The Great Aqueduct

The Story of the Planning and Building of the
Colorado River Aqueduct

The Metropolitan Water District of
Southern California
FOREWORD

This booklet tells the story of the planning and building of the Colorado River Aqueduct by and for The Metropolitan Water District of Southern California. The District is a political subdivision of the State of California, its area being the combined areas of the thirteen cities which comprise the District. These cities are Los Angeles, Anaheim, Beverly Hills, Burbank, Compton, Fullerton, Glendale, Long Beach, Pasadena, San Marino, Santa Ana, Santa Monica, and Torrance.

The Colorado River Aqueduct is the largest water supply line in the United States. Its construction has been financed by a $220,000,000 bond issue voted by the citizens of the District. The building of the aqueduct was started in December, 1932, and it is scheduled to begin the delivery of water to the District cities by July 1, 1941.

The articles which comprise the contents of this booklet first appeared in the Colorado River Aqueduct News, the official publication of the District. They were written by members of the District's staff. At the close of each article appears the date of its original publication. The position held by each of the contributors at the time the articles were written is indicated in the by-line heading each story.
THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA

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LAKE MATHEWS AND OUTLET TOWER

Lake Mathews, the terminal reservoir of the main line of the Colorado River Aqueduct. Located at the western end of the main aqueduct, this reservoir also serves as the headwaters of the aqueduct's distribution system. It has an initial capacity of 107,000 acre feet of water and will have an ultimate capacity of 225,000 acre feet.
Need For Water

Why Southern California Coastal Plain Requires Supplemental Water Supply.

By C. C. ELDER
Hydrographic Engineer

The water budget of Southern California has been unbalanced since long before the depression. The region's rate of water consumption has been exceeding its dependable income from all sources, a process made temporarily possible by borrowing from our age-long accumulated water capital in the sand and gravel banks of underground storage.

A rather involved hydrologic investigation and annual audit of the water ledger has been required to determine even the approximate amount of the defalcation. But that the next major drought period would mean widespread water bankruptcy has been clearly and simply evident from the rapid recession of water levels in thousands of pumped wells, many of which were once strongly artesian.

In considering the engineering problems presented by Southern California's existing and increasing water shortages, chief emphasis has at times been placed on the factor of expanding requirements. On other occasions more attention has been directed at the diminishing yield of local water supplies. Obviously, neither the credit nor the debit page of the ledger is singly to blame, the difficulty being the lack of balance between them.

Scanty Rainfall

The arid or semi-desert nature of the local climate is proved by the average rainfall of 15 inches annually at Los Angeles, increasing somewhat toward the mountains but diminishing to a mean of only 10 inches along the coast. Even the extraordinary general floods of March, 1938, serve to emphasize the usual deficiency of precipitation here, because in half the states of the Union (inhabited by nearly three-fourths of the population of the country), at representative rainfall stations with records dating back as far as 1738, the worst drought years ever experienced show more rain than fell in the last twelve months at Los Angeles.

Such a normal deficiency of rainfall, made far more acute by occasional years with only one-third to one-half the average amount and one 18-months' period described as without measurable precipitation, caused critical water shortages from the earliest days of the Spanish occupancy of the Missions. Sole dependence placed on perennial springs (now dry so many years their former existence is entirely unknown to present residents) during the long, dry summers, caused irrigation development to be sharply limited. Even herds and flocks suffered enormous losses due to drought, notably in 1857, 1864, and 1877. Although the irrigated area in Los Angeles only increased from 1,500 acres in 1849 to 8,400 acres in 1879, even this small oasis suffered seriously from lack of water in 1879, accentuated by upstream diversions for the bottom lands now included in Griffith Park. This encroachment on the Pueblo's ancient water right, as granted by the King of Spain, resulted in a celebrated water suit. Since that time the Southern California courts have seldom been free of involved and costly water litigation. About the same date, rapid and intensive development of wells began. At first this was largely in the artesian areas (now practically vanished) but soon extended to all portions of the Coastal Plain. The long, severe drought period from 1899 to 1904, widespread throughout the Southwest, forced Los Angeles to commence work on its Owens River Aqueduct, with importations starting in 1913.

Owens River Aqueduct

The completion of this project laid the basis for the unprecedented rapid growth of Los Angeles and seemed to end the City's water problems for all time. This conclusion proved premature, however. Average runoff was found to be much less than early measurements indicated, so that an extension to the Mono Basin is now under construction to secure a full, dependable supply for the Owens River Aqueduct. But the water supply from Owens River, used by Los Angeles, has never been legally available to the surrounding suburban areas. These, combined, have a population equal to that of Los Angeles, and a water requirement far greater, including citrus and other irrigational needs. The result has been a continued intensive development and rivalry for local water sources to a degree unequalled elsewhere in the country, with expensive and far from satisfactory results. Litigation sometimes changes the ownership of water rights but never increases the available supply. For the Coastal Plain outside of Los Angeles, the present deficiency of its permanent, safe water supply is now variously computed at 215 to 300 second feet, or from one-fourth to one-third of the dependable yield of the region's water sources.

A sufficiently accurate measure of the increase in local water demands is given by the growth in population of the Coastal Plain from 3,000 at the time of the American occupancy 92 years ago, to 3,000,000 at the present time. Even this comparison does not reveal the full demands due to still-rising standards of living.

Water Requirements

The large indirect water requirements of urban life are seldom realized. A normal adult drinks only about one ton of water annually—five or six bathtubs, but this serves to wash down about 200 pounds of bread or its equivalent and on the average, the same amount of meat. Crop plants require 300 to 600 times their dry weight of water for transpiration losses, and including soil losses, about 1000 times, or 400 tons, per adult. Meat production requires fully ten times as much water as plant crops, so for every ton drunk, we really “eat” 4400 tons of water. It probably takes about 20 tons of water daily (five acre feet per year) to keep a civilized adult in the style of life to which we are accustomed in Southern California.

To give such dry statistics more of a California flavor, when you sip your breakfast glass of orange juice you are really consuming, impossible as the fact sounds, 1250 glasses of water in rapid-fire fashion. The average family will dispose of about an acre-foot of water annually in irrigation and rain water due to this one item of diet alone.

Passing from the detailed to the general again (by skipping over the chapters of the story relating to the large and increasing industrial demands, population forecasts, and studies of future changes in land use with expanding urban, suburban, and agricultural developments, etc.), the need for a supplemental water supply may be summarized as including:

(1) Replenishment of accumulated overdrafts.
(2) Insurance against future severe droughts, as their frequent occurrence in the past evidently makes their future repetition here inevitable.
(3) Assurance of ample water supplies for future urban and industrial expansion, as water has been generally concluded to be the only factor that might limit such growth.

Thus in Southern California, the desert lack of dependable local water, in contrast to nature's prodigal provision of all other climatic advantages, reminds one of the text of the Koran, as true here as in ancient Arabia—"water is the fount of life, we have made of water everything living."
COLORADO RIVER BELOW PARKER DAM

The Colorado River from which water is diverted into the Colorado River Aqueduct and transported to the coastal plain of Southern California. Fed by melting snows from the western slopes of the Rocky Mountains, a water shed covering approximately 245,000 square miles, this is one of the great rivers of the North American continent. Its history in the development of the present civilization in America dates beyond that of the Pilgrims. The Colorado River was discovered in 1540 by the Spanish Conquistadores, Alarcon and Coronado.
Aqueduct Source

Why the Colorado River Was Selected as the Source of Supply.

By F. F. WEYMOUTH
General Manager and Chief Engineer

Southern California has just passed through a flood of almost record proportions—certainly a greater flood than any remembered by most of the "old-timers." Great volumes of water rushed down across orchards and fields, and through cities, causing great damage; and finally wasted into the ocean. Thousands of acre feet flowed over or under the Colorado River Aqueduct in a mad rush to the sea. It is natural that the public should become flood-minded, and that many should ask: "Why a Colorado River Aqueduct—why not, instead, conserve these flood waters?" The answer, of course, is that it is necessary to do both.

Hydrographic Engineer C. C. Elder, in the April 10, 1938 issue of the "News" calls attention to the significant fact that a record flood year in Southern California yields less rainfall than the worst drought year in a humid region. Hence, such a year fails to meet even the current needs of the area as a whole, although a few spots are temporarily deluged with unwanted water. Also, these years come only occasionally, with long periods of famine years between. Saving flood waters never can bring the available supply fully up to the 15-inch long-time average, which is far too little even for present developments, and entirely inadequate for ultimate needs.

Much already has been done on conservation, and additional works are planned for the near future. Only negligible portions of ordinary floods waste into the ocean now. Conservation is largely by "spreading," i.e., the surplus waters are spread over waste rocky areas and permitted to percolate into underground storage, to be later removed by pumping. Obviously, a vast flood such as that recently experienced cannot be guided into a few small absorbing basins and put underground, as it comes down from the mountains. At such times, even the rain falling on the flat valley floor cannot be held until fully absorbed, but much of it must be rushed away to the sea to reduce damage by flooding. The cost of completely conserving such a flood would be great and, because they occur only rarely, the average addition to the annual water budget would be small. Such floods must be controlled to reduce property damage, and should be conserved as fully as practicable; but it is difficult to avoid a little waste into the ocean at rare intervals. Such wastage will have a negligible average effect on available water supplies, hence in all studies of ultimate water resources and needs, practically complete conservation is assumed. But conservation of local floods is not sufficient.

Local Supplies Exhausted

It has long been recognized that the water needs of Southern California cannot be supplied from local sources. The fertile habitable lands are closely encircled by a narrow ring of hills. The area subject to intensive development is approximately half the total area of the drainage basin, an unusually high proportion. There are no long rivers bringing in water from distant points. The areas immediately outside of the encircling hills are arid and produce no exportable water, for which reason it is necessary to go long distances for additional supplies. The nearest area of high rainfall lies to the north in the high Sierras. That area drains generally to the west into the San Joaquin and Sacramento valleys, where all flows are over- appropriated for local needs. Because of precipitous slopes, the catchment areas on the eastern side of the Sierras are limited and stream flows are smaller than on the western side, but due to unfavorable settlement conditions, these waters have been less completely absorbed by local developments.

