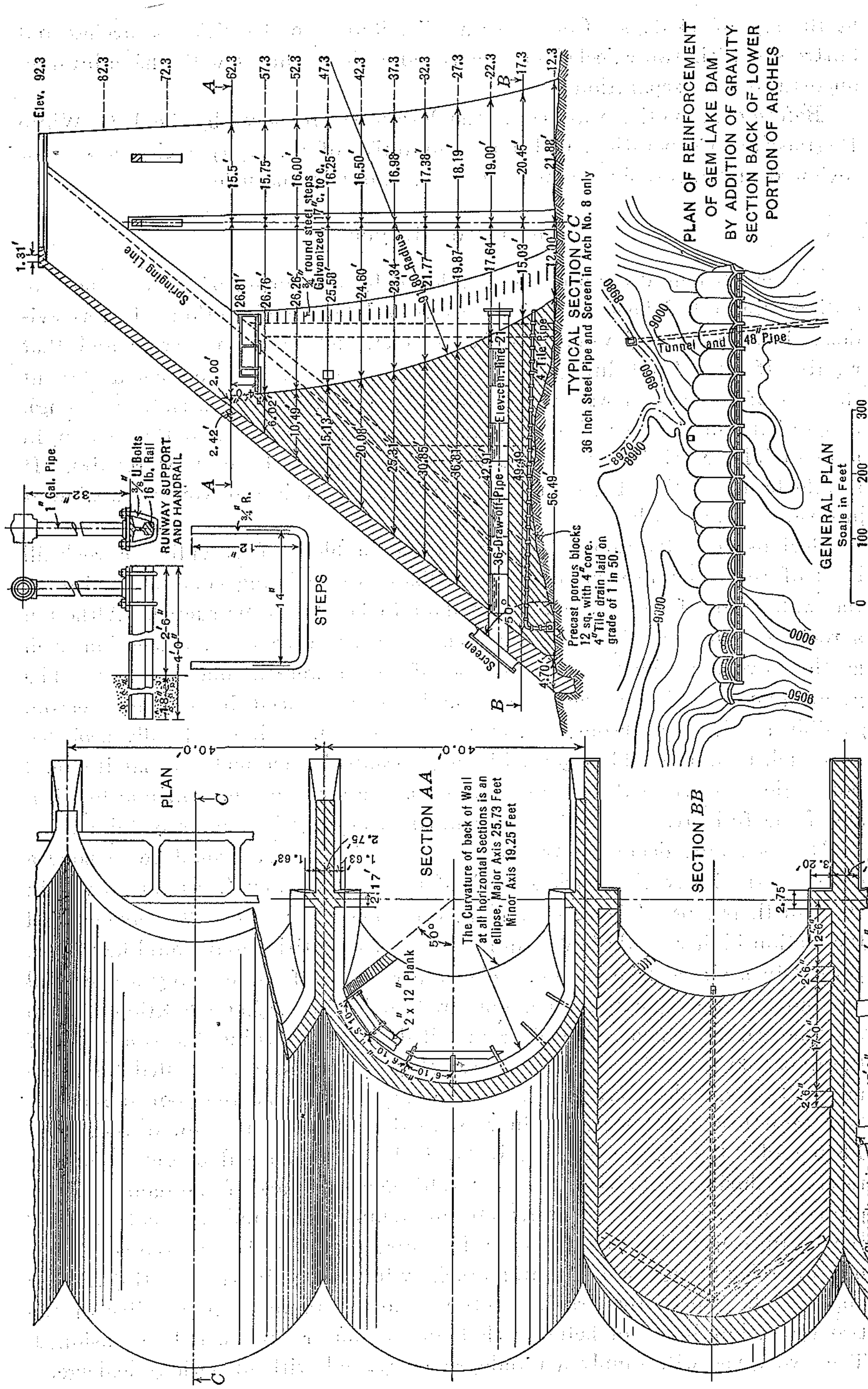

FIG. 8.

It will be noted that the section added back of the arches is not only heavier than standard profiles of gravity dams of similar height, but that, with the added pressure due to the reservoir being filled 30 ft. above the top of the gravity section, the resultant falls well within the middle third of the base, and the maximum pressure at the down-stream toe does not exceed 5 tons per sq. ft. (70 lb. per sq. in.). This is a very light pressure for the excellent hard rock foundation. In addition to the stability afforded by the gravity section, it is necessarily arched in plan, following the 40-ft. arches of the structure already existing. The section was also carried back to secure an excellent bond against the counterforts of the buttresses. It is not believed that stresses can be induced in the gravity section by pressures on the upper 30 ft. of the dam, because such pressures will be transmitted direct to the buttresses.

Drains of precast porous blocks 12 in. square with 4-in. cores were placed at the up-stream toe of the gravity section, and thus at the base of the rear faces of the arches of the former multiple-arch dam and also along the springing lines of the arches. These drains were connected to 4-in. tile-drains laid on a slope of 1 in 50.

Construction

The gravity section was constructed by Dwight P. Robinson and Company, Inc., E. C. Macy, M. Am. Soc. C. E., being in personal charge. The work was begun in June, 1924, and approximately two months of the short available field season was required for the installation of plant and equipment, consisting of rock crusher, aerial cableway, inclined tramway, bunkers, decking, etc.

The tramway from the power-house at Silver Lake to a boat landing at Agnew Lake, constructed in 1915, and previously mentioned, was again utilized after extensive repairs. This tram was constructed of 36-in. gauge track, and both 25-lb. and 16-lb. rails were used, the total length being 4 826 ft., the maximum grade, 68%, and the vertical rise more than 1 250 ft., with many curves and several trestles. A small flat car, 4½ by 8 ft., was used to carry materials. The ⅞-in. steel hauling cable was attached to a single drum-hoist driven by a 100-h.p. electric motor. All construction equipment, tools, camp supplies, lumber, and cement, was hauled up this incline; in fact, all material used except sand and rock. The usual load per trip was 5 tons. The maximum load, the jaw of the rock crusher, was 10 tons. The most troublesome load was the motor launch, 30 ft. long with 8-ft. beam, which had to be carried on two flat cars and shifted several times while in transit because of small clearances. In handling regular loads, such as cement, a round trip was ordinarily made in 50 min., including time for loading and unloading.

Material delivered at the boat landing on Agnew Lake was loaded on a barge (18 by 24 ft. by 3 ft. deep; capacity, 400 sacks of cement, or approximately 20 tons) and towed across Agnew Lake by a launch driven by an 8-h.p. motor.

From the upper end of Agnew Lake, a double-track, 36-in. gauge, incline railway was constructed to the concreting plant situated above the south end of Gem Dam. Because of the precipitous rock slopes, it was necessary to support this tramway on a trestle throughout its length of 1 715 lin. ft. The grades varied from a minimum of 10% to a maximum of 70%, and the total elevation surmounted was almost 600 ft. The tracks were straight with the exception of one curve, having a 40-ft. radius and a 48° deflection angle, located near the top. This tram not only carried the loads from the lower tramway, but also all the rock and sand for concrete. Only the southerly track was used for hauling sand and rock, although the tracks were located so that either could have been used. Sand and rock were hauled in a steel trip car of 4 cu. yd. capacity, which, when loaded, weighed approximately 7 tons. The northerly track, which was used for the transportation of cement, lumber, and camp supplies, was fitted with a small flat car similar to that used on the lower tram. Each car was hauled by a $\frac{3}{4}$-in. steel cable attached to a single drum hoist operated by a 100-h.p. electric motor. The motors were equipped with two speed controllers, a slow starting speed and a hauling speed of 400 ft. per min. The rock car was able to make approximately 4 round trips per hour. It is estimated that 26 428 tons of materials were hauled by this double incline during the short field season.

It was hoped that suitable rock could be found near and above the elevation of the top of Gem Dam, but final examinations showed the most suitable rock available for both the crushed rock aggregate and for making sand, to be a deposit of broken granite located below the dam and across Agnew Lake. Laboratory tests of samples of this rock showed it to be entirely satisfactory. To transport this rock across Agnew Lake, a cableway was constructed from the rock pit to the crushing plant which was at the foot of the upper incline. The rock was excavated and conveyed to the loading bunker by a $1\frac{3}{4}$-cu. yd. Bagley grader operated by a double drum hoist equipped with a 75-h.p. electric motor and $\frac{7}{8}$-in. hauling and haulback lines.

The overhead cableway between the rock pit and the rock-crushing plant required a span between supports of 950 lin. ft., the span between anchors being 1 250 lin. ft. The anchor at the end above the crushing plant comprised a set of four 2-in. eye-bolts grouted in holes drilled in a rock ledge about 300 ft. back of the plant. A single-sheave block was laced by $\frac{3}{4}$-in. wire rope to each of these eye-bolts, and a 4-sheave block was laced to another single-sheave block acting as a thimble for attaching the carrying cable. The 4-sheave block was about 50 ft. from the eye-bolts and was laced continuously through each of these single-sheave blocks with the loose end of the cable clipped back on itself. Whenever an adjustment for height was necessary, this loose end was attached to the hauling line for the cableway car and any slack was taken up by power.

The anchor back of the rock pit consisted of a "deadman" and head-frame of round timbers back-filled over with about 100 tons of rock. The dead end of the cable was clipped around a 36-in. log and carried up through the head-frame, where a 6-sheave block allowed adjustments for height. The hauling hoist was on the mountain side to the rear of the rock-crushing plant and directly under the carrying cable. It was designed to operate the car at a line speed of 500 ft. per min. The haulback hoist was set in the head-frame

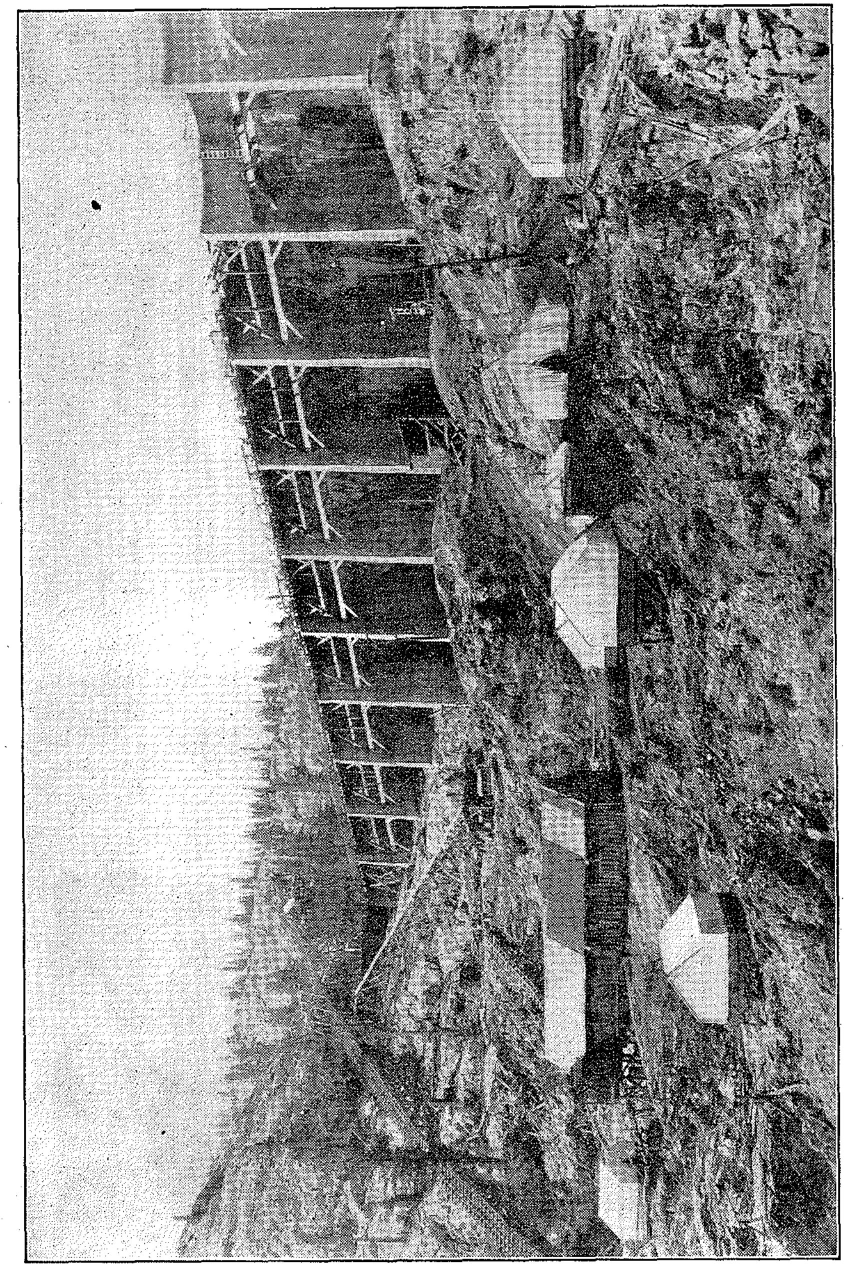

FIG. 9.—PARTIAL VIEW OF EQUIPMENT AND CAMP, SHOWING OPERATION OF INCLINED DOUBLE TRAMWAY, BUNKERS, DECKING, ETC.

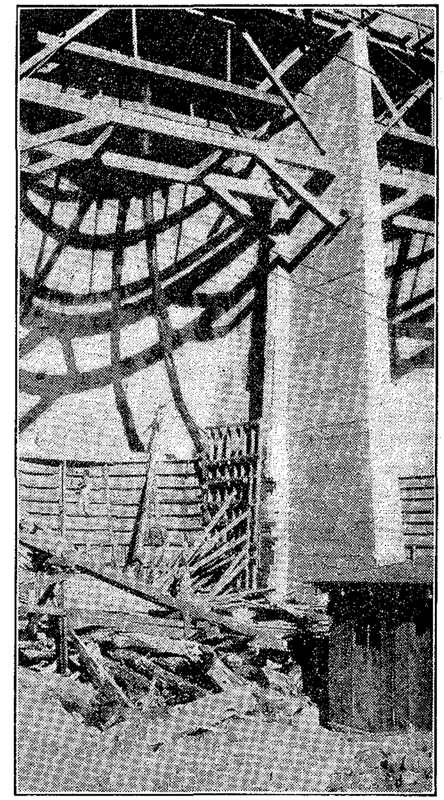

Fig. 10.—Form Work for Arches and Concrete Spout for Conveying Concrete from Overhead Deck.

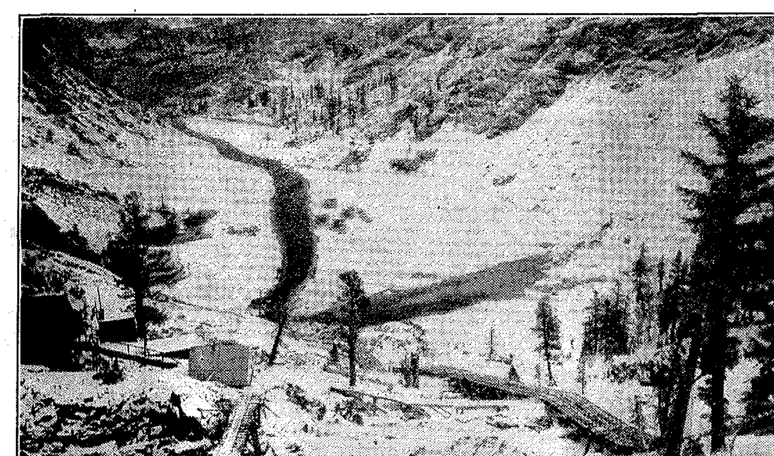

Fig. 11.—View of Agnew Lake, Showing Lanes Kept Open Through Ice for Passage of Launch and Barge.

of the rock-pit anchor. The erection of the original carrying cable, which was 2¼ in. in diameter, was a difficult task requiring the laying of the cable across the lake by utilizing the barge and motor, attaching the end at the rock-pit anchor, and pulling it up to position by use of the hauling hoist and rope. The original cable stranded soon after it was put in operation and was replaced by a 1½-in. Langlay, steel-core cable, which was much more easily handled. Pontoons across the lake, constructed by securing in position beneath the carrying cable a number of small logs held in position by ⅜-in. wires, prevented the hauling lines from dropping down in the lake and catching under rocks.

The concrete mixing plant was located above the south end of Gem Dam. From this point a trestle and deck was constructed over the top of the dam to serve as a platform on which to push the concrete in dump cars of the Kopple type to the point of pouring. Fig. 9 is a view of part of the equipment and camp, showing the inclined double tramway, bunkers, decking, etc. The concrete was dumped through platform hoppers into elephant trunk chuting 16 in. in diameter and conveyed to place in the forms. Owing to the use of large aggregate, it was difficult to handle concrete which showed a slump of less than 2½ in. without clogging the chutes, even with the steep slopes used. A concrete inspector made frequent slump tests and attempted to keep all the concrete of such consistency as to show a little less than a 3-in. slump. A cement bag shaker was utilized and 1 sack of cement was recovered from each 58.4 sacks shaken.

A total quantity of 12 004 cu. yd. of concrete was added to the dam and 16 425 bbl. of cement, or 1.368 bbl. per cu. yd. of concrete, were used. The approximate proportions of the mix were 1 part cement, 3 parts sand, 3 parts crushed stone (¼ in. to 1½ in.) and 1.84 parts cobbles. Compressive tests of concrete samples showed an average strength of 2 400 lb. per sq. in. at an age of 28 days, and 3 440 lb. per sq. in. at an age of 3 months.

Weather conditions permitted continuance of the work somewhat longer than usual, and the last concrete was poured on November 15, 1924. Fig. 10 shows the form work for the arches and the concrete spout for conveying concrete from the overhead deck. Fig. 11 is a view of Agnew Lake showing the lane kept open through the ice for the passage of the launch and barge.

Conclusions

To prevent deterioration of concrete subjected to water pressure and extreme low temperatures, it is necessary that impervious concrete be obtained. The slightest penetration of water will be followed by deterioration, further penetration, and further deterioration.

Plaster coats, such as "Ironite", might be satisfactory except for hair-line cracks which will be developed on any thin arch section by movement due both to temperature changes and to loading and unloading the arches.

Under the difficulties imposed at this site and similar sites in very remote high mountain areas, it is doubtful whether, under conditions of the present day, impervious concrete can be obtained. Therefore, structures composed of thin sections of concrete should be protected from extremely low temperatures. For such localities, the writers believe that a dam of the rock-fill type has many advantages over dams of other types.

ACKNOWLEDGMENT

In addition to the writers, those who reviewed conditions and assisted in planning the reconstruction include Messrs. R. G. Manifold and the late Charles Oscar Poole, M. Am. Soc. C. E., Consulting Engineers, in whose office the plans for reconstruction were made, and C. W. Comstock, M. Am. Soc. C. E. The construction work was under the general charge of E. J. Waugh, M. Am. Soc. C. E., Construction Engineer of The Nevada California Power Company. As previously noted, this work was performed by Dwight P. Robinson and Company, Inc., with E. C. Macy, M. Am. Soc. C. E., in personal charge.