It was natural that the City of Los Angeles, finding its water resources nearing exhaustion some thirty years ago, should look to the Sierras for a supplemental supply. After careful study of all possibilities, water rights were acquired in the Owens Valley, along the eastern slope of the mountains, and the Owens River Aqueduct, 233 miles long, was constructed. This aqueduct was completed in 1913 and with the Mono Basin extension now under construction is capable of delivering 450 second feet of water into the city. Water from this source, although limited in use to the area within the City of Los Angeles, has played an important part in the development of Southern California, and its past and future value can hardly be overestimated. However, this outside supply is inadequate for the future needs of the basin or even of the City of Los Angeles.

No further important unappropriated flows are available from the Sierras, within a reasonable distance. Accordingly, the Metropolitan Water District is now going to the Colorado River, which taps the snow fields of the Rocky Mountains in Colorado, Wyoming, and Utah, and flows within the reach (although somewhat long reach) of the metropolitan area. The natural low flow of this river is fully appropriated, but the United States Government has constructed a dam at Boulder Canyon which will store flood water and thus greatly increase the useful flow. This dam, which has the unprecedented height of 727 feet from foundation to crest, creates a reservoir having storage capacity of 30,500,000,000 acre feet. The primary purposes of the reservoir are flood control and the conservation of water. Incidentally, it affords opportunity for the development of from 4,000,000,000 to 6,000,000,000 kilowatt-hours of electrical energy per annum.

Records of flow made over a long period show that when properly controlled and conserved, the waters of the Colorado River are ample to supply the needs of the Metropolitan Water District without disturbing any existing rights. There is available no other source of supply suitable in quality and quantity. Fortunately, Colorado River water can be brought into the District at a reasonable cost.

The quality of Colorado River water and its acceptability for the many uses for which it is likely to be required have been carefully investigated. The lower Colorado in its natural state was notoriously muddy—"a little too thick to drink, and a little too thin to plough" according to legend—but, however, water now stored in Boulder Reservoir is entirely clear and exceptionally free from bacterial pollution. In mineral content it compares favorably with other waters in Southern California. Its suitability for domestic and agricultural uses is demonstrated by its long and successful use in the Imperial Valley and on the Yuma Project in Arizona.

The District has filed on a diversion of 1,000,000 acre feet annually from the Colorado River at the Parker dam site, under the laws of the State of California, and has entered into a contract with the United States Government for the delivery of this amount of water from the Boulder Reservoir. The rights thus secured are further fortified by signed agreements between the District and other prospective users as to the division of the waters of the river. The District likewise has entered into a contract with the government for the power from Boulder Dam that will be required to pump Colorado River water over the mountains and into the District area.

(April 25, 1938)
Purpose of M. W. D.

Organization and Functions of the Metropolitan Water District.

By DON J. KINSEY
Assistant to the General Manager

With the withering hand of Drought laying its devastating grip, year after year, first upon one populous section of America and then another, there stand out today in Southern California thirteen favored cities forever protected against the scorching menace of Man's most deadly foe.

These are the thirteen cities of the Metropolitan Water District of Southern California. Through the establishment of the District and its work in building the Colorado River Aqueduct, these thirteen cities are providing themselves with an abundant, an assured, and a controlled water supply. A water supply that always will be available to their people whenever, wherever, and however it is needed.

Almost twenty years ago the people of Southern California first joined forces to bring about the control and conservation of the wild waters of the Colorado River. Here was an untamed water giant wasting its substance into the sea and periodically breaking out of its channel in a mad torrent of flood waters that devastated towns and wide areas of farm land. At the same time, the rapidly growing urban and agricultural centers on the Coastal Plain of Southern California were beginning to feel the need for additional supplies of water.

Civic and governmental leaders of Southern California submitted their problem to the National Government. They did not ask for gifts or free assistance. They asked the Government to lend its cooperation in a sound economic and engineering plan to control the floods of the Colorado River and conserve these waters for domestic and agricultural use, and for the generation of hydroelectric power. Thus, was born the Boulder Dam project.

First of all, the United States Bureau of Reclamation set under way a thorough study of the flood control and water conservation problems of the lower Colorado River. These studies were made by Arthur P. Davis, then the Director of the Reclamation Bureau, and by Frank E. Weymouth, then the Chief Engineer of the Bureau. The Reclamation Bureau completed its studies and made its recommendations in a report filed with the Department of the Interior in 1921. In brief, the Bureau recommended the construction of a high dam in Boulder Canyon of the Colorado, and the building of the All-America Canal to provide for the dependable irrigation of Imperial and Coachella valleys.

A bill was drafted, based upon the findings and recommendations of the Reclamation Bureau. This bill was introduced in the Senate by Senator Hiram Johnson and in the House by Representative Phil D. Swing. Because the bill opened the way for the generation of large quantities of hydroelectric power at the site of the proposed Boulder Dam, it aroused the hostility of private power interests throughout the country. At the same time, senators and representatives from the Middle West, East and South were indifferent or inclined to be in opposition. State officers of Arizona, demanding a larger share of benefits for their state, were, for the most part, violently opposed to the bill.

The battle to overcome this tremendous obstacle of indifference and hostility was carried forward for six long years. In this long and arduous battle there stood out one man who deserves a major share in the credit for the final victory. That man was W. B. Matthews, then Chief Counsel for the Los Angeles Department of Water and Power, and later the General Counsel for the District.

In 1923, the first surveys and studies on the Colorado River Aqueduct were set under way by the City of Los Angeles. In 1925, the citizens of Los Angeles authorized a bond issue of $2,000,000 to finance these engineering studies. Many other communities recognized a need for water fully as acute as that of Los Angeles, but as individual cities they could not hope to finance the herculean task of building a waterway from the Colorado.

The problem was answered largely through the genius and efforts of Mr. Matthews and James H. Howard, the latter at that time being the City Attorney of Pasadena. These two men formulated and drew up the Metropolitan Water District Act. A bill containing the provisions of this Act was submitted at the 1925 session of the California Legislature. Various private interests were opposed to the adoption of the Act, and the bill was defeated by a narrow margin. Among those legislators who voted against the bill were several members from Southern California. At the 1926 elections, these men failed to be reelected. The bill was introduced at the 1927 session of the Legislature, and was adopted by a wide margin of votes.

The Metropolitan Water District Act is, in effect, the charter of the Metropolitan Water District of Southern California. It sets up the powers and functions of the District. It provides a new type of municipal corporation wherein separate incorporated cities and water districts may organize a Water District for the purpose of financing, building and operating a water supply system.

Under the Act, the District is governed by a Board of Directors, each city having at least one representative, and no city, regardless of size, being permitted to exercise more than 50 per cent of the governing power. The directors serve without pay.

Following the adoption of the Act, the City of Pasadena initiated the organization of the district. Acting on motion of the City Board of Directors, the Pasadena City Clerk mailed to various Southern California cities an invitation to submit to their citizens the proposition of joining the Metropolitan Water District. Twelve cities submitted the proposition to their voters, and in eleven cities the people voted decisively to enter the District. In the city of Orange the proposition failed by a narrow margin.

The eleven original cities in the District were: Anaheim, Beverly Hills, Burbank, Colton, Glendale, Pasadena, San Marino, Santa Ana, San Bernardino, Santa Monica and Los Angeles. Colton and San Bernardino residents had hoped that the aqueduct would come through the Coast Range by way of Cajon Pass in their immediate vicinity. These two cities withdrew from the District after the decision was made in favor of the route by way of San Gorgonio Pass. Before the aqueduct bond elections in September, 1931, however, Compton, Fullerton, Long Beach and Torrance had voted to join the District, and thus increased the number of District cities to thirteen.

Acting in accordance with the Act, District directors were appointed by the Mayors and confirmed by the City Councils of these eleven original member cities. The first meeting of the District Board of Directors was held on December 29, 1928, in the Huntington Hotel. Just eight days before this first meeting of the District directors, President Calvin Coolidge had signed the Boulder Dam bill. Thus, within the span of a few days, the people of Southern California had won two major objectives—the assurance of Boulder Dam and the creation of a new governmental organization legally and economically equipped to bring about the building of the Colorado River Aqueduct.
Financing

The Problem of Securing Funds for the Construction of the Colorado River Aqueduct.

By JAMES H. HOWARD
General Counsel

On the 29th day of September, 1931, the voters of the Metropolitan Water District of Southern California, by a majority of substantially five to one, authorized the issuance of bonds in the amount of $220,000,000, for the purpose of financing the construction of the Colorado River Aqueduct. The law requires merely a majority vote. The election was held two years after the financial crash of 1929 and during the period of economic depression which, in spite of attempted remedial measures, still continues. While the extent and duration of the depression may not have been realized in the fall of 1931, its effects had been definitely felt. Nevertheless the people of Southern California had sufficient confidence in the future of their country to support, by an overwhelming majority, the large bond issue required for aqueduct construction. In this connection it should be remembered too that at the date of election the idea of Federal financing through the Reconstruction Finance Corporation or Public Works Administration had not yet developed. The bonds were not voted as a means of securing and expediting Federal moneys.

The Metropolitan Water District Act required that before being issued, the bonds be subjected to the scrutiny of the courts. A proceeding was brought in the Superior Court of Los Angeles County, in which, by published notice, all interested parties were invited to participate and raise any and all objections to the validity of the issue. In a contested case the matter was carried to the Supreme Court of the State and, in June, 1932, resulted in an opinion sustaining in all particulars the validity of the issue.

In the meantime it was developed that the market for municipal bonds had fallen off to a point where District bonds could not be sold at any interest rate which the Board of Directors of the District was willing to pay.