DISCUSSION

J. Y. JEWETT,* Assoc. M. Am. Soc. C. E. (by letter).—In the early summer of 1923, the writer was called on to examine the structure referred to in this paper, and make a report on certain features of concrete construction related thereto. The repairs, involving use of the "Ironite" process, were at that time under way. Later, as mentioned in the paper, he was asked to make some tests of water-proofing materials, with a view to finding a suitable method of treatment for water-proofing the up-stream face of the dam, a brief description of which tests may be of interest.

The first series of these tests was confined principally to bituminous materials. Engineers of the Company felt that the solution of the problem might lie in the use of some substance having the flexible and elastic properties of this type of material, in contrast to rigid materials of the Portland cement mortar type which readily crack and allow the entrance of water under the severe temperature changes of that locality. The main points to be determined were: Durability under the prevailing climatic conditions; resistance to water pressure; bonding with the concrete surface; and penetration into the pores of the concrete under pressure.

Manufacturers of water-proofing materials of this type were asked to furnish samples of products which they could recommend as being especially resistant to the range of temperature involved. The samples received were classed in three groups, as follows:

(*a*) Solid material, to be melted and applied hot.
(*b*) Liquid material, to be applied with a brush as a paint.
(*c*) Material in mastic or putty form, to be applied with a trowel.

For practically all the samples submitted, the use of a light asphaltic paint as a primer coat was prescribed, and this was generally furnished with the sample.

In tests for resistance to water pressure, a pipe apparatus connected with the city system was used, on which a pressure of 55 to 60 lb. per sq. in. was available. The test specimens were 2 in. thick and 5 in. in diameter, coated on top with the material to be tested. These specimens were bolted between plates, with gaskets to make a tight joint, leaving an area, 3 in. in diameter, in the center exposed to water pressure, with provision for catching and measuring any water coming through. To determine absorption under pressure and penetration into the pores of the concrete, specimens 6 in. in diameter and 4 in. high, entirely coated with the material to be tested, were immersed in a closed tank under the same pressure. The effect of variation of temperature was observed by heating to 110° Fahr., and by exposure in cold storage at slightly below 0° Fahr.

All the materials except a light paint in Group (*b*) formed a coating which was water-tight under the pipe-pressure test. The tank apparatus did not prove to be adaptable to the purpose for which it was used on account of the unbalanced condition caused by difference between air in the pores of

* Testing Engr., City of San Diego, San Diego, Calif.

the concrete at atmospheric pressure and the higher pressure maintained in the tank. This produced rupture of the enclosing membrane, and caused it to puff out in small bubbles and pull away from the surface of the concrete. In no case was there any penetration into the pores of the concrete.

Under the conditions prevailing at this dam, application of the materials of Group (*a*) would be difficult. The hot melted material cools very quickly on striking the cold surface of the concrete, and tends to stick to the tool with which it is being applied, and to pull away from the surface in a sheet. The materials of Group (*c*), although possessing spongy, elastic properties, were in general too soft and easily abraded to form a satisfactory coating, and some of them became softer under water than in the air. Under an increase of temperature up to 110° Fahr. a few of the samples remained unchanged, but the general effect was to soften the material, although not sufficiently to cause flow or change of shape. The specimens placed in cold storage were recently removed after one year's continuous exposure, and were practically unchanged in condition, the coatings showing no sign of cracking or peeling. To show the effect of varying conditions of temperature and moisture as existing at the structure, field exposure tests would be needed.

The conclusion is that if material of this type is used, it should be in paint form, of the class included in Group (*b*). Some of the paints of this group are of heavy consistency, about as thick as can be readily handled with a brush, and dry with a hard, smooth, tenacious coating. Among the several samples having these characteristics, a difference in hardness and tenacity under water immersion was noticed. Trial of a combination coating of such a paint over the mastics of Group (*c*) indicated that, while retaining the advantages of the former, some benefit would also accrue from the elastic properties of the latter.

A second series of tests was made on samples of general water-proofing compounds of the type intended to be applied as surface coatings in paint form. These materials, although showing properties which might be useful in certain classes of work, did not develop results under water pressure that would recommend them for the purpose in question. This series included several brands of the so-called water-proof, plastic, Portland cements now on the market. The plasticity of these products is doubtless of benefit as an aid to workability, in some classes of work, but they did not show water-proofing qualities in these tests equal to those of straight Portland cement. A marked feature of these cements was their low strength in compressive tests of concrete, as compared with straight Portland cement.

To the writer, in view of the results outlined, the problem seems to narrow down to a choice between two methods of treatment:

First.—The use of bituminous paint of the type described. This, although an unusual form of treatment for a structure of this kind, gives indications of furnishing an effective water-proof coating at a relatively low cost. If, however, it should need renewal from time to time, as may be the case, the cost would be a continuing item.

Second.—The use of a Portland cement mortar or concrete coating of high density, reinforced against temperature effects. Although the original cement-gun coating did not prove to be satisfactory, the usual product of this process is well known as a material of high density, and it should be possible to apply such a coating in this case so as to obtain advantage of this feature; or the procedure could be carried a step further, taking the form of a coating of reinforced concrete, similar to that of which the walls of the concrete ships are built. Without entering into discussion of this type of ship in general, it may be noted that they have shown the possibility of concrete construction in thin walls, of high density. As an alternative to the use of Portland cement in this proposed mortar or concrete coating, the use of a quick-hardening, high-strength cement of the newly developed "alumina" type deserves consideration.

With reference to the discussion by the authors of the concrete in the original structure, it was evidently considered that the work was of a good grade of concrete construction, and that the gunite facing could be relied upon for water-tightness. Tests of the concrete, however, as reported* by L. R. Jorgensen, M. Am. Soc. C. E., and as obtained on the specimens taken from the structure in 1924, show a low compressive strength for the mix used. One feature contributing to this, judging from the writer's observation, was the presence in the rock used as aggregate—which was obtained from material near the site of the work—of thin, flat, smooth-surfaced pieces, which would have somewhat the same effect in concrete as mica in a sand mortar. The authors, in describing the new construction, refer to the selection of a more suitable rock at some distance from the dam site.

Experience with this structure indicates that concrete to be used under similar conditions should be of what may be termed a super-excellent grade. This raises the question of the adequacy of the ordinary contract system (with its natural emphasis on speed of operation and profit for the contractor) to meet such a condition. From the point of view of a testing engineer, who, from his study of materials, perhaps realizes more fully than others the possibilities inherent in concrete as a construction material, a more effective method would be to place such work directly in charge of an engineer familiar with the problem and give him a free hand to obtain the results desired. This is subject, of course, to the limitation that there be no waste or needless expense; but it does leave such a man free to devote his energies to obtaining these results, rather than to expend them in more or less futile inspection efforts under the contract system.

L. R. Jorgensen,† M. Am. Soc. C. E. (by letter).—The distintegration of the middle zone of the arches in the Gem Lake Dam, has naturally given great concern to the writer, as he was responsible for the design and construction of this dam nine years ago; he has therefore been seeking earnestly for a true explanation of this rapid deterioration.

As concrete consists simply of rock, sand, cement, and water, the problem is limited to the investigation of these four materials, aside from the mixing and general workmanship. At the time of the construction of the dam and

* "Multiple-Arch Dams on Rush Creek, California", *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), p. 850.

† Cons. Engr., Constant Angle Arch Dam Co., San Francisco, Calif.

also as late as June, 1923, these materials were analyzed and tested frequently. The following notes on the tests are taken from a report made by the Noble Inspection Bureau (now Abbot A. Hanks, Incorporated, San Francisco, Calif.):

"Water from Gem Lake	Parts per Million
Sulphates (as Na_2SO_4)	None
Chlorides (as NaCl)	2.90
Carbon dioxide (CO_2)	2.20

"As the sulphates, chlorides, and carbon dioxide were present in such a very small amount, it was not necessary to make further analysis in connection with the investigation of deposit on the concrete. This water is unusually pure."

Relative to crushed rock, the report states:

"We [Noble Inspection Bureau] treated the sample of crushed rock to determine its solubility in water. The results indicate that the calcium carbonate deposit on the down-stream surface of the dam does not originate from this rock."

The sand used was found along the shore of the natural Gem Lake, which was lowered about 15 ft. when excavating for the dam foundation. Approximately, one-half this sand required washing in order to eliminate excesses of clay and vegetable matter. Both mortar briquettes and compression specimens were made of the local sand and of standard Ottawa sand, and the local sand was washed whenever it gave results below the standard in compression and below 90% of the standard in tension. Three kinds of sand were used: A semi-silicious, a basaltic, and a granite sand from the rock crusher. The latter was mixed with the sand from the two natural deposits.

The original structure was built by the Duncanson Harrelson Company, of San Francisco, which Company had had large experience in concrete work and built a good structure. The water contents were kept to a minimum for reinforced water-tight concrete. It is true that the crushing strength of the concrete was not quite as high as ordinarily would be expected for the richness of the mix used. There are two reasons for this: First, concrete in reinforced arches which has to be water-tight can not be deposited as dry as required for maximum strength. In a gravity dam where men can work directly on the newly deposited concrete a slump of 3 in. can be used, but for reinforced concrete in forms, where the concrete can only be reached with long-handled tools, a slump of approximately 5 in. must be used to obtain water-tight concrete. Secondly, the shape of the crushed rock was somewhat elongated. The stresses used in the design were conservative, and therefore the structure was never over-stressed due to the water load.

When the dam was first subjected to water pressure it was remarkably tight. The first time the writer observed anything wrong was about three years after completion. A very heavy white deposit consisting of practically pure calcium carbonate was noticed on the down-stream face 30 ft. below the crest. It is almost impossible entirely to avoid this white deposit on the down-stream face of the dam, at least in moist spots, but in this case the deposit was too heavy to be harmless and kept increasing.

The small white deposits often seen on the down-stream face of dams originating merely from the leaching of the free lime in the cement, or from whatever laitance there may be in the construction joints, are harmless, but when these materials have leached out and appear on the down-stream side in the form of calcium carbonate, the process should stop and nothing further should happen. In the case of the Gem Lake Dam the process never stopped; it seems that in the zone subject to water pressure the cement itself broke down during the coldest weather. Where else could the large deposit come from?

The cement had passed the usual test. It might, however, have been slightly underburned without being noticed, causing it to be at the point of unstability when exposed to the severe cold. Under ordinary conditions the concrete undoubtedly would have kept its strength, but under the severe climatic conditions imposed on it in the middle zone, it deteriorated and lost its entire strength.

The deterioration started at the construction joints, as they were naturally the weakest points in the structure, but if the leaching had only been confined to whatever laitance or free lime there might have been in the joints, the process would soon have stopped. Fig. 7 shows clearly that the deterioration of the concrete was not confined to the joints. A zone 30 ft. high, beginning 30 ft. below the crest and extending all the way across the structure, was subject to heavy frost while the water level fluctuated between the two levels. In this zone the concrete is practically uniformly deteriorated, whereas above and below it is still in good condition.

If the sand had been the cause of the poor showing of the concrete, it could be expected that there would have been good and bad spots of the material, as three kinds of sand were used, sometimes washed and sometimes unwashed.

An analysis of the deposit on the Gem Lake Dam shows the following:

	Percentage
Silica (SiO_2)	0.76
Iron (Fe)	0.05
Alumina (Al_2O_3)	0.39
Calcium carbonate ($CaCO_3$)	97.44
Magnesium carbonate ($MgCO_3$)	0.11
Total	98.75

showing that the deposit is practically all calcium carbonate.

Inasmuch as the deposit continued to accumulate, it was due, in the writer's opinion, to the cement breaking down gradually and the lime in the cement being leached out continually. The time of actual breaking down was during the coldest weather.

The Agnew Lake Dam, built of practically the same material on the same stream, but 500 ft. lower in elevation, is still in first-class condition. The water level in this reservoir, however, is not appreciably lowered during the cold season, and snowdrifts protect the down-stream face to a great extent from the extreme cold weather.

Three years ago (1922) the writer acted as Consulting Engineer on a multiple-arch dam then being built in Northern Sweden on the River Luleaa, 50 miles north of the Arctic Circle. Two dams of a design similar to the Gem Lake Dam were constructed at a location where at times the temperature drops to 50° Fahr. below zero. Both dams have been in use for two years; they are being carefully watched for frost action, but so far none has appeared.

These dams are provided with a back-fill of earth on the down-stream side for a short distance up. The back-fill was put in to protect the lower arch portion against the very low temperature and consequent contraction near the footing where the arches are fixed to the rock. The upper portion of the down-stream face is still uncovered and, therefore, open to inspection. The water level fluctuates during the cold season.

On recent designs of multiple-arch dams, the writer has favorably considered arches of 50 ft. span, instead of 40 ft. A greater thickness of arch is necessary, but this should make it possible to keep the construction joints tight, just by careful workmanship, without plastering the up-stream side. When an arch is so thin that heavy frost can penetrate the concrete and cause freezing on the water side below the water level in the reservoir, it can hardly be expected that a plaster face will have a long life; the adhesion is seldom 100%, and reliance for water-tightness therefore should be placed as much as possible in the concrete itself.

Walter H. Wheeler,* M. Am. Soc. C. E. (by letter).—The description of the Gem Lake Dam is interesting, but the disintegration of the concrete in the structure by frost can be readily explained.

In the description of the aggregates two facts are mentioned which would account for the difficulty. One of these facts is that the lake sand used in the concrete contained 3½% of clay and 1% of dirt, and the other that the screenings from the rock crusher were mixed with the lake sand in the proportion of 1:3. Presumably, the blue limestone, referred to as the country rock at the dam site, was used in the concrete without removing the dust which resulted from the crushing operation. It is the writer's experience that concrete made of aggregates which contain clay and dirt will not resist frost action, and also that limestone dust is very detrimental to the durability of concrete, also that concrete made with certain varieties of limestone aggregate will be quickly disintegrated by frost. The writer has observed many examples of the disintegration (by frost) of concrete in which similar aggregates have been used, and also many examples of concrete made with clean durable aggregates, which have resisted the frost under equally trying conditions. He does not hesitate, therefore, to assign at least a part of the trouble on the Gem Lake Dam to the aggregates used in the concrete. If concrete is to be exposed to frost the aggregates must be carefully selected with that possibility in mind.

There may also be other contributory causes which are not so apparent from the published description.

* Designing and Cons. Engr., Minneapolis, Minn.

C. A. P. Turner,* M. Am. Soc. C. E. (by letter).—This paper should prove of much value to the profession in calling pointed attention to that particular kind of concrete which will not withstand frost action, namely, concrete compounded of sand as fine aggregate containing 3½% of clay and 1% of dirt. The broad conclusion that concrete disintegrates in like manner when made with suitable aggregate is not warranted from this example. Good initial resistance to compression of sample specimens is too often mistaken as a determinant of frost resistance although in no wise related thereto.

For purposes of discussion, the concrete utilized in the construction of dams may be classified as (*a*) structural concrete; and (*b*) mass concrete. Hollow dams (such as the original Gem Lake design), flat slab dams, and the like represent Class (*a*), while the mass concrete of the gravity type present examples of Class (*b*).

That frost disintegration occurs in Class (*a*) concrete because of the relative thinness of the section, but does not occur in Class (*b*) concrete because of its greater thickness, is apparently the deductions of the authors from the single experience described and discussed.

In certain slabs of reinforced concrete dams much thinner than the Gem Lake section and exposed at times to temperatures of 50° below zero, or lower, no material disintegration by frost has occurred in twelve years or more, whereas in some structures of the gravity type with far thicker sections, in which care had not been used to secure clean aggregate, the writer has observed disintegration by frost.

The importance of the question at issue lies in the fact that the structural concrete dam may commonly be safely built at a much lower cost than a dam of the mass concrete type. Many irrigation projects are rendered commercially feasible by using the economic dam structure whereas they would be lacking in feasibility with the more expensive gravity types. The disintegration of mass concrete, or the thinner section of concrete, by frost appears to the writer as one of progressive action which may render even the massive structure unsafe within a period shorter than its expected life. Hence, the need of care in the selection of concrete materials whether in the bridge pier or dam structure exposed to the elements. The additional first cost of washing sand and securing sound aggregate is always small compared to the cost of repairs when proper care has not been exercised.

Thomas H. Wiggin,† M. Am. Soc. C. E. (by letter).—There is at present under construction from the writer's designs a multiple-arch dam about 300 ft. long and 33 ft. maximum height, and the subject is, therefore, of great interest to him.

Many concrete structures, including dams, are deteriorating with the aid of moisture and frost and it is generally impossible to fix the cause with certainty. The authors call attention for the first time in a pointed way to the fact that the immersed side of a thin exposed wall of concrete is in the same danger from the formation of ice crystals in its pores under the influence of

* Cons. Engr., Minneapolis, Minn.
† Cons. Engr., New York, N. Y.

cold coming through from the dry side of the structure as the side not immersed of a thick, leaky wall.

Deterioration was expected and occurred in the mortar lining of uncovered steel pipe, but here the exposure was severe as only a thin plate of steel intervened between the outside cold and the saturated mortar lining only 2 in. thick.

Filter roofs, 6 in. or more in thickness, covered with about 2 ft. of earth, are often wet with condensed moisture and sometimes permit thin ice to be formed on the water below, showing that the air which touches them is, at least, as cold as the unfrozen water against a thin dam. The writer has never noticed deterioration in the lower surface of such filters. None of these filters was in a region of extreme cold.

In the United States some concrete stand-pipes have deteriorated outside from leakage and freezing, but the writer does not recall deterioration inside although the concrete was porous and had to be water-proofed on the inside to prevent further damage outside. The French have constructed some of these stand-pipes that seem to have no imperfections from leakage or frost. These stand-pipes, again, are not in semi-Arctic regions; also, there is more or less circulation of water.

The Stony River Dam in West Virginia is a hollow dam of the Ambursen type. It is at an elevation of about 3 000 ft. and experiences very severe winters compared with most places in the East. Ice forms on the inner faces of the hollow. Deterioration has occurred on the water face, although mostly high up in the zone of fluctuating water levels.

The writer has been advising on the repair of a gravity concrete dam. The concrete has deteriorated both on the water face and on the down-stream face. Disintegration down stream is apparently due to leakage and freezing; that up stream, similarly, is apparently due to saturation and freezing. The concrete is about 1:3:5 and rather poor. Several hundred thousand dollars will be expended in repairs. The safety of the dam has not yet been endangered by deterioration. The interior is sound. This is only one of many dams that have shown signs of surface disintegration. Only good stone masonry seems exempt, and that needs repointing in some cases.

It is not agreeable to contemplate that in spite of all care, concrete structures so often fail to endure. The writer started thirty years ago with the feeling that the place for concrete was underground. Unfortunately, stone for stone masonry is not often available at a reasonable price and the advent of concrete was the beginning of the decline in the supply of stone masons. Engineers are often forced to use concrete where its expectation of life may be comparatively limited, or at least doubtful, because stone would cost so much more that the concrete structure could be often renewed at a less total capital cost. "Hope springs eternal" also that vigilance will produce concrete of such quality that it will be among the structures exempt from major deterioration.