In January of 1932 the R.F.C. had been created by the Congress, for the purpose of financing banks, insurance companies, and railroads. During the spring and early summer, the General Manager and Chief Engineer of the District and the General Counsel devoted themselves to the then pending "Emergency Relief and Construction Act of 1932," designed to authorize R.F.C. loans to aid in financing self-liquidating public works projects. The thought was a new one and the natural inertia of the Congress had to be overcome. Even after the basic idea had been accepted, the tendency was to hedge such lending power with restrictions inconsistent with the District's borrowing power. To enable the District to go ahead upon its long-term financing program, it was necessary that such proposals be defeated.

Senator Wagner of New York was in charge of the bill. It was due to the efforts of Senator Hiram Johnson of California that the text of the amendment was so written that, upon the adoption of the act, the R.F.C. was authorized to buy the long-term bonds issued by public corporations engaged in self-liquidating public works projects. The act became effective in July of 1932.

The District immediately applied for a commitment from the R.F.C. for the purpose of initiating aqueduct construction. Here again the novelty of the Federal lending program made for difficulty. An Advisory Board of Engineers was appointed by the R.F.C. for the purpose of studying the engineering and economic set-up and to make a determination as to whether the District's project satisfied the definition of self-liquidating public works, as described in the act. The attorneys of the corporation went very thoroughly into the corporate structure and legality of the District's organization and its bond issue. After weeks of work a favorable report of both engineering and legal phases of the project was secured, and on the 13th day of September, 1932, the R.F.C. made a commitment of $40,000,000 for the purpose of initiating aqueduct construction.

An attempt was made to enjoin the loan by action in the District Court of the District of Columbia, on the ground that the project did not come within the statutory definition. The action was decided against the objectors, however, and the initial loan was made.

The path was not yet clear. With the incoming Democratic administration in the spring of 1933, the Public Works Administration was set up, and the authority of the R.F.C. to make loans to self-liquidating public works projects was terminated. It was the desire of the P.W.A. to procure immediate expenditure of large sums of money. The District's application then pending before the R.F.C. was automatically transferred to the P.W.A., but the latter organization was unwilling to make commitments for a construction program extending over a period of years.

Although every effort was made to secure favorable action, no funds were derived from the Public Works Administration other than those taken under a loan-grant agreement in the amount of $2,000,000, limited in its application to the construction of cooling tanks and transmission tunnels at Parker Dam.

Realizing that the general market was not yet in a position to absorb District bonds at a favorable interest rate, representatives of the District again became active in congressional circles. In 1934 an amendment to the R.F.C. law was pending, relating to loans to industry. To this bill an amendment was attached, authorizing the R.F.C. to make loans for the purpose of financing projects which had been initiated by such loans prior to June, 1933.

After weeks of effort, during which the legislation hung in the balance more than once, the law became effective. Thereupon negotiations with the R.F.C. were resumed and, with the exception of the $2,000,000 loan-grant agreement made with the P.W.A. in 1933, all of the bonds of the District have been sold to the R.F.C. Of the bonds so sold, $147,000,000 have been delivered and the money received. The R.F.C. has committed itself to take an additional $60,000,000.

As the result of an amendment to the Metropolitan Water District Act made in 1933, it is possible for the District to issue refunding bonds. The fact that the loans have been centered in the hands of the R.F.C. will, it is expected, enable the District to issue permanent bonds under conditions much more favorable than would have been the case had the District been forced into the general market at any earlier time.

The fact that the District's project had been carefully planned and was ready for financing in the summer of 1932, all of the engineering and legal work having been completed, enabled the District to proceed with its financing program under extremely favorable conditions. Construction costs were much lower by reason of the fact that the program was commenced in 1932. Had the District been compelled to accept whatever interest rate the general market of the time might have offered, or had it been compelled to defer its operations until the market had become stabilized, the costs of the aqueduct would have been far greater. The combination of circumstances and the cooperation of the R.F.C. have worked greatly to the advantage of the taxpayers of the District and the prospective users of Colorado River water.

(May 25, 1938)
Surveys

Scope and Purpose of the Preliminary Aqueduct Surveys.

By J. B. BOND
Division Engineer, Division 5

When reconnaissance surveys covering possible aqueduct routes from the Colorado River were started in 1923, much of the desert area between the mountain ranges surrounding the south coastal plain and the river was unsurveyed. Unfortunately, there was no well defined belt, clearly better than any other area, to which surveys might be confined. The problem was so extensive and there were so many possibilities and so many preconceived ideas as to where the line should be located that it was decided to make a general topographic survey of the region. This work, which constitutes one of the most comprehensive topographic surveys ever undertaken in this country by any agency, other than the Federal Government, was begun and practically finished between the fall of 1923 and the spring of 1930 by the Water Bureau of the City of Los Angeles.

The area mapped covered 25,000 square miles, slightly greater than the total area of the state of West Virginia. The work was difficult. Heat during the summer months was intense. Localities where potable water was available were widely separated. Practically all of the roads through the undeveloped region were entirely unpaved. They were not laid out along definite lines but followed in a general way the easiest natural routes, crossing valleys and threading mountain passes, and avoiding as much sand and as many hills as possible.

The topographic sheets were inked, traced, and assembled in strip maps suitable for use in projecting work. A study of the data showed that diversions were possible at Bridge Canyon, Black Canyon, Bulls Head, Parker, Picacho, and All American. Bridge Canyon is located 120 miles upstream from Boulder Dam. At the time the preliminary aqueduct surveys were under way the site of this structure was known as Black Canyon. Bulls Head, Parker, Picacho, and All American are 50, 143, 275, and 289 miles, respectively, downstream from the Boulder Dam.

Other possible routes were suggested by interested individuals. These were given consideration in order that no worthy plan should be overlooked. The highest on the river was the San Juan route, diverting from the Colorado near the mouth of the San Juan River in Utah. From this point an aqueduct 850 miles in length would lead through southern Utah, across Nevada, south into California and thence to the coastal plain. At the other extreme was the so-called Southern Sea Level route, leaving the Colorado below Yuma in the Republic of Mexico. The intake and all of the location for a distance of 130 miles were south of the International Boundary. It entered the United States near Tia Juana and extended up the coast by way of San Diego.

A great number of line studies were made from the six possible diversion sites between, and including, Bridge Canyon and All American. The number exceeded 100. As the work progressed on the many alternate lines and the knowledge of physical conditions, especially geological complications, increased, it became evident that whole, or parts of, lines should be abandoned for more favorable routes. This process of substitution and elimination led to the selection of the most promising route from each of the six proposed diversions. These lines were run out in the field and studied in detail on the ground by engineering forces and a corps of geologists. A few of the controlling features of each route, beginning with the highest on the Colorado River, are described in the following paragraphs:

The Bridge Canyon route would divert from Bridge Canyon by means of a dam from 600 to 900 feet in height. Leaving the dam, a tunnel 75 miles long, lying at great depth, would carry the aqueduct beneath Grand Wash Cliffs and Peacock Mountain in northwestern Arizona. Deep shafts were required on this line, some of them located in alluvial-filled valleys. The crossing of the Colorado, about 16 miles below the city of Kingman, required a steel pressure line 3 miles in length with maximum head of 1025 feet. West of the river, the line passed several mountain ranges in the Mojave Desert. The one through the Old Woman Range required a tunnel 22 miles long, with shafts up to 2000 feet in depth. Near Ludlow the location went into tunnel which extended for a distance of about 90 miles under the Bullion Mountains and beneath the water-filled Lucerne Valley, finally emerging at a point near San Bernardino. This tunnel would cross the active San Andreas, Glen Helen, and Lytle Creek faults far beneath the surface. Access would be by deep shafts. The terminus of the Bridge Canyon line was Puddingstone reservoir 316 miles from the intake.

The Black Canyon route would divert from the reservoir above the Boulder Dam by a pump lift of about 1660 feet. For the first 60 miles, the location was through the State of Nevada and parallel to the Colorado River. In this reach several mountain ranges were pierced by tunnels of comparatively short length. After leaving Nevada, the location was in a general westerly direction to Daggett, a distance of 155 miles. This stretch was close to the main line of the Santa Fe Railway and for the most part called for open construction. Near Daggett, the route entered a tunnel passing beneath the western end of the Bullion Mountains, under a portion of Lucerne Valley, emerging from the San Bernardino Mountains near the City of San Bernardino. From this point it followed a fairly easy location to Pine Canyon reservoir. The 51-mile tunnel from Daggett to San Bernardino would require very deep shafts. There is considerable faulting in this region with danger of encountering soft water-bearing material beneath Lucerne Valley. The total length of the line was 300 miles.

The Black Canyon route passed reasonably close to Bulls Head dam site, located 50 miles downstream from Boulder Dam. The diversion from Bulls Head, connecting with the Black Canyon line near Goffs, shortened the distance to the terminus about 50 miles. A diversion dam to raise the normal water surface about 120 feet was required at the Bulls Head. Considerable power could be developed. However, the foundation was deep. The pumping lift was higher than from Black Canyon.

Parker Route

The best aqueduct line from the Parker location required the construction of a dam across the Colorado River, immediately below the mouth of the Bill Williams River, which is about 17 miles upstream from Parker, Arizona. The river, at the site selected for the dam, flows between precipitous walls about 350 feet apart. The structure would raise the mean water surface about 72 feet. Considerable power would be generated and the basin back of the dam would provide for regulating and clarifying the water.

Actual diversion into the aqueduct would be made by a pumping plant located about two miles upstream from the dam. This, together with four other pumping plants placed in the eastern half of the line, would elevate the water up to the height of Shaver's Summit, requiring a total lift of about 1617 feet. From this point the water would flow by gravity into the metropolitan area.

From the Colorado to Shaver's Summit the Parker route followed a general southerly course. This location tra-
versed long, smooth, alluvial slopes. The mountain ranges separating the valleys required comparatively short tunnels. The saddles are crossed at aqueduct grade, or at an elevation where the head on siphons would not be very high. Two excellent reservoir sites near the intake and one at the last pump lift near Shaver's Summit would provide storage, regulation, and clarification. No geological complications were discovered.

West of Shaver's Summit the Parker route followed along the base of the Little San Bernardino Mountains and their extensions to Cabazon. The elevation of the line is such that for considerable stretches it is located on the alluvial fans built up at the mouths of the canyons, but for about 57% of its length it is in tunnel through spurs reaching southward from the crest of the ranges.

The east portal of the 13-mile tunnel, required through San Jacinto Mountain, is near Cabazon. Emerging from the tunnel, near the town of San Jacinto, the line continued westward across San Jacinto and Perris valleys to Lake Mathews which is the terminal storage location for this line. West of San Jacinto two tunnels are required through Bernasconi Mountain and the granite ridge in the vicinity of Valleyville station. The total length of the Parker route was in round numbers 242 miles.

At the point of intake for the Picacho site, the river is confined between definite rock walls and has no chance to meander. Some drilling was performed at this location but bedrock was not encountered. A diversion dam was considered infeasible. It was planned to pump directly from the river to a height of about 50 feet and pass the water through mechanical clarifiers. A second pump lift of 282 feet was required to deliver the water to the intake of a 15-mile tunnel through the Picacho Mountains. The outlet for the tunnel was located near Ruthven, a station on the Southern Pacific Railway.

From Ruthven, the location extended in a northwesterly direction along the east side of Imperial and Coachella valleys, parallel to and near the Southern Pacific Railway, to a point near Cabazon, where connection was made with the Parker route.

The section between Ruthven and Cabazon is fairly smooth. Pumping lifts were high and were located in flat country requiring long delivery lines. A number of short tunnels were necessary through spurs extending down from the Chocolate, Oroopia, and Little San Bernardino mountains. The route was parallel and very close to the San Andreas fault for a long distance.

The length of the Picacho and Parker lines were practically the same. Two additional pumping plants were required on the first one mentioned and the total lift was about 350 feet greater.

It is possible to eliminate the eastern section of the Picacho route by pumping from the western end of the Coachella branch of the All American Canal in the vicinity of Indio. From the discharge end of the long delivery line on to Cabazon the Picacho location was followed.

From a geological standpoint the Picacho and All American routes did not differ materially as regards the formation through which they would pass, but the All American followed the San Andreas fault zone more consistently and would be subject to greater danger from fault disturbance.

The use of the All American Canal would probably involve unavoidable operating difficulties. There would be seepage losses and possible interruptions from an unlined canal passing through a cloudburst and earthquake area. It would be difficult to enforce necessary sanitary regulations along the irrigation canal.

On November 10, 1930, after a long period of intensive work in securing engineering and geological data, the General Manager and Chief Engineer submitted to the Board of Directors of the District his report and findings on the problem of selecting the safest, most economical, and most practicable route for the aqueduct from the Colorado River. In this report it was recommended that the aqueduct be constructed on the Parker route.

Under date of November 25, 1930, the report of the General Manager and Chief Engineer was submitted to a Board of Review consisting of Thaddeus Merriman, A. J. Wiley, and Richard R. Lyman, engineers outstanding as consultants on water supply. During the preceding twelve months the members of this Board had been studying the engineering and geological data and had made careful examination of the project in the field.

The Board of Review submitted their report on December 19, 1930. They concurred in the conclusions and recommendations of the General Manager and Chief Engineer that the Parker route be adopted for the following reasons:

1. From the viewpoint of geology it passes through the country of best terrain. It involves no unusually long tunnels, the construction hazards are the smallest, and its subsequent safety against earthquake damage is the greatest.

2. The net operating cost per acre foot, after the retirement of the bonds, will be lower than that on any of the other routes considered.

3. It is the only route on which it is practicable to provide intermediate storage.

4. The Parker route for its entire length is on the soil of California, and no question of taxes or assessments in other states is involved.

(June 10, 1938)
EXCAVATION FOR PARKER DAM

This picture, taken on June 30, 1937, vividly illustrates the vast amount of excavation that was necessary in order to reach the bedrock on which the foundation of the dam was built. At the time the picture was taken, the bottom of the excavation was 201 feet below the original bed of the Colorado River. The foundation of the dam was actually placed on bedrock 233 feet below the original bed of the river, and for this reason Parker Dam is known as the deepest dam in the world.
Design

Controlling Factors in the Location and Design of the Aqueduct.

By JULIAN HINDS
Assistant Chief Engineer

Any attempt to catalog and discuss all the factors which had a controlling influence on the location and design of the Colorado River Aqueduct and its various features would involve an endless statement of rather uninteresting details. It is possible here to mention only a few of the more important points.

The first problem, of course, was the determination of the need for water, the amount to be provided, and the source. These problems have been discussed in preceding papers. The Colorado River has been shown to be the “last water hole,” and the need for an average diversion capacity of 1,000 second feet has been established. In preparing plans for the aqueduct, the capacity was set at 1,605 second feet to allow for unavoidable shutdowns for maintenance and repairs.

Generally, in planning a water system, the selection of the source largely determines the location and nature of the project. For the Colorado River Aqueduct, this was not true. The aqueduct might conceivably divert at any of a number of points all the way from the mouth of the river in Lower California to Glen Canyon in Utah, and might conceivably follow any of many widely separate routes across the Southern California desert. Because of the complexity of the problem and the many balancing factors, it was not possible to select by general inspection the two or three alternative routes worthy of detailed study. The problem had to be studied in a widespread manner, covering a vast area, in order that no worthy possibility might be overlooked.

The problem was complicated by an important psychological element. The development of the Colorado River has long been subject to romantic speculation. The coastal basin in which Los Angeles is situated is capable of almost unlimited development except for the lack of water. The idea of transporting a portion of the flow of the Colorado River into this potential empire has long held a firm grip on the imagination of the people. Individuals in all walks of life have dreamed of great dams on the Colorado River and great waterways leading to thirsty desert areas.

Rapid expansion in Southern California in the early part of the present century, with the consequent exhaustion of local water sources, gave great impetus to these dreams. Community leaders and particularly those responsible for water supply began to search for a means of making some of these dreams come true. The public soon followed suit, and plans for the development of the Colorado River sprang up in great numbers. Proposals were submitted by hard-headed engineers with their feet on the ground; by visionary promoters, sometimes sincere and sometimes with an axe to grind; and by a multitude of citizens between these two extremes. Prior to the organization of the Metropolitan Water District of Southern California, many of these schemes had been widely publicized. The public was interested and naturally “took sides.” Every advertised plan had its following.

Public Confidence

If the project were to go forward, it must be founded upon the confidence of the public. The necessary funds must come from the taxpayers and water users. The people must vote the bonds with which to accomplish construction work, and to this end must approve the adopted scheme. Consequently, the District’s engineering staff and its Board of Directors found it necessary not only to satisfy themselves as to the most acceptable plan, but also to sell their conclusions to the public. To adopt a plan that could be proved sound and practicable was not enough. Each of the many preconceived schemes had its “boosters.” The virtues of each were being widely acclaimed, although little was being said about shortcomings. Naturally, some of the schemes had “holes” in them—some serious, some insignificant. Many of these holes had been so smeared over with propaganda that they were difficult to see. It was necessary that each scheme be cleansed by careful analysis and hung out on the line of public opinion in such clear light that all might see both faults and virtues.

One of the most popular notions was that there should be no pumping. Popular opinion among both water men and laymen has always favored a gravity supply for a metropolitan area. Such a supply has many advantages. It was natural that many of the schemes for developing the Colorado River should propose gravity delivery of water to Southern California, and it was proper that all such proposals should be carefully studied.

An ambitious plan contemplated a high dam on the Colorado River and high-level diversion at Glen Canyon, far upstream from the Grand Canyon, with an enormous canal some 800 miles long leading to Los Angeles and serving on its way large areas in Utah, Nevada, and California. Another gravity scheme contemplated a diversion dam 900 feet high at Bridge Canyon, near Kingman, Arizona, with a gravity line to the coastal area. Such a plan involved the construction of tunnels of enormous length—sometimes under mountain ranges and sometimes deep beneath the surface of water-filled alluvial plains.

Another interesting proposal was a single tunnel from a point near Monrovia straight into the reservoir at Boulder Dam. This plan was investigated in detail both from an engineering and a geological point of view. The proposed tunnel lay deeply buried in alluvial fills and passed under, rather than through, mountain ranges known to be badly fractured and faulted. It was found to be impracticable if not actually impossible to construct. Even if built, it would not have entirely eliminated pumping. Its terminal elevation was about 400 feet above sea level, while much of the area in need of Colorado River water lies above that elevation.

Each of these schemes was carefully considered. In the end, it was necessary that they be dismissed as physically and financially impossible, or at best, as involving expenditures out of all proportion to benefits; and thus the project acquired a pumping problem.

Pumping Necessary

One difficulty with the gravity schemes was the rigid restrictions imposed on the elevation and horizontal location. Lack of flexibility in fitting the line to ground conditions and inability to choose the general location necessitated costly construction. With the introduction of pumping, these restrictions were partially removed. Diversion could be made at any of several convenient points on the river and by distributing the pumping plants along the line, the aqueduct could be fitted to the ground in the most economical manner. This introduced the problem of finding the best location out of many possibilities.

It was necessary to establish an economic relationship between cost of pumping, length of aqueduct, percentage of tunnel in the line, and size and type of conduits. The cheapest place to pump the water for a given lift was at Boulder Dam, as the cost of transmission was eliminated. Also, the low water level of 895 feet in Boulder Reservoir is considerably higher than the river level at any other available diversion point. At first glance, this indicated a lower pump lift.

However, the mountain passes available to such a line were higher than
for other possible lines, requiring a higher
summit elevation, and the line was
longer, requiring more fall for the main-
tenance of flow. As a result, the pump
lift for a line from Boulder was actually
greater than required on other shorter
and cheaper lines. Also, topographic
conditions were such that the required
pumping could not all be done at the
dam site.