Among those who are engaged in research on cement and concrete are some who lay the deterioration of concrete to the use of too little cement. In the Gem Lake Dam only 1.5 bbl. per cu. yd. were used. Perhaps 1.75 or 2 bbl. would have shown different results. Some old structures with even less cement are still without blemish, it is true, but this may have been due to extraordinarily good sand and proportioning.

The writer chose a multiple-arch dam for the case mentioned at the beginning of his discussion because rock foundation was found near the surface and other conditions made it by considerable the cheapest type, except possibly a slab dam. About 1.6 bbl. of cement per cu. yd. are being used in the piers and 1.75 bbl. in the arch which is only 1 ft. thick. Even with this thickness the stress is only about 150 lb. per sq. in. from water pressure alone and it is still (October, 1925) very low, with scarcely any tension, with extreme conditions of temperature. It is a flexible structure and no joints need slip to provide for temperature changes. It was hoped to make the dam tight by the excellence of the concrete, but in addition a complete water-proofing of asphalted fabric and asphalt, covered with mastic for protection against ice, is to be provided. The circulation of water in the reservoir will be fairly vigorous and the climate is that of the New York region, that is, generally free from prolonged intense cold.

In their struggles to avoid one set of difficulties, human beings are prone to run into others just as serious. Nature will not be altogether circumvented. An earth dam with generous slopes, paved water slope, grassed down-stream slope, masonry core, and well-drained toe comes as near to being a part of the landscape in permanence as can be produced by man, yet it requires a generous masonry spillway for its protection and perhaps fails by overtopping when the record storm for the region occurs. The masonry dam even partly disintegrated may safely withstand overtopping at such a time.

C. H. Howell,* M. Am. Soc. C. E. (by letter).—This paper is an exceedingly instructive one. The writer believes with the authors that "all the story is not yet told" concerning multiple-arch dams; he would also include all flat slab dams.

The smaller volume of concrete contained in these hollow types, as compared with ordinary gravity and arch sections, has often led to their erection at sites utterly unsuited to them. To expose thin concrete slabs or thin arches to high water pressures and low temperatures is inviting ultimate failure. It is a misuse of types of dams which have a definite, although rather limited, use.

Like all innovations, these hollow types of dams have their over-enthusiastic supporters who can see no merit in the older types and strenuously insist on multiple-arch or flat slab designs for every site. The history of the Gem Lake Dam will probably diminish some of this enthusiasm. The writer knows of one other dam, a flat slab structure, which is deteriorating in the same manner as the Gem Lake Dam. Both these dams were erected in climates that are too cold.

E. W. Lane,† M. Am. Soc. C. E. (by letter).—Since many dams of the multiple-arch and Ambursen types have not been seriously affected by frost action, the trouble at the Gem Lake Dam does not seem to be inherent in dams

* Engr., U. S. Bureau of Reclamation, Denver, Colo.

† Lafayette, Ind.

with thin concrete walls. It does serve, however, to emphasize a possible source of weakness, and the necessity of much more than ordinary precautions in the construction of such dams, especially in cold climates.

A few years ago, the writer inspected a large gravity dam in which the concrete was disintegrating in a manner very similar to that at Gem Lake. The dam was constructed by competent engineers, but within a few years the concrete began to disintegrate and, when inspected, had scaled off in places to a depth of as much as 6 in. and could readily be dug with a knife for some distance from the surface, being about as resistant as compact gravel. The writer was informed that the cause of the trouble was the limestone aggregate. This had been brought from a considerable distance, as the local stone was unsuitable. It had passed all the ordinary tests, but an examination to determine the cause of the disintegration had revealed that the limestone was filled with microscopic veins of shale which broke down on exposure to the weather. Had this material been used in a dam with thin sections, it would certainly have necessitated reconstruction.

The fact that the buttresses of the Gem Lake Dam were not affected strongly points to the water as being an element in the cause of disintegration, but this does not prove that it was not the quality of the aggregate that was the primary cause of the difficulty. In his description of the construction of this dam, Mr. Jorgensen* states that, in the lower part, limestone from the outlet tunnel was used for the aggregate. Is it not possible that the limestone aggregate was the cause of the trouble, and that the reason the upper part was not affected was because it was constructed with granite aggregate?

The writer believes that the materials entering into the construction of a multiple-arch or buttressed dam should be subjected to a much more critical examination than for a dam of gravity section. He would suggest subjecting the aggregate and moulded specimens of concrete to a considerable number of alternate freezings and thawings. This should not be difficult with the small mechanical refrigerators which are coming rapidly into use. In northern climates it could be readily done in winter by natural means.

The danger resulting from disintegration of multiple-arch dams was called to the writer's attention by an inspection which he made of a dam of this type in Central New York. This dam (Fig. 12) consisted of three vertical arches supported by buttresses, flanked by an ogee gravity spillway section at one end and a gravity section abutment at the other. The concrete had disintegrated badly in places (Fig. 13), especially at the springing line of the arches and at a crack (probably caused by temperature) which extended down the crown of each of the three arches. The construction joints were also seats of attack. The disintegration was not confined to the arches, but included also the buttresses and the ogee spillway section. The writer understands that this dam has been repaired, but is not aware what method was used.

E. J. WAUGH,† M. AM. SOC. C. E. (by letter).—In any discussion involving disintegration in concrete the first question that naturally arises is what was

* *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), p. 868.

† Constr. Engr., The Nevada-California Power Co. and Southern Sierras Power Co., Riverside, Calif.

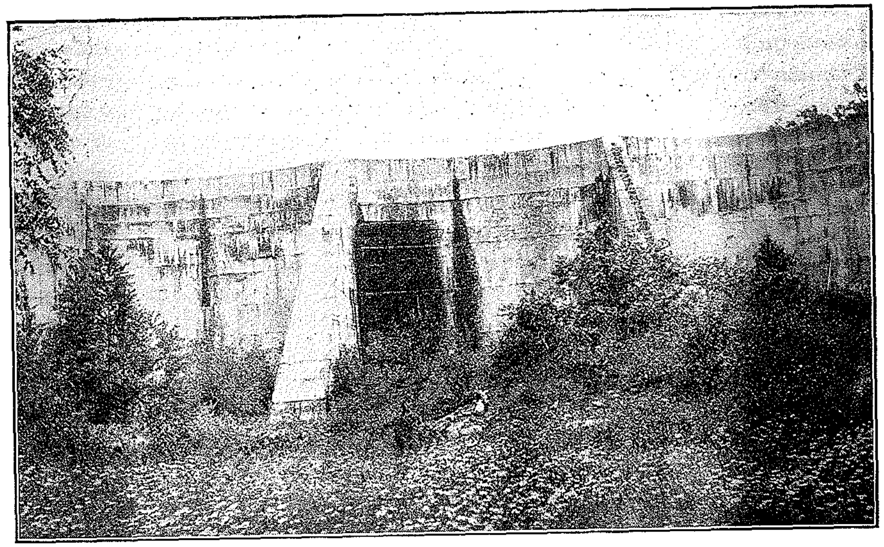

FIG. 12.—MULTIPLE-ARCH DAM IN CENTRAL NEW YORK, DOWN-STREAM FACE, SHOWING DISINTEGRATION.

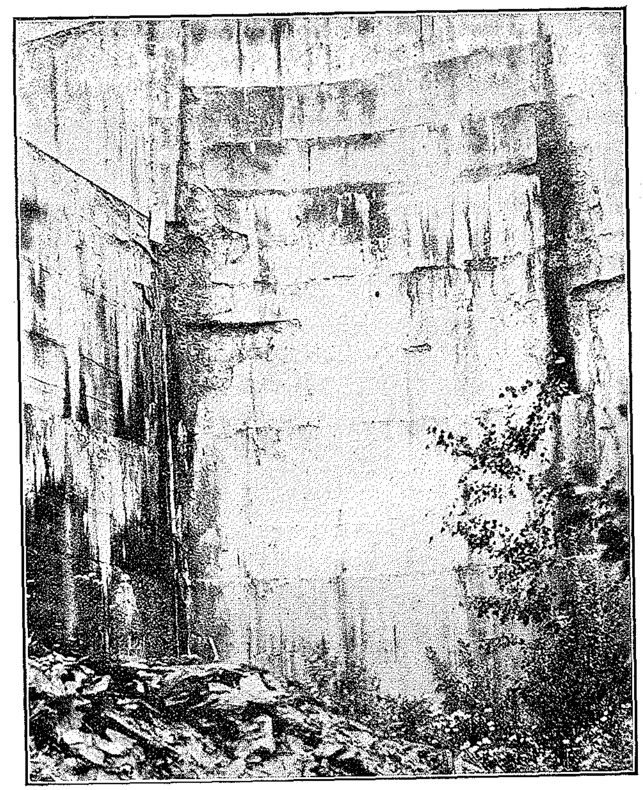

FIG. 13.—DETAIL OF DOWN-STREAM FACE, MULTIPLE-ARCH DAM (LEFT BAY IN FIG. 12), SHOWING EXTENT OF SPALLING.

the quality of the concrete before deterioration commenced. If the up-stream face had been absolutely water-tight and had remained so, it may be assumed that the original concrete in the Gem Lake Dam would have given satisfactory service, as no deterioration appears in the buttresses. Also, the arches, where not subjected to freezing when filled with water, are not seriously affected as to structural strength, as is evidenced by compressive test samples taken in 1924.

The failure of the gunite coating to absolutely prevent moisture from getting in back of the top skin was the primary cause of the trouble. During the long season of freezing temperatures, extending from September or October to April or May, any moisture admitted would freeze and in expanding would either loosen the material at the face or tend to enlarge the pores throughout the mass. This operation repeated itself each time the weather warmed enough to thaw. After seven winters, slabs of gunite coating of all sizes had been loosened; that this was not due to faulty bond of the gunite is proved in part by the fact that often a thin layer of concrete adhered to the gunite when it was forced loose from the arch.

The quality of the concrete and the character of the bonding at construction joints has a direct bearing on the rapidity of disintegration, but it is doubtful whether any concrete would resist such freezing conditions indefinitely. It is inconceivable that any concrete will prevent the penetration of moisture. With temperatures that will cause ice to form under water on the reservoir face of the wall, any saturation of the wall whatever will cause damage. Either some facing must be provided that will be water-tight to the extent of allowing no moisture to reach the concrete or else the dam should be back-filled or otherwise insulated against cold. In the original construction a water-tight metal up-stream form would be the most satisfactory solution. It could be asphalt dipped, or otherwise treated, so that it would not rust against the concrete and it could be repainted when necessary on the up-stream face and maintained in water-tight condition at comparatively little cost. Such a form could be designed with expansion joints. In this way the concrete in the arches could be kept dry and the full strength would remain so long as the up-stream metal facing were maintained water-tight. It would be impracticable to carry the metal form below the ground line, but at this point it would be a simple matter to fully protect it by back-fill and still leave the structure open for observation.

It is possible that metal is still the best protection for the Gem Lake Dam, but it is much more difficult to place than it would have been in the original construction. Some substance that has the qualities of adhesion and elasticity and can be sprayed or brushed may solve the difficulty; field tests are now being made with certain bituminous compounds to determine the feasibility of their use.

ALFRED D. FLINN,* M. AM. SOC. C. E.—There is danger in over-emphasizing one notable failure. It is creditable to engineers who have knowledge of failures to report them for the benefit of the profession; but it would also

* Secy., United Eng. Society, and Director, Eng. Foundation, New York, N. Y.

be of service if the Society, through a small committee of inquiry, or an existing committee, would set down against this failure the record of the thin concrete dams under as great or even greater exposure that have stood successfully for years. There are many such dams in the United States. The importance of presenting such countervailing information is not slight. Engineering Foundation might be asked to collect the data for the Society.

Dams are among the structures that are supervised by certain States. Some supervising officials are not well informed about the theory or the practice of the construction of dams. Their responsibility is to make sure that structures which they approve do not fail. The cost put on the owner, or the limitations on the engineers in charge of design and construction, are only secondary to the officials.

Endeavors of American engineers to build successful dams at moderate cost are being watched closely by engineers in other countries. Recent correspondence with an Italian engineer indicates that some American experiences have been misinterpreted. He has been strongly opposing the use in his country of any thin dams. American engineers owe it to themselves to answer the questions which have been raised. These questions may be grouped under the heads: Sufficiency of design, suitability of materials, efficiency of construction methods, and adequacy of maintenance.

For the case in hand: What is known about the materials put into the concrete which failed? What were the chemical and physical characters of the water, cement, sand, stone, and gravel? What attention was given to the proper placing and curing of this concrete for the particular purpose and conditions of this dam?

In some instances is not concrete being used with about the degree of intelligence that would use window-weight iron or alloy steel indifferently as materials for tools for cutting metal? In other words, is not concrete too often designed without sufficient regard for the purposes and conditions of the structures into which it is to be put, and with still less discrimination in supervising its mixing, placing, and curing? Concrete for simple foundations, or for structures which will be wholly protected from the weather or active destroying agents, may be different from concrete suitable for thin hydraulic structures under pressure and exposed to severe weather. This fact is so obvious that slowness in carrying it to the necessary limit in practical operations is hard to understand. Probably the tardiness to realize the relation between cause and effect has been due partly to the fact that the results of some wrongdoing in concrete construction do not appear for several years and partly to the fact that the men who design and construct often do not see their structures again and, therefore, do not learn the lessons which develop during years of maintenance. However, notable progress has been made.

In engineering textbooks, reports, journals, and specifications it is commonly implied that Portland cement is uniform; that cement from any source may be used just like cement from any other source; but experience in testing and using cement shows that, instead of being uniform, cement is a various material and that some cements are not well suited to certain special services, for example, hydraulic structures. It is encouraging to know that a fundamental study of hydraulic cements has recently been undertaken at the U. S. Bureau of Standards with the co-operation of the Portland Cement Association, and that a number of engineers have been giving thought to this branch of the subject. In this connection reference should be made to the paper by William G. Atwood and A. A. Johnson, Members, Am. Soc. C. E., entitled "Disintegration of Cement in Sea Water".*

Engineering Foundation is aiding the Committee on Arch Dam Investigation, made up of members of the Society. Its experiments on the Stevenson Creek Test Dam, near Fresno, Calif., and on concrete used in that dam, and its observations on existing and proposed dams, should add knowledge that would be helpful to engineers designing and constructing dams of several types. This project has already been described.†

LUIGI LUIGGI,‡ HON. M. AM. SOC. C. E.—This is a most valuable paper. Greater information is to be obtained from structures in a critical condition or from disasters than from those that are physically successful. Engineers, like physicians and surgeons, to become experts must operate on bad cases.

The paper emphasizes three important factors in a successful work, that is, design, materials, and supervision during construction. Dams, even in the most favorable circumstances, are difficult structures to build; and often the design has been considered more as a calculation of stresses than as a construction problem. Indeed, the design is an exceedingly important factor, for a badly designed dam is destined sooner or later to fail; but it is not sufficient merely to design the dam well—it is necessary to choose the materials best adapted to the conditions of the locality of the work. In particular, the cement must be of the highest class and be used in quantities substantially in excess of the theoretical proportions to allow for losses and deterioration.

It is easy to test cement in a laboratory and from the test to specify the exact proportion; but in the field, at a distance from the cement factory and lacking good material, it is necessary to adopt precautions that only practice can suggest. Consider the case of the Gem Lake Dam. The cement traveled over a normal railway, a narrow-gauge railway, then across a lake, and finally up a mountain side. It thus became very expensive; and when a material is costly there is always the temptation to use it sparingly. That is bad economy. Instead, more than the computed quantity should have been used to counterbalance the inevitable local losses: The wind blows some of it away, some of it sticks in the mixer and in the chutes. The best practice is to use 5 to 10% more than the theoretical quantity or even more than this under especially difficult conditions. It is bad economy to make weak concrete; this is dearly paid for later in the cost of repairs.

If the builders of the Gem Lake Dam had been more generous as to the cement, the concrete would have been less porous, and all the heavy expenditure to remedy this condition would have been avoided. As an adjunct to

* *Transactions*, Am. Soc. C. E., Vol. LXXXVII (1924), p. 204.

† *Proceedings*, Am. Soc. C. E., October, 1925, Society Affairs, p. 340.

‡ Hon. Pres., State Council of Public Works; Insp. Gen. of Civ. Engrs.; Prof. of Hydr. Eng., Univ. of Rome; Member, International Technical Committee for the Suez Canal; Senator, Rome, Italy.

good design, a proper proportioning, a particularly good cement, and an excess of it, are indispensable for hydraulic work that must not be porous.

A third necessary precaution is a thoughtful and conscientious supervision of the work. To impress these three points more deeply on the minds of engineers—especially younger engineers—the speaker will instance a multiple-arch dam which, in height, design, and general dimensions, was practically a reproduction of the Gem Lake structure. The failure of this dam in the Valley of Gleno, in Italy, high up in the Alps of Bergamo, caused an immense loss of lives and tremendous damage. This dam was built about 6 000 ft. above sea level in a very cold climate and with difficult transportation.

As to design the Gleno Dam, although not excellent, was fairly good; but the materials were rather bad and the supervision even worse. The work was begun during the World War. Cement was scarce and costly because all building materials were going to the front. Workmen were scarce—either older than 50 or younger than 18 years of age—and unskilled. Supervision was almost completely lacking. The work was mainly under the supervision of a manufacturer, a self-made man, exceptionally clever as a cotton weaver, but with little experience in construction work. Under him were only ordinary workmen in charge of the construction. The work was carried out trusting to Providence.

During that time and for a few years after the war, Italy had a very inefficient Government; Socialists, not to say Communists, easily imposed on the Government officials, who were powerless. This employer was permitted, therefore, to proceed, carrying out this dangerous work without any technically competent man to advise him. Although Government officials occasionally went to inspect the progress and reported that the work should be stopped, should be partly demolished and rebuilt, still nothing was done to effectuate this. Further, because coal was extremely expensive and difficult to obtain and because hydro-electric power was the only remedy for the lack of coal, water was allowed to impound behind the dam, to produce as soon as possible the electric energy which, in turn, would keep the cotton mill busy and provide cloth for soldiers and work for the men at home. When the war was over, little was done to remedy this state of affairs.

As the dam was leaking in many places, some inefficient repairs were made, but these did not cure the consumptive condition of the whole structure. Then came a rather heavy storm, almost a cloudburst; the spillway was not large enough to discharge all the surplus water, which rose behind and nearly overtopped the dam. It was only a question of minutes, as described by an eye witness, before the dam began to crack and suddenly burst. This happened during the night. In the valley below several hundred people were killed and damage estimated at 150 000 000 lire was done. Many of the people were drowned in their beds.

As a result of an inquest into the cause and responsibility for this terrible disaster, some men were imprisoned and now have to answer for the disgraceful condition; but no one can resuscitate the drowned, nor compensate for the property destroyed. It is more to the point to search out the reasons for failure and thus avoid the mistakes made in the Gleno structure.

Although its design was questionable, with excellent materials and good workmanship, conscientiously controlled, the structure might have stood; but the defectiveness of the cement, the porosity of the concrete, and the badly built masonry which allowed water to percolate, were the main causes of the failure. In addition, there was an underlying mistake in the foundation, namely, a large mass of masonry which blocked up the bottom of the gorge and formed a platform on which the dam rested.

So poor was the cement mortar in this block, that it allowed water to pour out through the masonry. Worse still, it was not founded by means of proper steps cut out of the rock, but was laid on top of the natural surface which had been rubbed smooth by glacial action. No cut-off trench was provided to prevent leakage and consequent uplift. The only precautions taken were to grout iron bars into the rock where it was too smooth and thus, one might almost say, to nail the dam to the foundation. As a result of all these dangerous factors, the percolating water must have exerted an uplift, and when this occurred the masonry must have moved slightly, the iron bars lost their grip, and the whole structure slid down to destruction over a part of the dam where these treacherous foundations existed. Thus, the disaster was due primarily to lack of proper and skilled supervision.

State authorities should always insist on the advice and inspection of competent engineers. The author states that "for such localities [the Gem Lake Dam], a dam of the rock-fill type has many advantages over dams of other types." The speaker fully concurs in these conclusions; it is certain that in the case of the Gleno Dam, if a rock-fill structure had been built—which during the war could have been effected more easily than the multiple-arch dam—the disaster would have been avoided.

Regarding the use of preparations like "Ironite", the speaker's experience of more than forty-six years convinces him that it is impossible to construct masonry and make it absolutely impermeable under a head of more than 40 or 50 ft. Not even a coating of neat cement, applied with a cement gun, will resist the percolation of water, because, besides stresses due to water pressure and change of temperature, there is another important effect, often disregarded, namely, the slight imperceptible movement of the crust of the earth to which the structure is subject almost daily. On a large scale these movements become earthquakes; but the very small daily tremors, noted only by seismography, cause the masonry to develop small hair cracks, which enlarge little by little and allow the water to percolate. In addition, the filling and lowering of the lake causes an elastic movement of the dam and of the foundation, which produces slight stresses that result in hair cracks. The great dam of the Murrumbidgee River in Australia is an illustration of this condition. The structure is about 240 ft. in height and the enormous pressure of the water causes actual movements in the foundation, as have been clearly recorded by seismographs set up in that locality.

Although it is possible to make masonry water-tight for some time by using special compounds, these infinitesimal movements, as years pass, will cause the masonry to crack. The speaker believes there is only one way of making the surface impermeable—at least as nearly so as possible—and that is by covering the up-stream face with a membrane of sheets of bitumen, now commercially available in sizes about 4 ft. wide by 10 to 20 ft. long and ⅛ in. in thickness. These should be made to overlap and should be fused together with hot tools to form a plastic, continuous, and absolutely impermeable coating over the masonry. To protect this sheet from summer heat, floating logs, and blocks of ice, a revetment of masonry 1 to 3 ft. in thickness must be provided.

The durability of bitumen is attested by archeologists who have found in Nineveh sewers made with brick laid in bitumen which is still impermeable after 3 000 years. The speaker's belief that the Gem Lake Dam could have been properly protected in this manner, is strengthened by the instance of a rock-fill dam in the Alps, the Devero Dam. The up-stream face of this dam has a sheet bitumen coating protected by masonry 1½ ft. in thickness at the top, increasing to nearly 3 ft. at the bottom. After twenty-five years this dam shows no sign of leakage.

Thaddeus Merriman,* M. Am. Soc. C. E.—The buttresses and the arches of the Gem Lake Dam were both made of the same concrete. In the buttresses this concrete endured, while in the arches it failed. The paper seems to demonstrate that concrete which is serviceable in one exposure is not necessarily serviceable in another.

Mr. Flinn has made a fair statement. Much good concrete has been placed, but there has also been some of doubtful quality. All concrete which disintegrates is not bad because the cement with which it was made was poor. Many of the troubles with concrete seem to be due to the fact that those who make it do not fully appreciate all the conditions which the process of concrete making involves. The speaker is free to admit, after many years of study, that this great problem still seems to be far from final solution.

On September 16, 1925, the speaker mixed a Portland cement with 43% by weight of water and poured a part of the mixture into one bottle and a second part into a second similar bottle. Forty-eight hours thereafter the first bottle was broken and the cement specimen so formed has since been exposed to the air. Twenty-one days later, on October 7, 1925, the second bottle was broken, and both specimens are here for examination. The first is soft and chalky, while the second is hard and dense. These specimens appear as if they had been made of entirely different materials, but, in fact, they are merely a demonstration of a difference in curing conditions. This is a simple experiment and one which all may profitably try.

The first of these specimens was treated in about the same way that most concrete is treated. It was put into a form, the form was pulled off at an early age, and Nature took its course. The specimen immediately dried out, leaving the hydrations uncompleted. In the second specimen, however, the conditions were such that the hydrations went on to practical completion and the resulting texture indicates a strong, hard, and durable material. Concrete so cured would be a wonderful compound.

* Chf. Engr., Board of Water Supply, City of New York, New York, N. Y.

Between the texture and the quality of these two specimens there are many intermediate kinds of texture and quality. Under one condition of curing, one quality of product is realized; under other conditions, other qualities result. Some are good, some are indifferent, and some may be decidedly bad. So it is that one structure is very good, while another in the course of a few years may show serious disintegration. The quality of a concrete is not only a function of the conditions under which it was cured, but it is also dependent on the conditions of subsequent exposure. A thoroughly cured concrete, all other conditions being the same, will resist almost any exposure. A partly cured concrete, depending on the conditions of exposure, may or may not prove to be satisfactory.

The curing of concrete, and particularly that in thin sections, is, in large measure, dependent on the weather and moisture conditions during the first five or six days following its placement. If the humidity be low, nearly all the water necessary for the completion of the reactions will be lost, while, if the air be moist or water supplied, the hydration of the cement will proceed in an orderly manner. It has been claimed, if the process of hydration be interrupted, and if water be supplied at a later time, that the hydrations will resume themselves. No proof of this supposition has been adduced. Such evidence as the speaker has been able to develop is to the contrary. If the first specimen described is given plenty of water at any time after it has been dried out, it will never take on a texture resembling the second.

In the case of the Gem Lake Dam, all the conditions for rapid drying out were favorable. The high altitude, and the consequent low humidity, did its fatal work in withdrawing from those thin sections the moisture which was the very life blood of the cement. For weeks, and possibly months, that cement product was athirst. It was like the first specimen previously mentioned—spongy, chalky, and unstable. It could not resist the solvent effect of the water, and its constituents were leached out. On the other hand, that same imperfect cement product, in the buttresses, served its intended purpose. Freezing was not the primary cause of this disintegration. Frost merely hastened the visible evidences of deterioration. The quality of a cement product is always dependent on the maintenance of an environment in which the cement reactions may complete themselves. Good concrete can be realized only if it is kept for several days after making, under such conditions as will insure for the cement an opportunity to develop its latent possibilities. These conditions are clearly indicated by the bottle experiment which has been outlined.

In many cases the treatment accorded to concrete after placing is analogous to that of abandoning a two-day infant to its fate. On State highways it has been learned that curing is one of the most important single operations in the entire process of concrete making. In many other situations, however, concrete after placing is allowed to shift for itself and then, as in a post-mortem investigation, the causes of disintegration are vainly sought.

The problem of durable concrete is the problem of durable cement. With a given cement the best results are not possible of attainment unless that cement be used with understanding skill of workmanship. Cements differ among themselves and results which can be obtained with one cement are impossible with another. The task which confronts us is twofold: First, we must learn to differentiate cements with respect to the quality of the hydration products they are capable of producing; and, second, we must learn how to use a cement of given quality so as to secure the results which any particular situation demands.

At present, none of these matters is susceptible of standardization. Standards of measure are useful as means of convenience and of comparison. Standards of quality and of methods operate to suppress individual initiative. Standards imply averages, and if quality of product be a consideration they tend toward mediocrity.

In this great matter of concrete and of cement we cannot rest content with averages and with mediocrity. Until the uttermost of the problem is within the grasp of our understanding we must do no less than seek for the very best within the present possibility of attainment.

M. M. O'Shaughnessy,* M. Am. Soc. C. E. (by letter).—The authors are to be commended for their frank discussion on the repair of the buttressed arch dam in the high Sierras near the State of Nevada, south of Lake Tahoe, California. No estimate has been furnished as to the resultant losses sustained by The Nevada-California Power Company due to the two years failure of this dam to function in storing water, which losses must have amounted to far in excess of the cost of initially building a properly designed dam of a type suited to the conditions and available materials. It is hoped they will furnish these data before closing the discussion, so that a frank statement of all conditions may be available to engineers interested in this type of dam.

The building of this dam followed the conventional design for this type of structure at the date of its construction (1916), and the failure is not primarily due to theoretical design features. Its designer, after describing it in a paper† before the Society, deservedly received the Norman Medal. He was retained by the writer in 1917 to aid Assistant Engineers McIntosh, Nishkian, and the late Mr. Wood in designing the Lake Eleanor Dam, 70 ft. high, 1 200 ft. long, on the Hetch Hetchy Project. Further studies on the design for this type of dam resulted in several beneficial modifications being incorporated into the Lake Eleanor Dam,‡ which is a structural and economic success.

The true principle controlling dam design and construction was tersely elucidated by Mr. George L. Dillman,§ namely, that there must be only one impervious surface next the water, and that this face must be adequately supported by solid masonry, buttresses, rock, or earth-fill, depending on the locality and the type of dam.

* City Engr., San Francisco, Calif.

† "Multiple-Arch Dams on Rush Creek, California," by L. R. Jorgensen, M. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), p. 850.

‡ *Engineering News-Record*, September 4, 1919, p. 455.

§ *Transactions*, Am. Soc. C. E., Vol. LXXV (1912), p. 52.

The term "multiple arch" as applied to this type of dam is a misnomer; there are so-called "multiple-arch" dams in India 120 years old, and the name is meaningless as to design. This particular type of dam survives because of the buttresses, and the principles and reason for its selection were first described (after a structure built in Oregon) in 1902 by Mr. Dillman,* and due credit should be given him for his initiative in recommending it.

Overtopping the Gem Lake Dam with 4 in. of water is not a very severe test. The Upper Otay Dam (a single arch), in San Diego County, 84 ft. high, built by laymen without engineering skill, was topped to a depth of 30 in. without injury. However, an enlarged spillway now prevents a recurrence of this happening.

The sections are so thin in the buttressed arch type of dam that it is essential to have the concrete of such density that it will be water-proof, and this can be accomplished only by a careful selection and proportioning of the materials, avoiding an excess of water in mixing, and thoroughly spading the concrete after it has been deposited in the forms.

The writer's impression of the value of alleged water-proofing compounds on concrete surfaces subjected to water pressure is in entire agreement with the experience of the authors; that is, these compounds have no worth except to their manufacturers and salesmen.

The concrete in the Gem Lake Dam failed because it was defective in that it was porous, thus allowing the water to penetrate it, and, with the heavy frosts and ice formation, permitting destructive disintegration to set in.

Why was the concrete porous? It may have been due to an excess of granite, mica, dust, and clay in the sand, or defective cement; or, as Mr. Jewett states:

"* * * the presence in the rock used as aggregate—which was obtained from material near the site of the work—[cheaply, of course, which feature should not be considered in dam construction] of thin, flat, smooth-surfaced pieces, which would have somewhat the same effect in concrete as mica in a sand mortar."

This class of rock prevents the proper interlocking of the remainder of the rock in the mass, and has a tendency to reduce the density of the concrete; and it is in such a situation that the experienced man, with judgment of materials, is needed fully as much as the designing engineer or the testing laboratory in determining the character and suitability of the materials to be used in the structure.

In building the 396 000-cu. yd. concrete dam at Hetch Hetchy, the engineers had quite a controversy with the contractors on their initial attempt to use a readily accessible, cheaply obtained sand. Exhaustive tests were made on samples of concrete and briquettes from this sand. They were found to be defective and failed to show the proper strength and hardness characteristics under time tests. The chemist's analysis subsequently disclosed the fact that the sands were heavily coated with a black compound which was largely tannic acid (from a dense grove of oak trees) and which caused the trouble.

* "A Proposed New Type of Masonry Dam," by George L. Dillman, *Transactions*, Am. Soc. C. E., Vol. XLIX (1902), p. 94.

Three miles up stream from the dam, at the junction of Tuolumne River and Rancheria Creek, there was found a bank (250 000 cu. yd.) of excellent sand which, after some protest on the contractor's part (because of the necessity of building a 3-mile narrow-gauge railroad to reach it), was used with very satisfactory results.

Evidently, Mr. Jewett's experience as a testing engineer indicates a doubt as to the value of the ordinary contract system for dam construction, since the tendency is to slight this class of work because of the contractor's desire for speed of operation and profit; this agrees in general with the writer's ideas. It may be mentioned in this connection that Lake Eleanor, Early Intake, Cherry Diversion, and Priest (145 ft. high) Dams were not built by contract, but in a very satisfactory manner under the direct charge of the resident engineers; and the O'Shaughnessy Dam at Hetch Hetchy was built by contractors who faithfully and promptly complied in every respect with the wishes of the resident construction engineer, who was assisted by a staff of twenty men, inspecting and testing.

In December, 1923, the Gleno Dam (buttressed arch type) failed in Italy, drowning 500 people and damaging property below to the extent of $5 000 000. No doubt, inadequate preparation of the foundations, together with defective lime masonry and concrete, put in without engineering control by the over-zealous contractor in critical parts of the structure near the base, without Government supervision, caused the accident.

There is now a barrage of literary experts for contractors and damage claimants mailing reports back and forth on the causes of and responsibility for this failure, with one certain result, namely, that the Italian Government is allowing no more questionable dams to be erected by any one, and has commissioned skilled Government engineers to inspect all materials and supervise all designs, so that there will be no repetition of the Gleno Dam disaster.

It is a pleasure to note that an engineer of extensive construction experience, such as Mr. Huber, endorses the virtues of a rock-fill dam for this type of location, with its abundance of cheap rock, thereby saving the expensive hauling of cement.

The Morena rock-fill dam, built under the writer's direction, survived the cloudbursts of 1916 in San Diego County, California, when the Lower Otay Dam failed, and when every county and railroad bridge in that community was destroyed by floods.

The idea of the rock-fill type of dam is traveling eastward, crossing the Mississippi River, as witness the Dix River Dam, 280 ft. high, in a limestone formation, in Kentucky, built for the Middle West Utilities Company by L. F. Harza, M. Am. Soc. C. E., to conserve water for power.

Although time and the financial exigency in 1917-18 compelled the City of San Francisco to build the buttressed arch Eleanor Dam (forming an 8 000 000 000-gal. reservoir at a cost of less than $300 000), definite plans are now being made for practically scrapping this structure, and substituting the ultimate dam of the rock-fill type at this point. This rock-fill dam will be below the present dam, using the 70-ft. concrete buttressed arch for the lower part of the up-stream toe or water-tight skin, and carefully placing and thoroughly grouting rock in layers, with spalls behind the arches to give them adequate support and so prevent their failure.

The writer would strongly urge all engineers first to heed the careful words of Mr. Dillman on design; next to examine exhaustively all the materials in the vicinity of any proposed dam that might enter into the structure, eliminating any cheap untried methods of experimenters and scrutinizing carefully vendors of special cheap types; then to select a type of structure that is best suited to the location and service required, regardless of the cost; and then to build so that it will not fail—not like Lord Macaulay's idea of the New Zealand tourist who, to illustrate the instability of things, was to stand on a broken arch of London Bridge and sketch the ruins of St. Paul's (London Bridge and St. Paul's are now being underpinned due to defective foundations in both structures, and the work is being done by British engineers).

J. B. LIPPINCOTT,* M. AM. SOC. C. E. (by letter).—The authors are to be commended for writing so frank a discussion of the failure of the Gem Lake Dam due to the freezing and thawing of the concrete on the outer side of the arches below the water levels in the reservoir. The use of this type of dam in regions subject to severe frost has long been a subject of conjecture among Western engineers. Although a thin shell of concrete may be made water-tight against percolation, it is not possible by any process known to the writer to prevent it from absorbing water when in contact with it. The Gem Lake Dam has shown that this is an unsatisfactory condition, in locations of extreme cold.

The multiple-arch dam because of the economy of its construction has such merit that its future use in many localities is assured. This type of structure, however, has its limitations which enthusiasts, in the past, have sometimes overlooked. Most of the dams of this type have had buttresses of plain concrete without reinforcement.

The writer has had occasion to examine the buttresses of five of these dams and in each has found one or more diagonal cracks in some of the buttresses, starting from the junction with the arch approximately two-thirds down from the top of the dam, and running in a line generally normal to the water face to an intersection of the foundation. These cracks do not extend into the reinforced arch rings. In one dam this type of crack developed prior to the time that the arch rings were built on the buttresses. In another instance the cracks are reported to have appeared after the arch rings were placed, but before the reservoir was filled. They are believed by the writer to be due to shrinkage caused by either the drying of the concrete or by temperature changes, because they open wider in winter and partly close in summer.

It is almost impossible to set up a triangular slab of concrete, say, 100 ft. high, with a base length of 100 ft. firmly anchored into bed-rock without having shrinkage cracks occur. This shrinkage and cracking of flat concrete pavements at intervals of 30 to 50 ft. is common. These cracks do not occur

* Cons. Hydr. Engr., Los Angeles, Calif.

in all the buttresses of the dams examined, but usually in a number of the higher ones. Some cracks of this kind have been noticed, however, in buttresses that are not more than 30 ft. high. In every multiple-arch dam having an age of, say, two years, that has been examined by the writer, such cracks have been found, including one having reinforcement.

It is believed that these cracks do not indicate a failure or any serious weakness of the structure, but they are disturbing and lead to discussion and comment. They distinctly suggest the necessity of thoroughly reinforcing the buttress walls of multiple-arch dams in order to minimize such conditions. This paper does not mention any such occurrence in the Gem Lake Dam, but as attention has been called by the authors to some of the limitations in this type of structure, it is deemed appropriate to call attention also to an improvement of past practice.

OREN REED,* JUN. AM. SOC. C. E. (by letter).—The writer has followed the fortune of the Gem Lake Dam with a great deal of interest. The Company with which he is associated has plans for two regulating dams on the North Fork of Kings River on the west side of the Sierras, at elevations of 6 550 ft. and 8 170 ft. The failure of the Gem Lake and other dams leaves a doubt in the minds of engineers as to the permanency of such structures when subject to the action of frost and ice. On the other hand, Lake Eleanor Dam,† 4 660 ft. above sea-level, of the multiple-arch type, has withstood frost action without damage, and several dams of the Ambursen type have been built in Canada and the northern part of the United States with slight damage from frost.‡ The Southern California Edison Company is constructing a multiple-arch dam at Florence Lake on the San Joaquin River, at an elevation of about 7 200 ft.