At the other end of the scale, a plan
proposed and strongly advocated in cer-
tain quarters contemplated a diversion
near the mouth of the river in the Re-
public of Mexico with a "sea level" aqual-
duct along the coast via San Diego.
Pumping on such a line would have been
scattered and at a maximum distance
from the source of power, hence expen-
sive. Proponents of the line claimed a
low total pump lift. This was true only
if the aqueduct were terminated at a
very low elevation, leaving much pump-
ing to be done locally. This line was
not found to be practicable, although it
had the advantages of offering service
to a valuable potential area along the
southern coast.

Between these two extremes, numer-
ous possibilities were carefully studied.
Surveys and estimates were prepared for
literally hundreds of lines. These lines
covered all of Southern California, not
in a symmetrical or uniform manner but
as a sort of irregular network, knotted
together by controlling geographical
features. Like the wagon trails of the
pioneers, the lines all headed for moun-
tain passes to avoid the long and treach-
erous tunnels required by more direct
alignments. The wagon trails went over
the tops of the passes. This the aqual-
duct could not do, because of the ex-
cessive cost of pumping. Controlling di-
vides must be passed in tunnels, and
mountain passes frequently are not good
tunneling ground. They usually repre-
sent weak spots in the mountain barrier
whereas the rock is broken, and easily
eroded. Such ground caves badly in a
tunnel and is difficult and dangerous
to handle. Some of the passages into
the coastal area are traversed by active
earthquake faults, which are a hazard
to any kind of deeply buried construc-
tion work. Many were waterlogged
and otherwise destructive. A careful geological
study of possible passages had an im-
portant influence on the final selection of
the aqueduct route.

Points of Diversion

A first essential was a satisfactory
diversion point. Several otherwise ac-
ceptable routes required diversion from
a wandering river in wide, low-lying
silt plains, where a satisfactory diversion
was impossible. It was essential that
the river be confined at the point of di-
version between rock beds and that the
ground slope steeply up to the top of
the first pump lift, to avoid long and
costly delivery lines from the pumps.
Although not absolutely essential, it was
desirable that the diversion be made
from a storage reservoir of sufficient
size to clarify the muddy Colorado River
water.

A line diverting near Parker, Arizona,
and entering the coastal area through
the San Gorgonio Pass, south of Bea-
umont and Banning, was finally adopted.
This line takes its supply from a reser-
voir to be created by a dam about 18
miles up the river from Parker, Arizona.
The normal water level in this reservoir
is to be 450 feet above sea level. The
aqueduct will be lifted through a
total height of 1617 feet. This lift is
required to overcome the difference in
water surface elevation between Parker
Reservoir and the critical point in the
aqueduct at the outlet of San Jacinto
Tunnel, and to maintain flow in the
aqueduct between these two points. In-
cidentally, this lift results in a con-
veniently high delivery elevation for the
aqueduct flow, but the same total lift
would have been required on this route
if the water were to be delivered at
sea level.

Under the prevailing topographical
conditions, the general elevation of the
line and the total pump lift were de-
termined by end conditions at the San
Jacinto Tunnel, particularly the outlet.
The relation of these conditions to the
pump lift was studied with care. First,
the "value of a foot of head" or the cost of
lifting the specified aqueduct flow of
1500 second feet (average) an additional
foot, was determined. This "value" is
made up of the cost of pumping facili-
ties, including transmission lines and
other power producing equipment, plus
the cost of perpetual operation which was
"capitalized" at a fixed amount. This
latter amount represented a theo-
retical sum of money, the interest from
which would yield an amount sufficient
to provide for perpetual power and other
operating costs. The total of these fac-
tors (pumping facilities plus the "ca-
ptialized" cost of perpetual operation) was
estimated at $65,000 per additional foot
of head.

Having derived this figure, a cost
estimate was made for San Jacinto Tun-
el in a fairly high trial position. Low-
ering the tunnel a few feet from this
trial elevation added slightly to its
length and its cost. If the tunnel were
lowered, the aqueduct could be lowered
all the way back to the nearest pumping
plant and the pumping head at that
plant reduced, thus saving on pumping
cost. If lowered excessively, the tunnel
portals began dipping below the alluvial
fills along the mountain slopes, requiring
long and deep approach cuts. Also, seri-
ous groundwater conditions were en-
countered in the approach to the west
portal. A point was soon reached where
to go a foot deeper added more than
$65,000 to the cost of the tunnel and its
approaches, thus more than offsetting the
saving due to reduced pump lift. The
point at which this first occurred marked
the economic tunnel elevation.

A similar procedure was followed in
determining the size of the aqueduct. If
a water conduit is given a very steep
slope, the water will flow rapidly, en-
abling a small channel to deliver a large
flow. If the slope is flat, the velocity of
flow will be low, requiring a much
larger and more expensive conduit.
Hence, if there is "plenty of fall," it
should be utilized to reduce construc-
tion costs. In the case of the Colorado
River Aqueduct, fall could be provided
as required, but its value was $65,000
per vertical foot; hence, it had to be
used sparingly. If the aqueduct slope
were made too steep, much fall was
required and the cost of pumping was
excessive. A very flat grade reduced the
cost of pumping but increased greatly
the cost of the wayfar. For each type
of conduit there was an "economic slope"
which gave the smallest combination of
construction cost plus capitalized cost of
providing the head required to main-
tain the flow.

Types of Conduit

The aqueduct is made up of several
types of conduits, to suit various topo-
graphic situations. The cheapest type
acceptable for the service required is a
cement lined open canal. This type is
used across relatively smooth desert areas
where the handling of cross-flows from
occasional floods is not too serious a
problem. A closed concrete conduit built
in an open ditch and then backfilled,
called "covered conduit," is used in
more difficult locations. Concrete lined
tunnels are used where mountains must
be pierced or where the topography is so
rough that covered conduit following a
contour is not feasible. Finally, pres-
sure pipes, or inverted siphons, are re-
quired for crossing drainage channels and
other depressions.

The costs of these conduit types vary
about in the order named. Canals were
used wherever possible, then covered con-
duits. Tunnels and siphons were used
only where unavoidable.
determined from cost estimates. Beginning at the established elevation at the San Jacinto Tunnel outlet and proceeding eastward, these slopes were added up back to the top of the nearest pump lift, at Hayfield, thus determining the peak elevation of 1807 feet above sea level. Although this peak is only 1357 feet above the elevation of the water in Parker Reservoir, a pump lift of 1617 feet is required to get the water there. The difference of 260 feet is used up in the slope of the intervening aqueduct.

It would have been desirable, if feasible, to do all the pumping at a single point, i.e., at the Intake. However, the desert floor, leading away from the river, is too low to support an aqueduct 1617 feet above the reservoir level. The ground rises gradually to Shaver's Summit, about 130 aqueduct miles west of the Intake. The pumping was divided between five plants and these were distributed along the line to secure the best possible fit between the aqueduct and the ground.

**Pumping Plants**

The first plant is at the river and the second one is nearby, the two having a combined lift of 504 feet, which is sufficient to deliver the water through the Whipple Mountain tunnels onto the tableland in the Vidal-Rice district, and cause it to flow 70 miles by gravity to the foot of Iron Mountain. Here a 144-foot lift provides head for flow through the Iron Mountain and Cocom tunnel and across the desert to Eagle Mountain. A fourth lift of 438 feet provides elevation for turning the corner of the mountains northwest of Desert Center and delivering the flow over a divide into the Hayfield Dry Lake area. This old lake bed is to be utilized as a natural reservoir. West of this reservoir, the terrain rises rather rapidly to Shaver's Summit, hence the fifth and last pumping plant is required.

This plant lifts the water 441 feet to the peak elevation of 1807 feet. This elevation is somewhat higher than required to clear Shaver's Summit, but is necessary to provide the head needed to pass the controlling elevation at the San Jacinto Tunnel outlet.

West of San Jacinto the value of a foot of head is no longer related to the cost of pumping but is dependent upon the value of the fall for the maintenance of flow in the remainder of the aqueduct, and the value of elevation in making deliveries to the various District cities. The value was somewhat smaller than for the eastern end of the line, hence siphons and tunnels were slightly reduced in size.

The availability of storage facilities was a further controlling factor in the location and design of the aqueduct. As the maximum demand is reached, it will be necessary to keep the aqueduct running at full capacity day and night, all the year, except for unavoidable interruptions. The result is a constant stream of water. But neither the supply of water at the Intake nor the demand at the outlet is naturally constant. The natural flow of the Colorado River is variable and the use of water is much lower in winter than in summer. If the aqueduct is to be used to full efficiency, a space must be available at both intake and outlet for storage.

**Terminal Storage**

Terminal storage is also required for safety. Any waterway as long as the Colorado River Aqueduct is subject to accident, due to earthquake, flood, or other natural cause. An interruption of as much as a month is conceivable. Although such interruptions will occur rarely, if ever, it is necessary that such a contingency be provided for by a reserve in local reservoirs. A reserve of two months' supply is about the minimum for safety.

The storage required at the intake is supplied by the Boulder and Parker reservoirs. The latter also serves to clarify the flow before its diversion into the aqueduct. Additional storage is required as near as possible to the end of the aqueduct.

Reservoir sites are very scarce in Southern California and generally expensive to develop. The storage capacity of every "wrinkle" in the topography of the coastal area was investigated. Many apparently possible sites were prospected. Convenience, safety of dams, cost of reservoir, and influence on aqueduct cost, were carefully considered. Finally, the Lake Mathews site, about ten miles southwest of Riverside, was chosen. This site is very safe and is capable of being developed in stages, as the demand for water grows. The reservoir is formed by an earthen dam across Cajalco Creek, and a long earthen dike along the north rim of the basin. The initial capacity is 107,000 acre feet, which can be increased as required to a total of 225,000 acre feet.