One wonders whether the primary cause of the failure of Gem Lake Dam was frost action or whether frost action was made possible by a weak porous concrete. It would have been of interest if the authors had stated whether the Agnew Lake Dam had also been damaged by frost, since it is only 550 ft. lower in elevation.

Since information as to the destruction of concrete by acidic and even pure water is very meager, some discussion on that important subject may be of value. While in Europe in 1922-23 the writer was much impressed by the general interest among engineers in this subject. Many tests of concrete, as used in the construction of dams, have been made in Germany, Denmark, and Norway during the last few years.§ It was found that some dams had been failures, but as a rule these failures had been of a purely local character and could be laid to poor workmanship and frost, and a few to poor sand, etc. In other cases the weakening had been more general, especially where water had an opportunity to work in porous concrete. There are several factors which were thought to have contributed to these failures.

* Asst. Designing Engr., San Joaquin Light & Power Corporation, Fresno, Calif.

† *Engineering News-Record*, Vol. 95, July 20, 1925.

‡ *Loc. cit.*, September 3, 1925.

§ Ing. Bonde, *Teknisk Ukeblad*, No. 14, April 3, 1925, and Ing. Groner, *Teknisk Ukeblad*, No. 10, April 17, 1925.

1.—Sand.—Sand containing dirt, humus or humic acids was found to make poor concrete. Concrete made with humus-holding sand has a comparatively low early strength and must be kept moist while hardening in order to gain its normal strength. These humus materials can be disposed of by heating, and, in part, by washing. The sand used should be clean, sharp, and well-graded. Whenever crushed artificial sand is available or can be produced cheaply enough it should be used.

2.—Cement.—In many cases it was found that the cement was at fault. In almost all concrete construction only pure Portland cement is used. This is composed of about 63% lime (CaO), about 20% silicic acid (SiO_2), about 6% of clay and smaller parts of iron oxide (Fe_2O_3), magnesia (MgO), sulphuric acid anhydrate (SO_3), etc. In hardening after hydration lime is freed, which, together with water, forms lime hydrate ($Ca(OH)_2$); this comprises about 15% by weight of the cement's mass. Lime hydrate is soluble in water and is washed out of the structure by leakage water, and, under the action of the carbonic acid in the air, becomes carbonate of lime. This is the white coat to be found on the structure. By the dissolution of lime hydrate the concrete becomes more porous and the voids are filled with leakage water. When freezing takes place, the sand grains are further loosened. This dissolution of lime takes place most easily when the mixture is lean and when humic acid is present in the water or in the sand. Dissolution of the lime may be prevented by adding to the concrete mixture a material which, reacting with the free lime, forms an unsoluble compound, as a silicate of lime. For this purpose the Germans use trass. This is a pale yellow or gray volcanic rock found in the valley of the Eifel in the Lower Rhine. It is a wholly neutral material, but with lime undergoes a chemical combination, forming an insoluble silicate of lime. Finely ground brick clay has also been used with good results.

A concrete may be made water-tight by using a rich cement mortar, but this is a costly method. The French alumina cement, which is especially rich in clay (Al_2O_3), containing 36%, is very durable against acids.

3.—Water.—Water for concrete must be clean and free from organic matter. From tests it has been proven that a plastic concrete gives better results than a dry mixture. A plastic mixture gives a less porous concrete.

4.—Workmanship.—The fourth factor in concrete placing is workmanship. This must be high grade to insure the proper mixing and placing. Poor workmen can produce poor results with the best materials.

The natural lakes and meadows on the west slope of the Sierra Nevada Mountains are, in effect, marshes. To a great extent they are of glacial origin. In many cases large tracts of meadow or marshy ground are covered by water when a dam is constructed. Many tests, especially in Germany, have been made on these marsh waters.

Most marshes contain more or less sulphur compounds, in the form of gypsum, sulphuric pyrite, or even free sulphuric acid. It is well known that sulphuric acid and sulphate-holding water attack concrete by combining with the lime to form gypsum, which is soluble. Destruction by these sulphuric acid combinations occurs not only to new but to old concrete.

Furthermore, great quantities of carbonic acid are found in marshes, which combines with the lime of concrete to form soluble salts. The free lime is thus seen to be the main point of attack and, to prevent failure of the concrete, the lime must be fixed. Tests on marsh water have given varying results but concrete made with it has become weakened sooner or later in nearly all cases. As a general rule the acids which may be present in a reservoir will be in a very dilute state and will not be effective but, where there are large marshy tracts near the dam, and especially with low-water level in the reservoir, the acids will no doubt have a certain effect on the durability of the concrete.

It is not only the sulphate and acid-holding water which damages concrete. Under certain circumstances, pure water, on account of its high dissolving power, may act equally as effectively as weak acids. The water from the granite regions near the crest of the Sierras will often be nearly pure.

In general, concrete tests are concerned only with strength without regard to density, but in dams density is very important. A dense concrete made of the best materials prevents attack both from weak acids and from pure water. A porous concrete has many points of attack for mechanical and chemical action.

Many multiple-arch and flat-deck dams have been successful in Norway and Sweden. One of the most important of these is Holmevand Dam, A/S Saudefaldene, in South Norway. This is a flat-deck dam of the Ambursen type, and is 740 m. (2 400 ft.) above sea level. Fjergeng Dam, in Central Norway, north of Trondhjem, is also a flat-deck dam. As a protection against frost action, it was provided with a vertical insulating wall between the buttresses on the down-stream side. At the Porjus Dam, in Sweden, just above the Arctic Circle, there are concrete arch spillways 648 ft. in length. The remainder of the dam consists of earth embankments faced with stone. The up-stream side of the crest of the concrete dam is inclined, in order to force the ice to break up and be pushed over the crest. A stone-protected dirt fill, furthermore, has been placed in front of the dam to insure against leakage, as in dams of the Intze type. This spillway structure is a modified Ambursen dam and consists of concrete arches between concrete buttresses. The arches in front, against which the fill rests, have a curved exterior, while those forming the crest of the dam and the down-stream face are covered by a flat concrete deck paved with stone set in the mortar.

When it is guarded against, frost action of itself has no great effect on concrete in dams, but as a secondary factor it can do great damage.

B. F. Jakobsen,* M. Am. Soc. C. E. (by letter).—It would be hazardous in the extreme to conclude anything from the behavior of a single structure, and more especially since other similar structures subject to equally severe conditions, have shown no sign of deterioration.†

It would seem to the writer that some experiments on concrete made up of the material used in the dam and on other concrete, by subjecting it to

* Engr. in Chg. of Dams, Los Angeles County Flood Control Dist., San Fernando, Calif.

† See letter by M. M. O'Shaughnessy, M. Am. Soc. C. E., in *Engineering News-Record*, July 30, 1925, p. 194, stating that the Lake Eleanor multiple-arch dam located at an elevation of 4 660 ft. shows no sign of deterioration; also a letter by Spencer W. Stewart, M. Am. Soc. C. E., in *Engineering News-Record*, September 3, 1925, p. 396. Mr. Stewart states that a record of about seventy-five Ambursen dams built in Canada, in the Northwest, and in the New England States, shows that only three dams have deteriorated. Many of them are subject to minimum temperatures of between 40 and 50° below zero Fahr.; the oldest of these dams was built 22 years ago.

water pressure and freezing, could not have failed to throw some light on the subject; they might have furnished some explanation as to why this structure has deteriorated while other structures have not. The mere statement that a structure has deteriorated, while another has not, is of no great value to the engineer, who needs to know the why and wherefore—the *modus operandi*, so to speak—so that he can guard against a repetition.

The authors state that the gravity section is heavier than "standard profiles" of gravity dams. There are gravity dams in existence with base widths of from 64% to in excess of 90% of the height. What is meant by "standard profile"? A dam with a base width of 64% has no provision for uplift; but that can hardly be termed standard. In Italy and Switzerland, where there are Government provisions governing the construction and design of gravity dams, uplift must be included in the design and this was also true in France until recently. The new French regulations do not prescribe uplift, if the dam is provided with proper drainage, not only at the foundation, but throughout the structure, since a construction joint may be quite as weak as the joint at the foundation. The new French regulations, however, prescribe such moderate maximum stresses, that for a dam of any magnitude it is the same as if uplift were included. When a base width in excess of 81% is obtained it is quite immaterial whether this is accomplished by considering uplift or by lowering the maximum permissible stress.

The authors also state:

"It is not believed that stresses can be induced in the gravity section by pressures on the upper 30 ft. of the dam, because such pressures will be transmitted direct to the buttresses."

This may be an important question, however, and therefore well worth investigating, rather than leaving it to an offhand assumption. The multiple-arch dam is a much more elastic structure than a gravity dam and the writer's guess would be that the gravity dam might share to a considerable extent the load on the upper 30 ft. of the multiple-arch dam. Since a gravity dam—even the full section having a base width in excess of 81%—has a rather small factor of safety, an additional load applied at the crest and for which no allowance has been made might be a serious matter.

The writer wonders if any provisions were made to prevent the closing of the drain-pipes from the foundation by frost and what the factor of safety of the gravity dam would be in case these drains should become clogged by ice, or in any other manner, and the dam be subjected to uplift?

In the writer's opinion it is of no importance whether the maximum stress is 70 lb. per sq. in., as stated by the authors, or 170 lb. per sq. in., for this does not affect the safety factor in the least. The question is whether tension can be produced in the up-stream face when the dam is affected by adverse conditions.

J. D. Galloway,* M. Am. Soc. C. E. (by letter).—There seems to be no question but that the Gem Lake Dam was designed by Mr. Jorgensen in accordance with standard practice and that it was well built. The character

* Cons. Engr., San Francisco, Calif.

of the contractors would lead to the latter inference. All the usual tests of cement and sand were carried out.

The progressive failure of the structure is clearly presented by the authors. Over the entire length of the dam, in the zone covered by the winter fluctuations of the water surface, the concrete was disintegrated and the dam had to be rebuilt as described. The value of the paper lies in the description of the failure.

To make the proper interpretation of this or any other failure of an engineering structure is seemingly more difficult than to describe the failure. It is of interest to read the various explanations given by different engineers. Practically all point to the quality of the concrete as the reason for the failure, the idea being that it was the internal composition of that material that caused the failure and not some cause independent of the concrete. Mr. Jorgensen thinks the cement itself broke down during the coldest weather. The question immediately arises as to why the cement in the concrete above the highest water did not break down. This concrete was subjected to lower temperatures than that in contact with water on one side. The Agnew Lake Dam did not fail and there the water was not lowered during the winter.

The evidence seems to the writer to be most plain and the explanation given by the authors correct. The disintegration of the concrete was due to the freezing of the water which had entered into the concrete from the reservoir. The force developed when water freezes is enormous and will easily disrupt concrete. In fact, the same agency is responsible for the wearing down of dense rock masses such as native granite in regions subject to temperatures below freezing. In the present case the thin concrete of the arches permitted the water in the reservoir to be frozen into the form of a layer of ice on the water face, and in addition allowed to freeze whatever water may have been in the voids and hair cracks of the concrete. It is conceivable that cracks would develop in the concrete when on the water face the temperature was that of the water of the reservoir and on the air face the temperature was that of the air, admittedly far below freezing.

The breaking down of concrete by freezing in dams and other structures is not unknown—in fact, is fairly common. Evidences of this have come under the writer's notice and several instances are cited in this discussion. It is unnecessary to look for the fault in the concrete—the cause is found in the type of dam and the operation of the reservoir. It should be noted that in this region the low-water season may occur in the winter when all ordinary springs and streams are frozen. It is then necessary to draw on the reservoir. During a winter, the water surface will alternately rise and fall.

With the conclusions of Mr. Flinn the writer desires to differ in every respect. The danger in engineering is not to over-emphasize a failure of this type; the contrary is the case. Usually, the effort is directed toward minimizing, or covering up, or explaining away the failure. It is to the credit of The Nevada-California Power Company that it permitted the authors to set forth in detail the failure as it occurred. In most cases the endeavor of the company manager is to suppress all knowledge of such a failure. It is partly by failures of this type that the Engineering Profession

advances. The Gem Lake Dam was a test to destruction of a full-sized dam under operating conditions—a test of the most valuable kind. Tests to destruction are always the best, especially if the progress of the test is observed. No others can yield such valuable results in the form of knowledge. This is the type of test to be carried out on the Stevenson Experimental Dam near Fresno, Calif.

Again, little if any information would be gained by counting the dams that have failed and those that have stood. Engineering is not a matter of majorities, one way or the other. For example, there was a time in the United States and elsewhere, when the compression members of metal bridges were made of cast iron. Many of them held together, but some did not. It took the crowning disaster at Ashtabula, Ohio, to teach engineers that cast iron was an improper material for the vital members of a bridge. Notwithstanding the numerous bridges of that type then standing, engineers eliminated cast iron. Too much emphasis cannot be given the Gem Lake failure. It teaches that under such severe climatic and operating conditions, the multiple-arch dam with its relatively thin concrete, should not be used.

The writer also wishes to call attention to what is believed to be an unfortunate tendency among engineers and is exemplified in the present instance. As soon as a concrete structure fails, a number of commentators feel that it is necessary to rush to the defense of concrete as such, and endeavor to explain the failure by citing some unusual defect. In this case, some think that the small percentage of clay and silt explains the whole matter. Possibly so, but the evidence is all to the contrary. As a rule, a small percentage of silt renders the concrete more water-tight. Comparison is made between the structure that failed and some ideal concrete that is sometimes obtained in the laboratory and rarely if ever in the structure as built. Engineering structures are built of the materials at hand. There are regions in the West, of volcanic or granite formation, where it is impossible to obtain anything but a medium quality of sand or rock. Construction, even under the best of supervision, is always subject to conditions that make the resulting structure far short of the ideal. This imperfect structure is the one that engineers have to deal with and that sometimes fails—not the ideal one for which everything is perfect. Although always striving for the very best, the Engineering Profession should design in the light of information obtained in actual practice as to just what degree of perfection may be realized in the structures built under ordinary conditions.

Mr. Jorgensen undoubtedly feels chagrined over the failure of the dam. The writer believes this to be largely unnecessary. His dam was well designed in accordance with good practice, and it was reasonably well built. It resisted the stresses of the water, but failed gradually under severe climatic conditions coupled with certain operating conditions not usual in many cases.

The value of the failure at Gem Lake will lie largely with those who interpret it correctly. To those who see in it merely another example of a defective type of concrete, to be added to the thousands of such examples already existing, the failure will be of no value. To those engineers who find in the combination of thin concrete arches, severe climate, and rather unusual operating conditions an explanation of the failure, the lesson will be of the utmost value. Had Mr. Jorgensen had before him a similar example when designing the Gem Lake Dam it is conceivable that he would have adopted another type. Therein lies the value of the lesson of this failure.

I. OESTERBLOM,* M. AM. SOC. C. E. (by letter).—This paper is unusually interesting and raises again a question that is causing anxiety all over the world. Slow disintegration of concrete, substantially as described at the Gem Lake Dam, seems to cause even more trouble and anxiety in the tropics. Naturally, one is, therefore, led to ask: Is it really the cold that does the damage? This is usually assumed—it seems so obvious; but the obvious is not always correct and is very often far from correct.

In the case under discussion it may be the cause in part, but there also seems to be evidence of other causes. Under the heading, "History of Operation" (page 715), it is stated that: "During the eight years of operation of the structure, very few cracks occurred in it." This does not seem to be the behavior of cold weather which acts on entrapped water with a great deal of violence and speed. The force is evidently of a slower nature, but is none the less very destructive.

There is further evidence that it was not frost that caused the essential part of the destruction. Referring to the first paragraph under the heading, "Condition of Dam in 1924" (page 723), it is stated that in the intervening middle belt, the concrete had become dead and inert, but that a section at the bottom of each arch was little affected. If frost had been the cause, would not the effect have been general?

The subsequently recorded opinion of investigating engineers would seem to be inconsistent. If there was sufficient porosity to permit percolation, the destruction, by necessity, would have taken place during the first winter after construction, but this Mr. Jorgensen, himself, is able to disprove by very competent evidence—his own records—long before any trouble was anticipated. The paper also states that "during this time [two years] no change in the structure was apparent." The concrete evidently was most excellent and of the highest consistency.

Everything seems to point to a more insidious force than mere frost and water. The writer suggests the supplementary compressive forces due to the colloidal expansion of the silica gels that make up the cement.

It would be interesting to know where the cracks really occurred from the viewpoint of stress calculation based on such expansion, in addition to the usual effects of gravity and temperature. Such calculations, compared with the actual records of the cracks, would really be conclusive.

Colloidal expansion is also due to presence of water but in very small quantities only and in such a state, ordinarily, that frost would have no direct effect. Even in the best of concrete this water is present and it is only necessary that the external water should vary—as it did in this case—in order to set up a change in colloidal absorption and subsequent variation of internal stress. It is well known how destructive such variation of stress is; it is also known how slowly it works and that a catastrophe, due to such conditions, sometimes may come without warning and most unexpectedly if special precautions are not taken.

* Care, Truscon Steel Co., Youngstown, Ohio.

It would seem that the destruction recorded at the Gem Lake Dam is an ideal example of how a most excellent piece of construction is being slowly destroyed by colloidal action. At the same time it offers another opportunity for the engineer to take a decided step forward in technical progress.

Destruction similar to that recorded is general in the tropics even to such extent that in certain parts competent engineers refuse to use concrete for permanent construction. The basis there for the change in colloidal absorption and subsequent stress variation is the monsoonal change, with some months very dry and others very wet. A comparison between conditions and effects in cold and warm climates is interesting, and the matter has been discussed.*

B. C. COLLIER,† M. AM. SOC. C. E. (by letter).—The writer has read with great interest the various points brought out in the paper, the discussion regarding the failure of the concrete in Gem Lake Dam to withstand the effects of cold or other disintegrating agents, and especially the statement in the Synopsis (page 713) relative to the necessity of providing a "positive and permanent method of water-proofing concrete."

For several years he has been an earnest advocate of the necessity of proper selection of aggregates in order to insure the life of concrete structures, especially when subjected to water conditions. The statements made by several discussors, to the effect that a very probable cause of the failure was the use of limestone as the aggregate, are fully in accord with his experience. For a number of years he has believed that concrete will not withstand the continued action of water pressures especially when it is in thin slab sections. Examination of a number of reservoir and similar linings seems to prove that the continued passing of minute quantities of water through the pores of the concrete has the effect of a gradual attrition of the cement particles, and the consequent breaking down of the structure.

This discussion has also been of especial interest to the writer, because he was asked, during the period of construction of this dam, to pass opinion on the thickness of the gunite covering to be applied to the up-stream face as a water-proofing medium. At that time knowledge regarding such details was very limited, but the suggestion offered to the effect that at least 1 in. of reinforced gunite should be used, was not accepted as advisable. According to the paper a very thin coat ($\frac{3}{8}$ in. at the bottom and $\frac{1}{4}$ in. at the top) was applied without any reinforcement.

It is, therefore, of particular interest to note what the probable result might have been had a thicker coating of gunite with proper reinforcement been applied. All statements made are to the effect that for a period of almost three years no seepage through the dam was noted, but that subsequently this seepage occurred and gradually increased in volume. In a structure such as this the

* *Proceedings*, Institution of Engrs. (India), Yearly Meeting, Delhi, 1925.

† Pres. Cement Gun Company, Inc., Allentown, Pa.

alternate rise and fall of the water naturally causes severe stresses and a tendency to movement in the up-stream surface. Without question, this stress, continued over a period of time, caused the development of checks or cracks in the thin shell of unreinforced gunite, thereby ultimately defeating its original purpose, and allowing the passage of the water through the dense surface covering to the porous concrete beneath. Although, as stated, at the time at which this work was done little knowledge was extant regarding methods of water-proofing with gunite, later experiences have indicated that had a heavier coat of properly reinforced gunite been used, it would probably have prevented the seepage of the water and the consequent disintegration of the concrete whether due to faulty sand, faulty aggregate, porosity, or frost action.

It is interesting to note the suggestion made by some of the discussors that a coating of asphalt on the up-stream face would have resulted in the saving of the structure. In view of the statements recently made to the writer by several engineers in charge of large water-works activities, to the effect that not only is asphalt, when subjected to such conditions, not water-proof, but also that the life of a membrane coating under water does not exceed 15 or 20 years, doubt naturally arises as to the efficacy of such treatment. An engineer of wide experience in testing work has recently stated that he had definitely proven that asphalt would absorb moisture.

The writer has long been an ardent believer in the adequacy of Portland cement, when it is properly applied, as a resistant to water action. In order to produce this resistance it is necessary to provide a density of application similar to that of gunite. In addition, however, a broad experience in inspection of such structures as this had indicated the necessity of properly reinforcing the gunite slab in order to eliminate the breaking down by "weave" and constant movement; or to insure against the development of checking or cracking from internal stresses. Such authorities as F. E. Turneaure, M. Am. Soc. C. E., have clearly shown that cement structures should always be reinforced against the initial "setting up" stresses, and, in accordance therewith, the writer is now recommending that, for gunite slabs for water-proofing, reinforcement of not less than 0.3 of 1% should always be used, and that preferably, under such severe conditions as those at Gem Lake, the percentage should be as high as 0.5. This percentage of reinforcement placed equally in both directions will also provide an almost positive protection against cracks that will arise from expansion and contraction. With such reinforcement, and with a thickness of approximately 2 in. of gunite, experience has shown that the positively water-proof conditions specified by the authors as being necessary will be obtained.

FRED A. NOETZLI,* ASSOC. M. AM. SOC. C. E. (by letter).—It is well known that certain concretes are subject to deterioration from frost and other actions when they contain a considerable amount of moisture. The deterioration of concrete in sea water is a striking example of this phenomenon. In this case the physical effect of the expansion of the salt crystals which, under certain

* Cons. Hydr. Engr., Los Angeles, Calif.

conditions, may form in the pores of porous concrete in sea water is increased by chemical action. In hydraulic structures subjected to frost conditions the particles of water contained in the concrete will expand considerably when this water is transformed into ice, and thus tend to spall the concrete or weaken it otherwise. In passing from the liquid to the solid state, water expands with a force equal to about 150 tons per sq. ft. One cubic inch of water at 32° Fahr. occupies 1.09 cu. in. in the form of ice at 32° Fahr., which is equivalent in expansion to about one-tenth of the original volume. Porous concrete is, therefore, apt to suffer considerably from frost action. Dense concrete is known to be practically immune against it.

The authors point out that serious deterioration has taken place in the arches of the Gem Lake Dam where the concrete was subjected to water pressure at the time of low temperatures. On the other hand, M. M. O'Shaughnessy, M. Am. Soc. C. E., has stated* that in the Lake Eleanor multiple-arch dam, built in 1918, at an elevation of 4 660 ft., "there are no indications of wear and tear on this concrete structure, and the location is subject to severe frosts without any noticeable depreciation whatever in the concrete"; further, that, in his opinion, "the failure of the Gem Lake Dam is due not to design of structure, but to defective granite dust and materials being incorporated in the sloppy overwatered concrete during construction."

The writer can testify from personal knowledge that, also, the Bear Valley multiple-arch dam, located at an elevation of 6 700 ft., shows very little, if any, deterioration from frost action.

The Gem Lake Dam was built in 1915 and 1916. The Bear Valley and Lake Eleanor multiple-arch dams were constructed in 1912 and 1918, respectively. The Gem Lake Dam suffered from frost action, the other two dams are apparently as strong as at any time in their history, although the climatic conditions are similar at all three sites.

What was wrong, then, with the concrete of the Gem Lake Dam? The authors state that the upper 30 ft. of the existing arches and the buttresses supporting them appeared to be in perfect condition. Only that part of the arches which was below the reservoir level during the severe winter conditions was damaged. The temperature variations in the upper arches and the buttresses were at least as great as for the lower arches, and probably greater. It was, therefore, apparently not the low temperature itself that damaged the lower arches, but evidently the water which had been filtered into the concrete and which expanded when it was transformed into ice in freezing weather. Similar deterioration of concrete has been observed in many structures exposed to water and frost, in canal head-works as well as in some gravity dams many feet in thickness. In most of these cases, deterioration could easily be traced to porous concrete, or unsuitable aggregate, or both.

For the construction of the Gem Lake Dam, a lake sand, containing 3½% of clay and 1% of dirt, was mixed with the sand from the rock crusher in the proportion of about 75% of lake sand to 25% of crushed rock sand. It is not stated whether or not this sand was properly graded. The fact that compression tests on specimens made during construction showed an average

* In a letter to the Editor of *Engineering News-Record*, July 30, 1925.

crushing strength of the 1:2:4 concrete of only 900 lb. per sq. in. at the age of 14 days would indicate that the quality of the sand used was not at all what it should have been for this type of structure. Chemical decomposition of certain ingredients of the granite dust of the "crusher run" may also have been one of the reasons for the troubles with the dam.

The authors deserve credit for emphasizing the necessity of seriously considering frost action when designing dams for cold climates. The method of repair adopted for the Gem Lake Dam is about as radical and expensive as could be devised, but it may have been necessary in view of the advanced state of deterioration.

The writer believes that a satisfactory water-proofing of the arches, as originally attempted by the owners of the dam, could have been obtained in the following manner: At the time when the concrete of the arches showed signs of deterioration, the weak spots, leaky construction joints, etc., should have been cut out as far as practicable and re-filled, for instance, by means of a cement gun. Then a four-ply water-proof membrane of a Malthoid or Tartex product might have been applied in successive layers on the up-stream face of the arches, and a protection slab of concrete, from 12 to 18 in. in thickness, cast against the membrane. The four-ply water-proof membrane would have protected the old arches from infiltrations of water and thus have stopped further deterioration. The concrete protection slab, besides preventing injury to the membrane, would have added materially to the safety of the dam. A dense concrete such as was used successfully for the Lake Eleanor multiple-arch dam, referred to previously, would have insured the permanency of the protection slab. The cost of this concrete slab would have been relatively small as no forms would have been required for the under side of the slab. The water-tight membrane of the character described would have cost about 15 cents per sq. ft. in place. The quantity of concrete for a 12-in. protection slab from the bed-rock up to an elevation of 30 ft. below the crest of the dam, would have been approximately 1 250 cu. yd. This compares with the 12 000 cu. yd. used for the method of repair adopted by the owners of the dam. The multiple-arch type of dam has the advantage of offering easy accessibility to all parts of the structure. Repairs may be made, therefore, before the danger point has been reached.

In what follows, the writer wishes to make a few suggestions which may be helpful for avoiding in future thin dams some of the difficulties that have arisen in connection with the Gem Lake Dam.

The writer agrees with the authors that an impervious concrete will prevent the deterioration of concrete subjected to water pressure and extreme low temperatures. A careful selection and the proper grading of sand and gravel or crushed rock will go a long way toward accomplishing this end. A somewhat richer mixture than the standard 1 : 2 : 4 proportion, say, about 1 : 1.8 : 3.5, will furnish a dense and strong concrete at a comparatively small increase in cost per cubic yard. Naturally, proper care in mixing and placing the concrete is also of great importance.

The arches of multiple-arch dams should be designed so that for shrinkage, rib-shortening, and maximum variations of temperature the tension stresses in the arches are safely within the tensile strength of the concrete. A liberal quantity of reinforcing steel should be added for additional safety. Special attention should be given to the preparation of construction joints between successive horizontal layers of concrete. Leakage is most likely to occur in joints that have not been properly cleaned of laitance and foreign matter. Attack by frost would inevitably start sooner or later in such joints, and the deterioration of the concrete would continue progressively. A 4-in. strip of galvanized iron, placed from 3 to 4 in. from the up-stream side of the arches, across all horizontal as well as vertical construction joints, will prevent leakage through the joints.

In important structures the entire up-stream face of the arches should be covered with a layer of properly reinforced gunite from 1 in. to 2 in. thick. Thin layers of unreinforced gunite, such as was used on the Gem Lake Dam, are not effective very long.

In spite of the partial disintegration of the Gem Lake Dam, the writer firmly believes that safe and permanent structures of the thin arch and multiple-arch type may be built in locations subject to severe weather conditions. A proper design of the arches, suitable, well-graded concrete materials, and careful mixing and placing of the concrete will result in structures which will be safe, water-tight, and permanent. A considerable number of such dams were built years ago and are satisfactory in every way. A few others, like the Gem Lake Dam, have given trouble for reasons which are fairly well understood by this time and can easily be avoided in future constructions.

A multiple-arch dam that will be 160 ft. high and more than ½ mile long is now (December, 1925) under construction in the high Sierras at an elevation of 7 200 ft. The multiple-arch type was selected for this structure after careful investigation of the probable causes that may have been responsible for the troubles on Gem Lake Dam.

The authors seem to favor dams of the rock-fill type for locations where extremely low temperatures may occur. Such rock-fill dams naturally would have to depend for water-tightness on a concrete core wall or on a concrete face slab. A loose rock-fill is relatively porous and permits of more or less free air circulation, including "chimney effect", that is, allowing the warmer and lighter air in the interior of the mass to rise and escape at the top of the dam, thus drawing in the cold outside air through the lower porous parts of the fill. The thin slab of a concrete core or face wall of such a rock-fill dam, therefore, would undoubtedly be subjected to some frost action, especially near the water line, which, in case of porous or otherwise unsuitable concrete, sooner or later would unquestionably lead to progressive deterioration of the concrete. Inasmuch as there would be no simple way of observing such deterioration of the most vital part of a rock-fill dam, a "blow-out" of a weak spot and a possible failure of the structure might occur in time.

According to the authors the Gem Lake Dam was overtopped during a severe flood to a depth of about 3 in. along the entire crest of the dam. Such conditions might have been disastrous for a rock-fill dam.

If on Gem Lake a rock-fill dam had been constructed, and if for the core or face wall the same kind of aggregate had been used with the same class of workmanship as for the multiple-arch dam, it is possible that the authors would have had occasion to describe the failure of a rock-fill dam instead of giving an interesting account of the successful repairs of a multiple-arch dam.

F. W. SCHEIDENHELM,* M. AM. SOC. C. E.—The discussion by Senator Luiggi is of exceeding interest to the speaker.

Senator Luiggi is of the land which presumably was the first to develop cement, namely, the Roman or puzzolan cements. From much that has been said and written (not by Senator Luiggi) one would infer that Roman cements, or more particularly the structures in which they were used, are everlasting. If so, an important art has been lost. However, the speaker suspects that the long life actually enjoyed by certain Roman puzzolan cement-bound structures is due to the fact that, except for the northern part, Italy is not subject to a rigorous climate. Freezing either does not occur or is of minor extent. In fact, the speaker's personal observation on the occasions of two visits to Italy lead him to believe that, under similar climatic conditions, Roman cement-bound structures behaved much like Portland cement-bound structures of the present age. In neither case does the cement seem to be perfect. Even Italy, as well as America, has its problems as to the durability of hydraulic structures.

A FUNDAMENTAL QUESTION

The Gem Lake Dam is a hollow concrete structure which, by reason of disintegration of its deck, has failed to perform its intended function. Long before the presentation of this interesting paper there was raised in the speaker's mind the fundamental question: Is a hollow dam of concrete an appropriate engineering structure, particularly for cold climates? This question carries with it the premise that the concrete is of a kind which is practicable of attainment under the present state of the art. The question applies to hollow concrete dams of both the multiple-arch and the reinforced concrete slab-deck types. Study of this question has led the speaker into a fairly broad investigation and the occasion seems opportune for briefly stating the results and presenting his deductions.

At the outset it may be stated broadly that the investigation has left the speaker optimistic as to the propriety of the use of concrete in hydraulic structures which are exposed to severe freezing and thawing and, until there is further and contrary evidence available, his answer to the foregoing question is definitely, even though qualifiedly, in the affirmative.

GEM LAKE DAM DISINTEGRATION

First consider briefly the conditions obtaining in the case of the Gem Lake Dam. The design involves relatively thin arches. The thickness was apparently from about 16 to about 34 in. within the areas of the arched decks where disintegration occurred. However, relatively thin decks, whether in the form of arches or reinforced concrete flat slabs, constitute an essential feature of hollow concrete dams. If the decks were not relatively thin, then hollow concrete dams would lose a considerable proportion of any economy which they may offer. It is fair to state that the design of the Gem Lake Dam follows the general lines accepted as structurally satisfactory for dams of its type.

* Cons. Engr. (Mead & Scheidenhelm), New York, N. Y.

As to the concrete of which the dam was originally built, the facts available from published information and private inquiry are none too detailed nor reassuring. Among other things it is not unlikely that the sand was considerably too fine. The coarse aggregate is questioned by certain interested engineers, but the information available is not such as to cause the speaker to attach any serious blame to it. The cement was presumably of a quality equal to the average of standard Portland cements and subject only to the qualifications that there is still much to be learned about cement in general and that undoubtedly there are some steps still to be taken for the improvement of the product.

The proportions in which the arch concrete is reported to have been mixed, namely, 1 part of cement to 6 of aggregate, might be adequate if the other factors of the manufacture of the concrete in point were satisfactory. However, it seems not unlikely that the fineness of the sand would have warranted a somewhat greater cement content. Moreover, a greater cement content would have been desirable, if indeed not imperative, in case the water-cement ratio was relatively high. As to the latter, the speaker does not doubt that in conformity with general practice at the time of the construction of the Gem Lake Dam (1916) the water content was too great. (If the builders of the Gem Lake Dam erred in this respect, let it be noted that many others, including the speaker, have made the same error.)

The speaker has been unable to learn that any particular attention was paid to the adequate curing of the concrete and agrees thoroughly with Mr. Merriman that conditions were most unfavorable for proper curing. Although impermeability and permanence of concrete are not direct functions of strength, nevertheless, it is pertinent to note that the 14-day strength of specimens of concrete tested during the original construction was only about 900 lb. per sq. in. in compression. That fact in itself was none too good an omen.

The outstanding characteristic of the disintegration of the concrete is that apparently the arch mortar has tended to change from the original texture and strength to a texture and strength approximating those of hard clay, or perhaps even chalk. The disintegration is reported to have been limited to the deck arches, the buttresses remaining in good condition. Although presumably there was a tendency to require greater workability and, hence, a wetter mix for the arch concrete than for the buttresses, yet this possibility and the disintegration of the arch do not necessarily indicate that the arch concrete was inferior to the buttress concrete—in fact, the buttress concrete is reported to have had a somewhat lower cement content. It seems clear only that the arch concrete was not of sufficiently good quality to withstand the severe physical conditions to which it was subjected. It is likely that if the buttress concrete were subjected to similar physical conditions for an equal length of time similar disintegration would result.

As pertinent to the causes of the disintegration and the possible means for preventing similar disintegration in other structures, it is to be noted that apparently the disintegration occurred only below the winter water surface of the reservoir. The reservoir is reported to have been drawn down regularly for the winter period to a level about 30 ft. lower than the "pool-full" level. Correspondingly, the upper limit of the disintegration is said to have been about 30 ft. below the top. It is, therefore, a reasonable deduction that percolating water from the reservoir was a prerequisite of the disintegration.

On the other hand, the authors report that "a section of the bottom of each arch was little affected." Clearly the absence of disintegration in the lower part of the arched decks cannot be attributed to the absence of percolating water. It is true that the lower part of each arched deck is thicker than that directly above, but such a difference in thickness is too gradual and too minor in amount to afford the explanation. Instead the speaker is strongly inclined to agree with the authors in attributing that better condition to the protection afforded by the drifts of snow which lodge against the lower parts of the decks.* Precipitation appears to be plentiful and must be in the form of snow even before the temperature becomes very low.

The absence of disintegration in the lower parts of the decks indicates that percolation of reservoir water through the concrete is not necessarily, or at least not rapidly, harmful provided there is no severe freezing at the under side of the deck. (Whether in the case of even the best quality of concrete permitting percolation of water such percolation might not *per se* cause some disintegration in the course of a number of years is another question.)

The speaker inclines to the view that the disintegration of the arched decks at Gem Lake was due to the combination of inferior concrete, percolating water, and severe freezing alternating with thawing, and that, in the absence of any one of these three unfavorable factors, disintegration would probably not have occurred. In fact, the number of unfavorable factors may practically be reduced to two, for if the concrete were impermeable percolation could not have occurred. It is of special significance that the down-stream faces of those parts of the arched decks which suffered damage were at no time of the year protected by structural or natural (snow) enclosure against severe freezing.

Successful Unenclosed Hollow Concrete Dams

Engineers may well take cognizance of the fact that there are in existence a number of hollow concrete dams, both of the multiple-arch and the reinforced concrete slab-deck types, which, despite their locations in regions of rigorous climate involving alternate freezing and thawing, have continued to perform their intended functions and which have suffered no disintegration or, if there has been any disintegration, such disintegration has been too insignificant to record. This fact indicates strongly that such difficulties as have been encountered with hollow concrete dams have not been due primarily

* Charles W. Comstock, M. Am. Soc. C. E., has informed the speaker that he was told by members of the local operating staff of the Power Company that the near-by 30-ft. Agnew Lake Dam becomes completely covered with snow on its down-stream side.

to the thin decks, whether in the form of arches or of reinforced concrete plates. Also, it shows that concrete can be produced which, in the accepted sense, is permanent and can successfully withstand the rigors of such climates.