As an additional safeguard, and to reduce the capacity required in terminal lines, the District is to acquire Morris Reservoir on the San Gabriel River, as soon as Colorado River water is ready for delivery. This reservoir was built by the City of Pasadena. Other small operative reservoirs are contemplated. Use is also to be made of a natural lake bed at Hayfield about the middle of the main aqueduct, for additional emergency storage. This basin is west of all the open lined canal and will supply the aqueduct in case flow in the canal should be interrupted by cloudburst.

The solution of these general problems cleared the way for detailed location and design, which were controlled by consideration of safety, permanence, convenience, and economy, with safety in first place.

**Safety**

The element of safety is divisible into two parts, viz., safety against damage to the public and safety against damage to the aqueduct. Where human life is involved, there can be no compromise whatever with safety. The Parker and Mathews dams, for example, must have an excessive margin of safety, under the worst conditions imaginable. These features and others involving the safety of "life and limb" must be as safe as human ingenuity permits, regardless of cost.

The requirements for safety against damage to private property, other than District property, are only slightly less exacting. It is theoretically permissible to risk injury to private property if the cost of reimbursing the private individual for the resultant loss is less than the cost of building in such manner as to avoid the risk of injury. However, claims for damage to private individuals cause dissatisfaction and ill-feeling and any possibility of such damage should be eliminated unless the risk is small and the cost of elimination enormous.

Risk of injury to the aqueduct itself can be treated on a more rational basis. There must, of course, be no risk of wholesale destruction, nor must there be any risk of an interruption in excess of the shut-down provided for in the design of storage works. Within the limits of such provision, risk of damage to the aqueduct itself, where danger to human life is not involved, can be worked out on a mathematical basis. For example, the use of open lined canal instead of covered conduit across favorable portions of the desert, effected a reduction of $20,000,000 in construction and operating costs. Unfortunately, an open canal cannot be made absolutely secure against damage, say by a flood like that which occurred in the coastal area in the spring of 1938. Such a flood, occurring on the desert, would be quite likely to damage the open canal. Complete safety under such extraordinary conditions cannot be attained at any reasonable cost, just as an "absolutely" fireproof house generally is not a good investment. The prudent owner builds his house well,
eliminating all needless hazards, and then insures against further risk of loss. Insurance on the aqueduct is provided by building in such a manner that, although occasional difficulties may be encountered, widespread destruction or frequent interruption will not occur. To this end the canal is set deeply into the ground; with only minor exceptions, the concrete lined waterway is entirely within the firm, undisturbed soil. The concrete lining is very substantial, heavily reinforced with steel bars and from 6 to 8 inches thick. No flood could destroy more than a short length of this structure. The worst that could happen, even under extraordinary storm conditions, would be a moderate repair bill and a short interruption in flow. Service during such interruptions may be maintained by pumping from the Hayfield Reservoir, which lies beyond the last open canal section, or by drawing on Lake Mathews at the end of the main aqueduct.

The canal section is thoroughly protected against all ordinary hazards. Great care is taken to exclude storm waters from the canal. The open waterway is interrupted at every drainage channel, the flow being carried across the floodway in pressure pipes, safely buried below the ground surface. Long diagonal drains reach far out on the uphill side to gather small rivulets and sheet drainage into the prepared crossing. Every foot of the uphill bank is protected by substantial embankments and parallel drains. With good luck, these defenses may never be breached and at worst they will resist all but the worst onslaughts of Mother Nature. These open canals are perhaps the most secure open canals ever constructed, yet they involve no element of elaborate extravagance.

The foregoing discussion of safety in the open canals illustrates the type of thinking that went into the planning of the entire aqueduct. The location and design of diversion work, pumping stations, power lines, covered conduits, tunnels, pipe lines, and reservoirs, all were scrutinized with equal care for elements of danger.

Permanence

The elements of “safety” and “permanence” are closely related. A dangerous structure is not likely to be a permanent one. The aqueduct is being built for the future as well as for the present, and must stand and give adequate service for an indefinitely long time. Aqueduct bond redemptions are to be extended over a period of fifty years and it is essential that the aqueduct last at least that long. Fortunately, most portions of it, with only nominal expenditures for repairs and replacements, will last much longer than that, in fact, indefinitely. The only important features subject to deterioration are the steel pressure pipes in the distribution system and these are being constructed and protected with such care that a trouble-free life of more than 50 years is confidently expected.

Certain machine parts in the pumping plants may wear out and need replacement. These are covered in all estimates by an allowance for depreciation, or replacement. These features are to be carefully maintained and will be delivered to “posterity” in good order when the bonds have been retired.

Convenience

“Convenience” is a somewhat less exacting requirement. It is important that the system be planned to permit smooth operation, that deliveries be made at convenient points, that lines be laid out to permit convenient connection to potential future areas, and that in all respects the system be eminently workable. In many respects “convenience” is relative. For example, it would have been convenient to have the terminal of the aqueduct high enough to serve gravity water to all parts of the District area, but in the higher portions of Pasadena, Los Angeles, and other foothill cities, this was impracticable and expensive. Hence, a compromise was required. The outlet ends of the distributing lines from Lake Mathews were lowered and consequently cheapened, until an economic balance was reached between the cost of feeder lines and the cost of getting water out of these lines and into the distribution systems of various cities. Similar measures of the value of convenience were applied all along the line.

Economy

The requirement for economy pervaded every element of the undertaking. The magnitude of the project was such that success required that the benefits sought should be attained at the minimum possible cost. It doesn’t follow that the cheapest possible line, nor the cheapest type of construction, was adopted, but every endeavor has been made to meet the requirements of safety, permanence, and convenience, for the least practicable amount of money.

As the project nears completion of its initial stage, this endeavor appears to have been successful.

(July 15, 1938)
Specifications
Their Preparation, the Problems Involved, and the Results Obtained.

By CHAS. A. BISSELL
Office Engineer

The first call for bids on permanent construction work in connection with the Colorado River Aqueduct was for the construction of the San Jacinto tunnel. The form developed for this set of specifications established a pattern which has been followed more or less closely in all subsequent construction specifications issued by the District. "The contract" is defined in the specifications as consisting of the Notice Inviting Bids, Instructions to Bidders, Proposal, Agreement, Specifications, and Drawings. These documents, together with the bond forms, are bound up into a single volume and issued to prospective bidders.

The burden of knowledge of and compliance with all applicable local, state, and federal laws and regulations rests of course with the contractor, regardless of specification provisions. Certain legislative enactments however are required by state law to be specifically set forth in the specifications, including those relating to the eight-hour law, prevailing rate of per diem wages, and prohibition of employment of alien labor. The Reconstruction Finance Corporation requires the inclusion of provisions relating to prohibition of employment of convict labor, use of domestic materials and machinery, regulations regarding rates of pay for labor, employment preference to ex-service men, and, west of Lake Mathews, the 30-hour (now 40-hour) week. In accordance with action by the District's board of directors, provisions are included requiring the contractor to give preference in employment to residents of the District, where they are qualified. In order to protect local surety company agents and brokers, attention is called in the Instructions to Bidders to the state law requiring premiums on risks located within the state to be paid to and credited to offices located in the state.

Following San Jacinto, specifications for other tunnels were issued in rapid succession, until by June 16, 1933, the construction of all main-aqueduct tunnels had been provided for, except East Eagle, bids on which had been rejected, and Schedules 7 and 8 of the West Coachellas which were later authorized for force account construction. The writing of this group of specifications was preceded by months of preparatory work. In addition to the location surveys and geological reports, District engineers experienced in tunnel work made complete designs, plans, estimates, and construction layouts for each job so that the specifications were based upon definite knowledge of the situation at each tunnel, as complete as the most competent contractor would collect as a basis for his bid. Subsequent construction specifications received equally thorough study. As a further guide in the comparison of bids and award of contract thereunder, regulations require that a sealed copy of the engineer's estimate be filed with the board in each case prior to opening bids.

Plans and specifications for the San Jacinto tunnel called for a 16-foot diameter full-capacity bore. The specifications for Valverde and Bernacconi and for the Iron Mountain-Coxcomb-Cottonwood group were issued with alternative schedules for half-capacity and full-capacity tunnels. The bids in both cases showed that the cost of the smaller tunnels would be more than 50 per cent of the cost of the larger, so all tunnels were constructed full size.

All conduit, canal, and siphon schedules east of the Coachellas tunnels, comprising 110,62 miles of open work, were included in Specifications No. 70, issued in August, 1934. Contract awards under these specifications aggregated $14,160,000. The remaining 30.5 miles of main aqueduct open work was advertised in October of the same year, followed in rapid succession by specifications for the distribution system tunnels, the Boulder Dam transmission line, Mathews dam and dike, and the upper feeder pipe lines. Intake and Gene pumping plants were advertised together as a single job in October, 1935; the other three pumping plants one after the other during the following nine months. Specifications for the Monrovia, San Gabriel, and Eagle Rock canyon crossings and the Gene Wash and Copper Basin dams were issued during the winter of 1936-37, and bids on the Palos Verdes feeder were opened September 1 of the latter year.

Ordinary purchases of standard articles of commerce are taken care of by the purchasing division, but where deliveries are to be made over an extended period, where the estimated cost is in excess of $10,000, or where the materials or equipment are of a special nature, formal specifications are prepared. Under such specifications there have been delivered to date 6,800,000 barrels of Portland cement, 75,000 tons of reinforcement steel, 695 miles of steel reinforced aluminum cable, pumps, motors, and electrical equipment for the five pumping plants aggregating more than $3,500,000 in cost, and hundreds of items of slide gates, radial gates, valves, steel forms, and other fabricated articles too numerous to mention. For construction operations by District forces 5,000 tons of explosives and 300 tons of drill steel have been purchased.

In the preparation of specifications for materials, the standards of the American Society for Testing Materials, Federal Specifications Board, A.P.I.-A.S.M.E. Welding Code, and other recognized authorities, wherever applicable, are incorporated in District specifications by reference. Constant contact is maintained with manufacturers and excellent cooperation has been given by them in the preparation of specifications relating to their respective specialties. Research by District engineers has developed new or improved specifications for a number of products, such as scaling compound and whitewash for curing concrete under desert conditions, and coal-tar enamel and primer for steel pipe. The District's experimental work in co-operation with the California Institute of Technology, the results of which are incorporated in Specifications 116 for 200-c.i.d. pumps for the aqueduct pumping plants, has been described elsewhere.