Agnew Lake Dam, California.—Of existing hollow concrete dams which are performing their intended functions the two which have the most direct bearing on the Gem Lake case are the Agnew Lake Dam (the mate of the Gem Lake Dam) and the Lake Eleanor Dam. The Agnew Lake Dam was built by the same company, by the same construction organization, and at the same time as the Gem Lake structure, so that it, too, has had a life of more than nine years.* It is situated on the same stream, at an elevation only about 500 ft. lower; hence, both dams are subject to practically the same climatic conditions. The Agnew Lake Dam, however, is only 30 ft. high and is in a small gorge, so that its crest length is only 280 ft. In consequence, the dam is reported to be snowed in every winter, with the snow on the down-stream side extending to the very top of the structure. Mr. Jorgensen, the designer of both dams, states that Agnew Reservoir remains practically full throughout the winter.

The design of the Agnew Lake Dam is the same as that of the Gem Lake Dam. In view of the low height of the Agnew Lake Dam, therefore, the thicknesses of arch decks subject to hydrostatic pressure from the reservoir during the winter are nowhere so great as in the cases of those decks of the Gem Lake Dam which have suffered disintegration.

The concrete of the Agnew Lake structure is practically the same as that at Gem Lake. The coarse aggregate was taken from Gem Lake to Agnew Lake. The sand apparently involved the only difference from the Gem Lake construction, as about one-half of it came from Gem Lake and the remainder from Agnew Lake itself. Hence in spots, at least, even the sand must have been the same as at Gem Lake; on the other hand, Mr. Jorgensen was of the impression that the local Agnew Lake sand was of the poorer quality. As regards water and cement contents and the method of making the concrete, the reasonable assumption is that there was no difference between the two structures.

Nevertheless, competent engineer observers agree that the Agnew Lake Dam is in first-class condition, having suffered no disintegration. Why, then, the difference? Presumably the unfavorable conditions as regards quality of concrete, percolation of water, and severity of climate are essentially the same. The one marked difference appears to be that involved in the complete snow covering, thus obviating severe freezing. The speaker agrees with Mr. Jorgensen in attributing the good condition of the Agnew Lake Dam to its snow cover protecting the down-stream faces of the arched decks.

Lake Eleanor Dam, California.—The Lake Eleanor Dam, of the City of San Francisco, located on a tributary of the Tuolumne River, is likewise of the multiple-arch type and is of approximately the same height, namely, 70 ft. gross against the 80 ft. gross height of the Gem Lake Dam. Lake Eleanor

* "Multiple-Arch Dams on Rush Creek, California," L. R. Jorgensen, M. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), p. 850.

Dam is on the western slope of the Sierra Nevadas at an altitude of only about 4 650 ft. above sea level, whereas the Gem Lake and Agnew Lake Dams are on the eastern slope of the same mountains at elevations about 4 000 ft. higher. Nevertheless, the Lake Eleanor Dam, too, is subject to the most important and severe element of climatological conditions—alternate freezing and thawing; in fact, the conditions at the Lake Eleanor site are, not unlikely, more severe in that, by reason of the lower altitude, the cycle of freezing and thawing may occur more frequently within a given time.

The panels of Lake Eleanor Dam between centers of buttresses are 40 ft., just as in the case of Gem Lake. Its length is approximately 1 260 ft. It was built in 1917-18 and the same engineer had an important part in the design of each of the two structures. Although there are certain differences in the thickness of members, these are relatively minor; it is fair to state that structurally the two dams are essentially alike. Furthermore, the likeness extends to the conditions of operation, for in each case the water surface of the reservoir is reported to be comparatively low in winter. Possibly there is somewhat more fluctuation of water surface during the winter season in the Lake Eleanor Reservoir than in the Gem Lake structure. As in the case of the latter, the Lake Eleanor Dam has no spillway apron, nor any other type of enclosure of the space between buttresses. Its spillway is in a solid gravity part of the dam.

That there has been no disintegration has been stated* by Mr. O'Shaughnessy, according to whose report, the present multiple-arch dam at the Lake Eleanor site is in due course to be displaced by a rock-fill dam. The ultimate dam is to be between 150 and 175 ft. high.† Apparently, the designers consider a multiple-arch dam—or a buttressed arch dam, in the terminology which they properly prefer—as being either unsafe or uneconomical for so great a height as that ultimately intended for the Lake Eleanor site. Nevertheless, the arched decks of the existing dam are intended to be utilized and relied on to furnish the lower 70 ft. of water-tight up-stream diaphragm for the ultimate, high, rock-fill dam. Evidently, those in responsible charge entertain no doubts as to the durability of this particular multiple-arch dam. Mr. O'Shaughnessy characterizes the Lake Eleanor Dam as being a structural, as well as an economic, success.

Aziscohos Dam, Maine.—A successful unenclosed hollow concrete dam which has had a fairly long life is the Aziscohos Dam, built in 1910-11, on one of the tributaries of the Androscoggin River in Maine. It is about 75 ft. high and the hollow concrete part is about 500 ft. long, of which one-half is spillway. The spillway portion has an apron extending down about two-thirds the way from the spillway crest to the foundation rock, but not a sufficient distance to have a material effect on temperature conditions in that part of the dam as compared with the bulkhead part, where there is not even a partial enclosure on the down-stream side.

The deck is reinforced and has a flat surface on the up-stream side, but is arched only on the down-stream side. The minimum thickness of the deck

* *Engineering News-Record*, July 30, 1925, p. 194.

† *Loc. cit.*, September 4, 1919, p. 466.

slab at the crown of the arches is apparently about 30 in. and the maximum about 36 in. The deck concrete is said to be of 1 : 2.5 : 3 proportions. A detailed description of the dam has been published.*

On the occasion of an inspection of the Aziscohos Dam in June, 1922, the only disintegration observed by the speaker was in the cases of two reinforced concrete brace-beams in the outlet bay, exposed to water and freezing. This good condition is confirmed by the observation of George C. Danforth, M. Am. Soc. C. E., who visited the structure in 1923. Admittedly twelve years is not a long life for a dam; on the other hand, in practically every case of serious disintegration of concrete the trouble has made itself known within ten years.

Eugenia Falls Development Dam, Ontario, Canada.—A hollow concrete dam exposed to temperature conditions approximating those of Gem Lake Dam is that of the Eugenia Falls development of the Hydro-Electric Power Commission of Ontario. This dam is of the Ambursen type, with the conventional reinforced concrete flat deck slab. It is situated about 70 miles northwest of Toronto, Ont., Canada, in latitude 44° 20′ North, where it is subject to a maximum annual variation of temperature of about 125° Fahr., ranging from 35° below zero to 90° above. The structure was completed in 1914, and thus has been in service for more than 11 years. It is about 50 ft. high and the hollow concrete part is about 1 250 ft. in length.

This part of the structure is entirely of bulkhead section, that is, open on the down-stream side, except a relatively short spillway the apron of which extends so short a distance below the spillway crest as to have negligible enclosing effect. During the winter the reservoir surface fluctuates throughout the upper one-third of the height of the dam. In this part of the structure the reinforced concrete deck slabs are about 16 in. thick. The deck concrete is of 1 : 2 : 4 proportion, the minimum thickness being 12 in.

In the main the foregoing information regarding the Eugenia Falls Dam was furnished by the Chief Engineer of the Commission, F. A. Gaby, M. Am. Soc. C. E. Mr. Gaby has further stated that recent inspection showed that the lower faces of the deck slabs have not disintegrated. A minor amount of flaking is said to be in evidence in the upper part of the up-stream face of the deck at some of the construction joints, this being attributed to the fact that the upper parts of many of the deck slabs were poured during the unfavorable temperatures of December. From the performance of this structure Mr. Gaby infers that concrete with proper proportioning and good mixing, so as to result in a dense product, will successfully withstand rigorous conditions of cold.

Enclosed Hollow Concrete Dams

One need not be surprised that there are various instances of hollow concrete dams (generally of the Ambursen type) which are completely enclosed along the down-stream faces of the buttresses and which have suffered no disintegration of concrete. In general, the enclosure results from the use of a complete spillway apron. An example of such structures, which has been visited in person by the speaker, is the Warrior Ridge Dam of the Penn Central Light and Power Company, on the Frankstown Branch of the Juniata River in Penn-

* *Engineering News*, March 9, 1911, pp. 288-291.

sylvania. This structure, about 30 ft. high and about 450 ft. long, is entirely of spillway section. It was constructed in 1906, thus having about 20 years service to its credit. The speaker's earlier observation as to absence of disintegration has been confirmed more recently by several other engineers.

OTHER CASES OF DISINTEGRATION

To mention several other instructive cases where disintegration of concrete in dams has occurred, the first is an intake dam,* on Bishop Creek, in California, likewise on the eastern slope of the Sierra Nevadas, which suffered some disintegration on the down-stream face of the relatively thin section of the dam. This disintegration is reported to have been stopped by an earth back-fill against the down-stream face, thus preventing extreme temperature variations at the surface of the concrete.

Stony River Dam, West Virginia.—A case with which the speaker has had considerable personal contact is that of the hollow, reinforced concrete dam of the Ambursen type, on Stony River in West Virginia.† This dam is situated in the northern part of the State at an altitude 3 400 ft. above sea level, and is subject to severe freezing weather. It was constructed in 1912-13, failed in part in January, 1914, by the undermining of a too shallow cut-off wall, and was reconstructed in 1914-15, the reconstruction being under the supervision of the speaker.

In the concrete of both the original work and the reconstruction local sandstone was utilized for the coarse aggregate and likewise, by crushing and rolling, for the sand. In both cases the concrete was placed wet, one might say "slushy". The deck slabs were of 1 : 2 : 4 concrete. In no respect had the failure of the dam been due to the quality of the concrete; in fact, the good appearance of the original concrete in the spring of 1914 led to the decision to continue the use of local aggregates. The only excuse for the wet concrete lies in the fact that at that time such was the generally accepted practice.

As part of the reconstruction certain structural modifications were made. That part of the dam which had failed had been of open bulkhead section, but this was replaced by means of a second spillway, which, like the original spillway, has a completely enclosing apron on the down-stream side. Furthermore, in order to prevent freezing of the foundation drainage system, installed throughout the entire dam as part of the reconstruction, a concrete housing was built in all the previously open bulkhead bays, except only the bays of lesser height near the ends of the dam.‡ This housing consists of a curtain-wall of concrete, 12 in. thick, extending for about two-thirds of the height of the dam, together with a roof, 7 in. thick, extending horizontally from the top of the curtain-wall up stream to a junction with the deck.

The water-level fluctuates considerably. There is no fixed regimen which applies one winter after another.

During the first six years of the life of the original concrete, that is, until 1919, practically no evidence of disintegration was discernible. An inspection

* See p. 724.

† *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), pp. 907-1100.

‡ *Loc. cit.*, p. 955, Plate XII.

in the autumn of 1919, however, revealed some spalling of concrete on the up-stream face of one of the original deck slabs near the center of the dam. It is presumed that the spalling originated during the severe winter of 1917-18, for which period a minimum temperature at the dam of 36° below zero Fahr., was reported. At the time of this inspection the spalling extended to a depth of about 5 in., the total thickness of the deck slab at this point being about 14 in. The spalling extended across the entire width of the deck slab (about 13 ft.); this fact, together with the further fact that this slab was the only one which had spalled, indicated that the disintegration may have been due to improper treatment of the concrete in that particular area. In 1921 the disintegrated slab was patched by superimposing a reinforced concrete slab. However, water penetrated between the original and superimposed slabs and the disintegration of the original slab continued, until finally the concrete crumbled and spalled on the lower or down-stream face of the slab in the same region, exposing the reinforcing steel.

In the meantime the two adjacent deck slabs were showing an increasing seepage through the concrete, thus casting doubt on the earlier indication that the slab first showing disintegration had been subject to an isolated instance of faulty workmanship. It is likely, however, that this particular part of the original deck was made of concrete in which, as compared with the remainder of the work, there was aggravated some error in making the concrete, as, for instance, excessive water-cement ratio or improper curing. The slabs in point were undoubtedly cast at a time when there was no freezing and possibly even during hot weather. Further repair work was done during 1924.

The area affected comprises only about one-fourth of 1% of the total deck area of the dam. It is important to note that there is no record of any disintegration below the roof of the housing (which applies to about three-fifths of the bulkhead sections of the dam), and, similarly, that there appears to be no disintegration whatsoever within either the old or the new spillway, and, therefore, completely enclosed, sections of the structure.

The fact that in the new spillway section there has been no disintegration, whether of deck, apron, or buttresses, is the more noteworthy because there has been considerable disintegration in the new spillway mat or channel flooring and also in the concrete placed during the reconstruction to reinforce the footings in that part of the dam which had not failed. This disintegration of the newer concrete was most marked on horizontal, or only slightly inclined, surfaces. The newer concrete which has suffered disintegration was undoubtedly made with too much water and too little cement, especially considering the quality of the aggregate used, and much of the concrete was placed during the winter. However, as compared with the new concrete which disintegrated, the concrete of the new spillway similarly contained too much water; the cement content for the spillway was greater only in the deck and apron (1 : 2¼ : 3¾), but not in the buttresses, which, like the spillway channel mat, were of 1 : 2¾ : 4½ mix.

The new deck concrete is not superior to that of the original decks. The former are somewhat thicker at the same elevations, but the speaker believes that it is primarily because of the complete enclosure that the new decks withstood successfully the severe winter of 1917-18 and appear still to be in excellent condition.

In considering possible causes of the disintegration of the small area of deck slab in the original part of the dam, the question arises whether the difficulty may not have focused at and been due to the ice sheet covering the reservoir in winter. The water surface of the reservoir may actually have been at or slightly above the disintegrated area during the winter of 1917-18; moreover, the fact that the disintegration was first noticeable on the up-stream surface implies that there may have been some plucking action on the part of the ice, thus causing the observed spalling. However, other facts indicate that the ice sheet is not primarily responsible, but rather that it may have accentuated and made obvious a disintegration which had an earlier and more direct cause, namely, percolation of reservoir water through the deck slab and consequent freezing of the slab while in a saturated condition and unprotected on the down-stream side. One fact bearing on this matter is that the water level is by no means fixed seasonably; another is the experience in the case of the Gem Lake Dam where the disintegration extended for many feet below the winter water level of the reservoir.

Limitation of Disintegration to Unenclosed Dams.—The speaker is familiar with or has reports on disintegration of concrete in various other hollow concrete dams, both of the multiple-arch and reinforced concrete deck-slab types. However, persistent inquiry on his part has not revealed to date a single instance where disintegration of concrete has occurred in the decks of hollow concrete dams in which the down-stream faces of the decks are protected against severe freezing temperatures. He would not have been surprised to learn of some cases where obviously poor concrete had disintegrated even under such protected conditions, for, at best, a relatively thin slab subject to percolation from reservoir water is functioning under severe handicaps. The apparently complete absence of disintegration in enclosed parts of hollow concrete dams thus seems all the more remarkable.

Time and space do not warrant consideration of the disintegration of concrete which has taken place in altogether too many solid concrete dams, but it is worthy of note that such disintegration has occurred primarily in regions where there is severe freezing and in parts of dams which are fully exposed to the prevailing atmospheric conditions. Incidentally, the disintegration which has occurred in such dams appears to be greater as the surfaces approximate the horizontal.

Tentative Conclusion

In the light of the foregoing considerations, the speaker has reached the tentative conclusion that hollow concrete dams may be constructed and relied on to be relatively permanent, provided:

1.—The design is good and the proportions of the members liberal, especially as regards thickness of concrete protecting any reinforcing steel.

2.—The concrete is made of proper materials and in a proper manner, in accordance with present knowledge of the art. This involves capable, conscientious, rigid, and authoritative inspection.

3.—The dams are enclosed by means of diaphragms or heat-insulating walls located at or near the down-stream faces of the buttresses.

This tentative conclusion has been reached with full recognition of the fact that hollow concrete structures of necessity can tolerate disintegration to a less extent than solid concrete dams. The point is that disintegration is believed to be avoidable.

The speaker is sufficiently optimistic to believe that hollow concrete dams can be built in freezing climates successfully even without the enclosure. However, in view of the present status of the art of concrete construction and the contingencies which at best enter into any concrete work, he believes it is not conservative to rely entirely on obtaining the proper quality of concrete.

The most important quality to be attained in the deck concrete is, of course, water-tightness and this, in turn, is directly dependent on the density of the concrete itself. Without presuming to have any final knowledge on the point, the speaker doubts the practicability of obtaining in dams reliably water-tight concrete decks by means of surface or membrane coverings. Acknowledging that, in general, such coverings must be of some benefit, he prefers to place his main reliance on properly attained density of the concrete itself.

As to the character of the recommended enclosure, it should be noted that the form of the enclosure in the case of the Stony River Dam was governed by a different consideration. If this point of protecting the entire down-stream surface of the decks had been in mind, the enclosure would undoubtedly have been carried to the full height of the dam. A fact of importance developed in the functioning of the Stony River Dam is that within the enclosure the temperature does not fall materially below the freezing point. For instance, during the winter of 1915-16, the lowest temperature within the enclosed part of the dam was + 26° Fahr., whereas the lowest outdoor temperature was — 12° Fahr. Under these conditions no serious ice formation took place within the enclosure. Evidently, the radiation of heat from the reservoir water and from the foundation material into the enclosed space to a large extent offsets the radiation of heat through the enclosing diaphragm from the enclosed space into the outside air.

The down-stream insulating wall may be of concrete, either single or, better still, double; in the latter case, it affords an insulating air space within the wall. Hollow tile also seems appropriate for the purpose. The tile might be coated with stucco or gunite if a more pleasing appearance is desired. Incidentally, such a diaphragm, especially if of concrete, serves as a brace between buttresses.

The water-works reservoir dam, at Coatesville, Pa., of the Ambursen type and constructed under the supervision of Alexander Potter, Assoc. M. Am. Soc. C. E., in 1916-17, is understood to have its non-spilling concrete sections enclosed by an approximately vertical diaphragm of No. 28, four-rib "Hyrib" (a form of metal lathing), covered by a 1-in. thickness of plaster. However, it is further understood that such an enclosure is solely for architectural effect. The speaker also notes with interest Mr. Reed's statement that one of the more recent Norwegian dams, the so-called Fjergeng Dam, is enclosed by an insulating wall on the down-stream side.

MISCELLANEOUS

The speaker will await with much interest the result of the long time test by Nature as to the quality of the concrete used in the Gem Lake reconstruction work, especially in view of the somewhat low cement content. It would be of interest to know in what direction the diagonal cracks extend, that are mentioned by the authors as having occurred near the up-stream toes of three of the buttresses. It appears not unlikely that these cracks are of the same nature as those mentioned by Mr. Lippincott.

CHARLES W. COMSTOCK,* M. AM. SOC. C. E.—The dominant note in the preceding discussion seems to be one of condemnation of the concrete used in the original construction. From this opinion the speaker dissents.

Records of concrete tests made during construction are not at hand, but the speaker has had access to them and has studied them carefully. To the best of his recollection compression tests on 6 by 12-in. cylinders at 28 days gave upward of 1 900 lb. per sq. in. Generally this would be regarded as satisfactory.

The speaker made an examination of Gem Lake and Agnew Lake Dams in May, 1924. The exposed portions of both dams, arches and buttresses, were carefully gone over with pick and hammer. Holes were drilled or dug at various places where indications were unsatisfactory. Except for the belt, about 30 ft. wide, of the arches of Gem Lake Dam, which has been described in the paper, the concrete was satisfactory in appearance and perfectly sound, ringing clearly when struck with a hammer. The buttresses at Gem Lake were in perfect condition. There was no spalling or other evidence of deterioration. Agnew Lake Dam was apparently in perfect condition throughout.

The speaker was not connected with the original construction of these dams and has no personal reason for defending the methods or materials used, but all the evidence indicates that the work done and the results obtained were as good as possible with the materials available.

Mr. Flinn has suggested that concrete materials should be selected with greater care than is usually bestowed upon them, that they should be carefully analyzed and scientifically proportioned. While the soundness of this suggestion will not be questioned, and it is certain that the best results cannot otherwise be obtained, it should be remembered that the constructor is nearly always limited by considerations of cost to the sand and coarse aggregate afforded by the surrounding territory. Cement is purchased under standard specifications with which all established brands comply. Defective concrete is rarely due to poor cement, although sometimes to improper manipulation.

In the speaker's opinion unsatisfactory concrete results more often from poor sand than from any other one cause, but in this material the constructor frequently has little or no choice. The alternative is to use the best that is available and be content with concrete of quality inferior to the ideal.

* Engr., Dwight P. Robinson & Co., Inc., New York, N. Y.

At the time of the reinforcement of Gem Lake Dam the sandpits used in the original construction were entirely submerged and inaccessible. The nearest natural sand would have had to be hauled 16 miles and then drawn up the inclines and barged across Agnew Lake, as was done with cement and lumber. The cost was prohibitive. It was necessary to grind the country rock to obtain sand. Whether the new concrete will be superior to the old remains to be seen.

A word as to Agnew Lake Dam—it is about 550 ft. lower than Gem Lake and was built to afford storage for one or two seasons prior to the completion of Gem Lake Dam. Since the completion of the upper dam water stands almost constantly at spillway level in Agnew Lake, thus protecting the water face against freezing on that side. Agnew Lake Dam is only a little more than 30 ft. high, and snowdrifts pile up to its full height on the lower side every winter. This affords ample protection against the freezing which has damaged a part of the Gem Lake structure, and accounts for the present sound condition of the lower dam.

After a careful study of both these dams the speaker was unable to find any other explanation of the peculiar nature and location of the damage than that given in the paper. He does not believe that the facts square with any assumption of poor concrete in the original construction. Whether it would have been better to have chosen an entirely different type of dam in the first place is another question.

GEORGE W. HOWSON,* ASSOC. M. AM. SOC. C. E. (by letter).—This very frank discussion of the failure of the concrete in the arches of the Gem Lake Dam is extremely interesting to those engaged in the design and construction of dams, and carries a warning to those building thin exposed walls subject to water pressure. Many theories may be advanced as to the cause of the failure, but all are without conclusive proof. The most logical conclusions have been reached by the authors that moisture found its way into the concrete and there froze, causing disintegration. They rightfully conclude that field construction conditions make extremely difficult, if not impossible, a concrete absolutely impervious to the slightest penetration of moisture. It is gratifying to note that they conclude that the rock-fill type has many advantages over other types of dams in such a locality as Gem Lake. The writer believes that the virtues of the rock-fill dam extend further than to localities such as Gem Lake. It adapts itself to certain foundations, such as loose rock or cemented gravel in stream beds, requiring a minimum of excavation compared with masonry dams. There is a tendency toward the popularity of the rock-fill dam, probably due to the increasing familiarity of engineers with it. The writer has knowledge of five large proposed dams, all of the rock-fill type.

The rock-fill dam is not susceptible to such a refined degree of analysis as the multiple-arch, and owing to the very nature of the structure it is not necessary that it should be. The design is largely a matter of experience and not of refined computation.

* Res. Engr., Dix River Dam Project, Burgin, Ky.

Recently, the writer has been in charge of the construction of the super-rock-fill dam on the Dix River in Kentucky, designed by L. F. Harza, M. Am. Soc. C. E. This dam is 275 ft. high above the stream bed and 296 ft. above the foundation excavations. It contains 1 800 000 cu. yd. of material and is by far the master effort yet attempted in this type of construction.

When properly designed the rock-fill dam has, for a water-tight skin spread over the exposed up-stream face, a layer of reinforced concrete which, in the larger dams, generally varies from a maximum of 2 ft. to a minimum of 6 in. in thickness. In this respect the rock-fill type has something in common with the multiple-arch; both rely on a thin slab of concrete for water-tightness. In case of the rock-fill dam the concrete slab is protected from the elements on the lower side by the mass of the rock-fill over which it is spread and on which it relies for support. In the multiple-arch dam the thin arches are exposed on the lower side to the elements, and it is believed to be this exposure at Gem Lake that caused the failure.

The large rock-fill dam must have a concrete water-skin of a quality equal to, if not better than, the arches of a concrete structure. It must be as nearly impervious as possible and, in addition, be able to develop great strength to meet indeterminate stresses due to movements in the rock-fill itself. By proper construction of the body of the dam, movements of the fill may be partly controlled and reduced in amount, but nevertheless they are present in a greater or less degree, depending on the intelligence, guided by experience, used in the supervision of the construction of the fill. Once the apron of concrete is poured against the fill it must conform to the movements or take stresses sufficient to overcome them.

No concrete apron spread over the face of a large rock-fill dam would be able to resist major movements of the dam, nor is it ever intended that it should in a well-designed apron; but the apron may be so designed and so constructed that it can overcome tendencies to small local movements. This is a matter of the fine combination of proper design and good supervision so necessary in dam construction.

FRED O. DOLSON,* AND WALTER L. HUBER,† MEMBERS, AM. SOC. C. E. (by letter).—The writers' conclusion that a type of dam other than the multiple arch should be selected for a site such as that at Gem Lake is well demonstrated by the great diversity of opinion, as to causes of deterioration and as to remedies, displayed in the discussions. The wide interest shown by this full discussion is, to them, a source of satisfaction.

The positiveness and the wide diversity of opinion regarding the quality of concrete in the original structure would be amusing if it were not to some extent a reflection upon the profession. It is interesting to note that criticism of materials and workmanship of the original structure is offered by those who have not made a personal examination, while others, as, for instance, Mr. Comstock, who made a careful inspection of the structure previous to its repair, defend both and state that the evidence indicates that the work

* Vice-Pres. and Asst. Gen. Mgr., Southern Sierras Power Company, Riverside, Calif.
† Cons. Engr., San Francisco, Calif.

done and the results were as good as could be obtained with the materials available. Many points brought out in the discussion are worthy of further consideration.

Mr. Jorgensen contributes some interesting notes from the laboratory which made the analyses and tests of materials used in the original construction, as well as some interesting facts relating to that construction. He refers to some similar dams in Northern Sweden where low temperatures are encountered, and states that no damage has occurred in two years, although he admits that these dams are partly back-filled with earth as a protection against low temperatures.

In personal correspondence Mr. Jorgensen states that for each of the dams the back-fill behind the arch section covers that part which remains below the water level during cold weather. The writers are in entire accord with his conclusion that under severe freezing conditions it can hardly be expected that a plaster face applied to a thin concrete section will have a long life.

Mr. Jewett has offered some of the results of the many tests he made for The Nevada California Power Company in an effort to find a coating which would afford a water-tight face and, at the same time, would offer some degree of permanence. The defects of many so-called "water-proofing" compounds are intimated if not actually expressed. It will be noted that Mr. Jewett has, wisely in the writers' opinion, avoided the use of any trade names.

As an example of incorrect conclusions, Mr. Wheeler and Mr. Lane attribute the disintegration of the concrete to the presence of limestone and limestone dust. It is interesting to note that, in the lower part of the dam where the limestone (mentioned by Mr. Jorgensen as coming from the outlet tunnel) was used, no disintegration has occurred, whereas in that part of the dam which has disintegrated this limestone was not used.

Mr. Turner mentions certain concrete dams, much thinner than the Gem Lake Dam, and exposed at times to temperatures of 50° Fahr. below zero, but he does not state where these structures are located and at what season the water stored behind them is drawn down; consequently, the writers have been unable to make a comparison.

Mr. Wiggin credits the writers with calling attention for the first time in a pointed way to the fact that the immersed side of a thin exposed wall of concrete is in the same danger from the formation of ice crystals in its pores, under the influence of cold coming through from the dry side of the structure, as the side not immersed in a thick, leaky wall.

The writers note Mr. Howell's agreement with their conclusions and his reference to another dam of thin section of the flat-slab type which is deteriorating in the same manner.

Mr. Waugh, who is thoroughly familiar with all conditions at Gem Lake Dam, having assisted in its original construction as well as having had charge of its repair, attributes the primary cause of the disintegration to the failure of the gunite coating to prevent moisture from getting in back of the top skin. His conclusions are substantially in accord with those of the writers, that the slightest penetration of water under such climatic conditions will be followed by deterioration. In the paper doubt was expressed as to whether, under conditions imposed for construction at such sites, impervious concrete can be obtained under present-day conditions. After several seasons of hard-earned experience in carrying the responsibility of construction in this difficult location, Mr. Waugh is even more positive that "it is inconceivable that any concrete will prevent the penetration of moisture."

Mr. Flinn's suggestion that Engineering Foundation should collect data concerning the behavior of other thin section dams is a valuable one, providing such data are complete and include temperature records, raising and lowering of water surfaces, etc. The writers feel that they have not over-emphasized one example of deterioration. They have placed a notable example before the profession as completely as they have been able to present it and, through the discussion which has followed, as well as from other sources, have learned that this is by no means an isolated instance. In their opinion the serious tendency has too often been to observe complete silence in the case of sad experiences. Such experience is a rightful heritage of the Engineering Profession. Examples of similar structures that have stood (and the writers do not believe such success will be found in similar locations) will not afford a sense of security to the designer contemplating a new structure of this type to withstand similar conditions. To use the terse expression of another discussor, "engineering is not a matter of majorities".

Senator Luiggi gives some interesting observations on the Gleno Dam, a multiple-arch dam in Italy, which failed but not from causes such as the deterioration at Gem Lake Dam. The writers are glad to note his concurrence in their opinion that for such a locality as that at Gem Dam a rock-fill dam has many advantages over other types. Senator Luiggi questions the use of preparations such as "Ironite", or neat cement applied with a cement gun, in which view the writers concur. The effectiveness of these coatings is impaired by the expansion and contraction of the arches of the dam. He suggests methods of water-proofing the up-stream face of the dam; but since the methods suggested would necessitate the loss of at least one season's storage the cost is thus rendered greater than that of the method chosen.

The contribution of Mr. Merriman is, in the opinion of the writers, one of the most valuable and constructive of all those submitted because he points out the difficulty, not only of making good concrete up to the point of placing it, but the danger in not properly caring for concrete while it is curing. Neglect of concrete during curing occurs in the great majority of cases. Mr. Merriman is to be commended for bringing this out so pointedly.

Mr. O'Shaughnessy makes inquiry concerning the resultant losses sustained by the failure of the dam to function during certain seasons. During 1923, when an effort was made to water-proof the face of the structure, the loss was 10 000 acre-ft. of storage—a heavy loss when it is realized that at this locality this quantity amounts to approximately 12 000 000 potential kw-hr. The probability of having to face a similar, or even greater, loss in 1924 was one of the deciding factors in favor of the method of repair chosen, which was carried out entirely from the down-stream side with no loss of storage. Mr. O'Shaughnessy states that in an arch dam it is necessary to have concrete of such density that it will be water-proof. In the opinion of the writers, concrete which will not absorb moisture to any degree whatever does not exist. Therefore, for climatic and operating conditions, such as obtain at Gem Lake Dam, it is absolutely necessary that the impervious surface be provided next to the water, as required by the principles of Mr. George L. Dillman which were referred to by Mr. O'Shaughnessy. If this face is provided and is permanent, it should be immaterial whether the concrete back of it is porous, so long as this concrete is able to withstand the stresses imposed upon it as a structural element of the dam. The writers are glad to note that Mr. O'Shaughnessy, with his extensive experience, commends a rock-fill type for a location such as that at Gem Lake Dam. It is also interesting to note that Mr. O'Shaughnessy plans ultimately to replace the buttressed arch dam at Lake Eleanor with one of a rock-fill type.

Mr. Lippincott very clearly expresses an idea, which the writers have endeavored to make plain, in his statement:

"Although a thin shell of concrete may be made water-tight against percolation, it is not possible by any process known to the writer to prevent it from absorbing water when in contact with it."

Observations of diagonal cracks in the buttresses of several multiple-arch dams have been made by the writers and they are in entire accord with Mr. Lippincott's views that these buttresses should be reinforced. These diagonal cracks, although not an important consideration in Gem Lake Dam, did exist near the up-stream toes of three of the buttresses. They are described and comments are made on their prevalence in other multiple-arch dams under "History of Operation" (page 716), in the writers' paper.

Mr. Reed makes inquiry concerning the conditions at Agnew Lake Dam, a smaller but similar multiple-arch dam on the same stream approximately 550 ft. lower in elevation. The concrete in Agnew Lake Dam has not disintegrated, but a small amount of leakage has developed. The gunite surface was removed in 1925 and various types of water-proofing compounds are now being tried on the up-stream face. In the opinion of the writers, deterioration of the concrete in Agnew Lake Dam has not occurred because some protection from extremely low temperatures is afforded by the snow with which the entire down-stream face is usually covered before the extreme cold weather occurs. In fact, the arches are banked full of snow at such times. The protection by such banking is apparent from the fact that a valve enclosed in a light board shaft does not freeze. Mr. Reed cites instances of multiple-arch and flat-deck dams that have been successful in Norway and Sweden, but indicates that protection against low temperatures has been provided. In the opinion of the writers such protection is essential.

Mr. Jakobsen opens his discussion with a statement that it would be hazardous in the extreme to conclude anything from the behavior of a single structure and more especially since other similar structures, subject to equally severe conditions, have shown no sign of deterioration. His references to such structures are very meager indeed. It would be interesting to know the exact location of each and to have exact climatic and operating data for each. Mr. Jakobsen apparently has missed the statement in the "Introduction" (page 714) to the writers' paper to the effect that a large amount of mathematical discussion concerning multiple-arch dams had already been presented, and that it was not intended to include any addition to such material. The paper was a discussion of a failure and a method of repair, not of the theory of design. He can rest assured, however, that thorough analyses of the new section and of its effect on the remaining original structure were made, not only by the engineers of The Nevada California Power Company, but by the several consulting engineers who were employed and that no important considerations were left to off-hand assumption as he seems to infer.

Mr. Oesterblom seems to have missed some of the salient points of the paper. It is easy to understand why the middle belt of the arches was affected and why the section at the bottom, as well as at the top, was little affected. The up-stream faces of the lower parts of the arches are generally submerged to considerable depth in water, which insures somewhat warmer temperature. At the same time the backs of these arches are protected from extreme low temperature by the early snows drifting against them, thus forming a blanket; also, the arches themselves are much thicker at this point, thus affording less opportunity for the extreme cold to chill the material completely. These conditions, combined with the fact that the upper sections, from which water is always drawn before the advent of cold weather, do not show deterioration, seem to afford ample proof that frost action is the controlling cause.

Mr. Collier offers a conjecture on what results would have been obtained had a thicker coating of gunite with reinforcing been applied. He states, in closing, that with a thickness of approximately 2 in. of reinforced gunite, experience has shown that positive water-proof conditions will be obtained. It would be interesting to know the number of years during which such conditions have obtained on any structure and what conditions of expansion and contraction, or of deflection, occur in the operation of the structure. The writers believe that a gunite face of these specifications would have prevented percolation of water at first, but that over a period of years the gunite would have absorbed water and would have disintegrated to such an extent that water would have been admitted to the concrete back of it, unless it was replaced before this occurred.

With much of the discussion of Mr. Noetzli the writers disagree entirely. Mr. Noetzli refers to the Lake Eleanor Dam as being an entirely successful structure, but apparently he has not noted that Mr. O'Shaughnessy, from his discussion, plans ultimately to replace this structure with a rock-fill dam. He refers to the Bear Valley Dam as being a similar structure with similar climatic conditions. At the Bear Valley Dam the reservoir is not regulated for hydro-electric power development and is ordinarily not drawn down during the winter. At this location temperatures do not range as low as at Gem Lake, nor do long sustained extreme cold spells occur. Climatic conditions are not

comparable. After referring to the adopted method of repair as being as radical and expensive as could be devised, he launches off with confidence into advocacy of a method that was considered and discarded by the several engineers who studied this problem for the owners. His method is not believed to be feasible, even if considered only with relation to this single structure. However, Mr. Noetzli has completely missed an important practical point. Gem Lake Reservoir is now an important and necessary part of a great operating hydro-electric system. Any method of repairing Gem Lake Dam that would render the reservoir useless for a storage season, or even a part of such season, must prove expensive, due to loss of revenue; Mr. Noetzli's proposed method would cause such a loss. The method adopted avoided this great economic loss and thus it has a large differential in its favor. Mr. Noetzli does not consider that a loose rock-fill, which is relatively porous, will materially protect a concrete core wall or a concrete face slab against low temperatures. The writers know the facts to be otherwise. Proof can be secured by taking temperatures in tunnels through rock-fill dams where it will be found that at a distance of about 60 ft. in from the tunnel portal water will not freeze. For example, Mr. Dolson had occasion to construct a tunnel 157 ft. in length through the Skagway Dam near Victor, Colo.; later, he used this tunnel for the storage of foodstuffs and found that 60 ft. in from the tunnel portal no freezing occurred.

The several examples of hollow concrete dams described by Mr. Scheidenhelm are interesting, but those particular structures which are enclosed by a deck on the down-stream face are not comparable.

The writers wish to express their appreciation of the very clear statement from Mr. Galloway, interpreting the lessons from Gem Lake Dam which they have offered to the profession. He has most clearly and concisely pointed out the value which may be gained from a proper interpretation of an engineering failure.

A dam of the thin multiple-arch type, if it is to resist the conditions existing at sites such as at Gem Lake, must depend on a permanently impervious face; but, under present-day conditions, the writers know of no practical means by which such permanent imperviousness can be obtained nor has the discussion disclosed one. They, therefore, adhere to the opinion already expressed that for this or similar locations a dam of the rock-fill type has many advantages over other types.

In closing, the writers express their appreciation to the officers of The Nevada California Power Company for their courtesy and their frankness in granting permission to publish a full account of the investigation and repair of this structure. It has been a source of satisfaction to note expressions of appreciation of the Company's attitude from many of those who have contributed to the discussion.