An extensive investigation of California portland cements carried on at the Banning laboratory by the District's testing engineer in co-operation with the cement companies and the University of California resulted in the preparation of specifications for five different types of cement for District use, each differing in greater or lesser degree from the then current A.S.T.M. standard and each especially adapted to definite requirements of some part of the aqueduct work. For the bulk of the work 6,000,000 barrels were manufactured under the District's Specifications No. 79, which call for a cement meeting in general the requirements of a standard Portland but somewhat more finely ground and more closely restricted as to allowable percentages of the less desirable compounds. The other cement specifications include sulphate-resistant cement for use where soil samples indicate that corrosive ground waters will be encountered, high early strength cement for temporary grout in support in tunnels and for grouting to cut off water ahead of tunnel excavation, low-heat cement for mass concrete in dams, and a Portland-pozzolana cement for a short test section of tunnel lining.

Up to May 16, 1938, a total of 281 major specifications had been issued. These have resulted in 403 formal contracts, involving a total expenditure of $106,840,000.

(September 10, 1938)
WELDING A STEEL AQUEDUCT PIPE

This unusual picture of a welder in action was taken on the inside of the Palos Verdes Feeder of the Distribution System. This particular schedule of that feeder is constructed of welded steel pipe having an inside diameter of 51 inches. Before being placed in the trench, the interior of these pipe sections was lined with cement mortar centrifugally applied, and the outside of each section was coated with gunite. The picture shows a welder making the inside field weld at a joint connecting two sections of pipe.
Safety

Planning and Enforcement of the Construction Safety Program.

By T. W. OSGOOD
Safety Engineer

Early in 1933, earth began to move on actual construction of the Colorado River Aqueduct project. Ahead lay the building of the main aqueduct and initial unit of the distribution system.

During the following five and one-half years, twenty-nine general contractors and two Metropolitan Water District construction organizations have been engaged in constructing this huge project. By September, 1938, the job practically was completed, for there remained only 0.66 miles of excavation and the placing of 6.68 miles of concrete lining at the 13-mile San Jacinto tunnel.

From the beginning, the work progressed twenty-four hours a day, in eight-hour shifts, with increasing momentum until high speed was realized and maintained with a maximum force of 10,000 men and a total employment of approximately 35,000.

The operations were carried on from sixty-one camps located at strategic points along the 309 miles of the construction activity.

Excavation of the 38 tunnels, aggregating 108 miles in length, has been prosecuted at 66 headings, and the construction of conduits, siphons and other open work, which constitute the connecting links between the tunnels, was carried on at many points of attack.

The safety work, with principal purpose to protect the employees from accidental injuries, has run concurrently with the construction activities along the 309-mile front from the Colorado River to Eagle Rock in the City of Los Angeles.

The Board of Directors and staff of the District have given the same thorough study to safety as they have to any other phase of the aqueduct work and, prior to the beginning of construction, the Board adopted this safety policy—"The application of every possible safety measure shall be practiced."

Safety Program

A safety program was adopted and provided for the following features:

1. Executive interest and control were laid as the foundation of the safety program, the purpose being to realize full co-operation from all concerned in achieving four vital objectives of the management—first, protection of life and limb of the employees; second, conservation of property; third, maximum progress under existing conditions; and, fourth, reduction in construction costs.

2. Adequate safety and health regulations were included in the construction specifications.

3. A safety engineer and staff were employed and general duties were designated, namely, to make safety inspections and reports on all aqueduct work; to study the safety problems of the job and advise the supervisors of the hazards and of corrective measures; to cooperate with the supervisors in the conduct of their safety work; to keep the executives and supervisors informed on the accident trend, on the causes and consequences of accidents, and on methods for preventing accidents.

4. A "Safety Orders" form was drafted for reporting any hazards found to exist on the aqueduct work.

5. Printed instructions were formulated for the organization and functioning of general and camp safety committees and safety clubs.

6. Safety bulletin boards were provided for the camps and safety posters and bulletins are furnished weekly.

7. First-aid training for the employees has been conducted annually in cooperation with the United States Bureau of Mines.

8. Mine rescue equipment and truck were provided and rescue squads were trained.

9. Safety rules and regulations bearing upon the following subjects were compiled and distributed among the construction force: Responsibility of supervisors and workmen; tunnel heading operations; haulage; tunnel shaft operations; hoisting engineers; electrical and mechanical equipment; gas and electric welding and cutting; rigging for moving equipment; automobiles and trucks, surface equipment and operations; fire protection; sanitation and hygiene; care of the injured; explosives magazines; safety primers; blasting equipment and procedure; organization and procedure in case of a tunnel fire or other major emergency; and, miscellaneous features.

10. Records of accident frequencies, causes and costs have been kept.

11. Safety literature published by the U. S. Bureau of Mines, the National Safety Council, U. S. Public Health Service, and other recognized authorities has been made available to the construction forces, and various other activities have been carried on to develop the safety spirit within the entire organization.

12. Membership in the National Safety Council has been maintained.

Safety Inspection

In actual practice the inspection and enforcement procedure has been as follows:

a. Collectively, the construction superintendents, on their own initiative, have been reasonably diligent in the endeavor to maintain safe conditions and safe practices on their respective jobs. It is not unusual that, among the many superintendents, the degree of diligence exercised in preventing accidents varies according to their personal attitudes and temperaments, and it may be added that each superintendent's attitude toward safety, good or bad, reflects the attitude and/or the control exercised by the company or organization for which he works. Also, our records indicate that when the attitude and control are good, the accident rate and costs are low, and vice versa.

b. Safety inspections of aqueduct work are carried on continuously by the division engineers and their resident engineers and inspectors, and by the safety engineer and assistant safety engineers.

c. Any hazardous conditions and practices observed are entered on the "Safety Orders" form, which is signed by the person who made the inspection, and also by the respective division engineers, who, through their signatures, direct that the unsafe conditions noted in the order be corrected at once. Copies of each safety order promptly are given or sent to the superintendent, division engineer, general superintendent, and safety engineer.

d. The division engineers, directly or through their resident engineers and inspectors, follow up these safety orders and enforce compliance therewith in the event that any of the unsafe conditions noted therein are found not to have been corrected.

e. The safety engineer and assistant safety engineers also check the unsafe conditions noted in the safety orders and notify the division engineers of failure to comply with any items therein.

The safety program on the construction of the Colorado River Aqueduct, as a whole, has resulted in a consistent yearly decrease in the lost-time accident frequency rate, and the frequency rate for the year 1937 was 38 per cent below that for other tunnel and heavy open construction in California for a five-year period.

(September 25, 1938)
Construction Water

Planning and Building the Construction Water Supply System for the Colorado River Aqueduct.

By O. J. SCHIEBER
Division Engineer, Division 6

In the construction of the Colorado River Aqueduct across approximately 200 miles of desert from the Colorado River to Big Morongo Canyon, the provision of an adequate and dependable supply of water for domestic and construction use was a vital necessity. The provision of this water supply, equal to the requirements of a city of 15,000 people, in a desert area where only a few scattered springs and wells existed, was a task of considerable magnitude. It actually required the building of a miniature aqueduct before the main aqueduct could be constructed.

Planning of the water system was based on providing a water supply sufficient to meet the maximum requirements of the construction program approved for the building of the aqueduct. The quantities required at the various places of use were based on estimates of the domestic requirements for the personnel and the construction requirements for cooling of air compressors, operation of air drills, wetting of subgrade, mixing and curing of concrete, washing of aggregate, etc.

Comparative estimates were made of the cost of supplying the water from various sources along the aqueduct where there was reasonable assurance that wells could be developed based on the topography and the contributory drainage area. From this analysis a tentative plan was adopted based on supplying water from wells drilled at the more favorable locations.

Well Drilling

Two well rigs were rented in December, 1932, and active drilling of wells was started and continued to completion in August, 1933. This drilling developed ten good wells with yields varying from 75 to 500 gallons per minute which were included in the final water system. These are located one each at Eureka, Earp, Sand Draw, Pinto Wash, Little Morongo Canyon, and Big Morongo Canyon, and two each at Vidal Wash and Buried Mountain.

Use of wells at Indio was originally considered but this was abandoned when good wells were developed at Buried Mountain and the Morongo canyons. The Morongo wells however showed rapid depletion and it was necessary in May, 1934, to supplement these wells with a supply from Covington Springs about 3/4 miles further up the Big Morongo Canyon. An additional well was required at both Eureka Wash and Earp and the well at Sand Draw, due to the poor quality of the water, was replaced by a new well.

The above wells were grouped into four separate sections. The wells in each section were connected by a steel pipe line which in general paralleled the aqueduct and was designed of proper size and provided with the necessary booster pumps, storage tanks and reservoirs. Beginning at the river, the first section supplied water for the work from Parker Dam to Copper Basin, the second section the work from Whipple Mountain Tunnel to East Iron Mountain Tunnel, the third section the construction from West Iron Mountain Tunnel to Fargo Canyon and the fourth section the work from Bernio Canyon to Big Morongo Canyon. During the season of heaviest construction on each section the following quantities of water were supplied: Section one, 400 gallons per minute; section two, 550 gallons per minute; section three, 900 gallons per minute, and section four, 325 gallons per minute.

The wells are 16 inches in diameter, lined with No. 8 gauge stovepipe casing for the deeper wells and 10 gauge casing for the shallow wells. They vary in depth from 26 feet to 785 feet, with the water level ranging from 11 feet to 31 feet. Production under steady pumping has varied from 50 gallons per minute for the Morongo wells to 500 gallons per minute for the Pinto well.

Pipe Line Construction

The pipe lines were constructed with standard O. D., line pipe 4 to 8 inches in diameter except for parts of the supply lines from the wells where heavier pipe was required due to higher heads. The pipe was supplied by the District in lengths averaging approximately 37 feet and the lines were constructed by contract. A trench with a minimum depth of 18 inches was excavated with graders, rooters, plows and bulldozers operated by tractors. The pipe was oxy-acetylene welded, tested to 500 pounds per square inch, and then lowered into the trench and backfilled with tractor-operated graders and bulldozers.

The well pumps, booster pumps and the smaller storage tanks were all installed by District crews. The guillotine reservoirs and the larger steel tanks were built by contract. The pumps are all electrically operated, power being supplied by sub lines from the District's 33-kv line with transformers at the pump sites which step the voltage down to 440 and 220 volts.

The booster pumps are of centrifugal type of various makes and sizes varying from a capacity of 150 gallons per minute at 200-foot head to 300 gallons per minute at 900-foot head. The well pumps are of the deep well turbine type with capacities varying from 150 to 750 gallons per minute and heads varying from 60 to 440 feet. All of the pumps are automatically operated.

Storage

The reservoirs and tanks located along the pipe lines provide storage to take care of breaks in the pipe lines or interruptions in the supply from the wells. Duplicate pump units are installed in all of the booster plants to insure continuous operation of these plants. The output of the well pumps and booster plants is all measured by flow meter and recorded by an automatic recording instrument. Water is metered to all users at the points of delivery on the District line.

The water supplied from the various wells has varied considerably in quality but has all been within the range of potability. All sources are tested at regular intervals, but no instances of contamination from bacillus coli have occurred. Some trouble was experienced at the Pinto and Morongo wells due to crenobrix in the water causing incrustation on the walls of the pipe line and a reddish discoloration of the water. This condition is corrected by aeration and chlorination of the water at the wells.

Costs

The complete water system consisting of 14 wells, 199 miles of pipe line, 20 booster tanks, 33 tanks, and reservoirs and the necessary transmission line connections and transformers cost a total of $863,000. The nominal cost of 15 cents per 100 cubic feet charged by the District for water furnished to tunnel work and 30 cents per 100 cubic feet for the open work has been sufficient to take care of operation and maintenance to date and provide a credit of some $40,000.

Except for the additional wells required at the river and Sand Draw, and the development of Covington Springs, the water system has functioned very much as originally planned. During the busiest part of the aqueduct construction work, from May to July, 1936, an average of 1,500,000 gallons of water was delivered each day, a quantity sufficient to supply the requirements of a city the size of Burbank.

(October 10, 1938)
Construction Roads

Planning and Building the Construction Roads for the Colorado River Aqueduct.

By CLYDE L. JENKEN
Engineer, Construction Division

From the Intake at the Colorado River to the 13-mile San Jacinto Tunnel, a distance of approximately 210 miles, the Colorado River Aqueduct is located in an arid and practically barren desert waste. The route passes over dry sandy valley floors which are alternated with solid rock mountain ranges that are pierced by tunnels. The climatic conditions for this entire 210 miles are typical for a desert region—the summers are long and hot and the annual rainfall is small, ranging from 2 to 4 inches.

Before construction of this portion of the aqueduct could be undertaken, it was first necessary to provide a system of roads over which construction equipment, supplies and material could be transported.

From the Colorado River to Desert Center, only a few desert trails existed, and while it was possible to pass over them in a light automobile at a slow rate of speed with much discomfort to both driver and passengers, they were definitely inadequate for any type of loaded truck.

Between these two points approximately 110 miles of aqueduct construction had to be served.

The State Highway from Desert Center to Banning was convenient for all through traffic and was located near enough to serve as a feeder road for approximately 40 miles of aqueduct construction between Desert Center and Mecca Pass and approximately 15 miles between Garnet and Banning. A portion of this State Highway between Shaver's Summit and Indio was constructed after actual construction on the aqueduct had begun. Prior to the construction of this cut-off all traffic had to be routed by the way of Mecca, which was about 10 miles greater in length. In order to expedite the construction of this new State Highway, the District participated in the cost to the extent of $20,000.

Approximately 45 miles of aqueduct construction between Mecca Pass and Garnet was too remote from the State Highway to use it for a feeder road.

To provide an adequate system of main feeder roads, it was necessary to construct 151.64 miles of new highways in addition to the new section of State Highway, about 27 miles in length, constructed between Mecca Pass and Indio.

Approximately 105 miles of these new highways extended from the Intake above Parker Dam to Desert Center; about 7.75 miles from the State Highway a few miles west of Desert Center to the Eagle Mountain pump lift; and approximately 39.2 miles from Indio to Berdoo Canyon and from the junction at the mouth of Berdoo Canyon to Garnet.

From these main feeder roads many camp and construction roads of from one and two miles up to ten and fifteen miles in length were constructed by the various contractors, and in Division No. 4 by the District's own force account crews.

While these roads are in general use by the public and may ultimately become a part of the State or County highway system, they were, nevertheless, intended only for use in the construction, maintenance and operation of the aqueduct. The District's only interest therefore was to provide the most economical type of road that would serve the unusually heavy transportation needs during the construction period of five to six years, after which the roads would only be used (as far as the District's needs are concerned) for the very small amount of traffic required in the operation and maintenance of the aqueduct.

Economic studies of transportation and road maintenance costs indicated quite clearly that some sort of paved road surface would be required to withstand the heavy wheel loads, volume of traffic and other unusual abuses that would naturally accompany such a large construction program. In order to effect a minimum cost per ton-mile for the hauling of construction materials and equipment, it was of course necessary to design a system of roads that could be constructed at a low cost.

These problems were solved by the design and construction of a system of roads laid out with long tangents and few angles, which resulted in a minimum length; grading a roadbed having an over-all width of approximately 30 feet with a finished surface approximating the natural ground, but at the same time maintaining a gradient of 6 per cent or less, which produced a minimum of roadway excavation; and surfaced the roadway with an oil treated mixture known as "Oil Road Mix" for a width of 20 feet and a compacted thickness of 3 inches, which gave the road the equivalent of a paved surface at a very low cost. Many drainage structures, such as culverts and bridges, were eliminated by constructing long sweeping dips that would permit a speed of 45 miles per hour without the usual throw or bump generally associated with dips. In many places through sand the subgrade was reinforced with 6 to 10 inches of selected borrow material before the oil treated surface was placed.

The total cost of construction, including right of way, engineering and administration for the 151.64 miles of feeder roads was $912,133.14, and the total maintenance cost for the first 5 years was approximately $120,000.

(October 25, 1938)

Because of the lack of roads in the desert country over which the aqueduct was built, early survey parties in some cases had to "pack in" as is shown in this picture. Before construction of the aqueduct could be started in this area it was necessary for the District to build more than 150 miles of modern surfaced highways.
NIGHT VIEW, PARKER DAM UNDER CONSTRUCTION

Construction work on Parker Dam and most of the other features of the Colorado River Aqueduct was carried on 24 hours a day. This midnight view of Parker Dam construction was taken in October, 1937, when the top of the rising dam was still more than a hundred feet below the surface of the Colorado River which was held in check by the high coffer dam seen in the left background.
Construction Power and Communications
Planning and Building the Construction Power and Communications Systems.

By J. O. BINNEY
Engineer, Electrical Division

Preliminary estimates of construction operations on the Colorado River Aqueduct indicated that 250 million kWhr of more than electrical energy would be required for efficient prosecuting of the work. Since there were no adequate local sources of supply it was apparent that a complete new power system would be required to supply this large amount of energy.

In order to determine the most economical scheme of power supply a number of alternative plans for serving the work were considered and comparative cost estimates were prepared. Included in the alternatives were various combinations of transmission and distribution voltages, numerous different arrangements in the location and capacity of substations, and many variations in the structural design of the transmission lines and other features. The comparative merits of copper and steel reinforced aluminum conductors was also given consideration.

The cost of generating power with steam or internal combustion engine plants located near the site of the work was compared with the cost of purchasing power in wholesale quantities from an operating utility company and it was apparent that the latter plan offered the best engineering solution of the problem. Under the specifications for the purchase of power, which were issued in June, 1932, the bidders were given the alternative of furnishing power at a central point near the western end of the aqueduct or of delivering it to substations located in the various construction divisions. A single bid was submitted jointly by the Southern California Edison Company, the Los Angeles Gas and Electric Corporation, and the Southern Sierra Power Company, and under this joint proposal 50-cycle power was to be delivered at the Colton substation of the Edison Company for transmission over lines to be built by the District. This proposal was accepted by the Board of Directors in July, 1932. The contract rate includes various elements of demand, energy and power factor charges, so that the actual cost of energy varies with the conditions of use. Due to careful operation of the power system and control of the District's and contractors' equipment, the rate has averaged about 6.3 mills per kilowatt hour. The use of energy has exceeded the estimated amounts largely due to the pumping in the San Jacinto tunnel, but the demand reached a maximum of only 20,000 h.p., which is considerably below the anticipated requirements.

Having settled upon the point of delivery, plans were prepared as rapidly as possible for the construction of 196 miles of 66-kv transmission line, 290 miles of 33-kv distribution line, 6 major substations and 72 distribution substations, together with the necessary dwellings for the operators and patrol crews. Because of the generally depressed business conditions at the time there were urgent requests on the part of construction contractors that this first work on the aqueduct be done by contract, and such a plan had many advantages. Preparation of specifications was difficult because the location of the roads, water lines, and tunnel camps had not been completely determined at the time but in spite of these obstacles contract work was considered to be the best plan. The results were very satisfactory and excellent progress was made in the construction of the power system. The work was divided into geographical divisions, starting with the western end of the aqueduct and proceeding toward the east as fast as plans and locations could be completed. This also had the advantage of dividing the work into units of a size which could be efficiently handled by local contractors. Construction was commenced in December, 1932, and with the exception of a few minor extensions and additions was completed in December, 1933. Power was first delivered in March of 1933 and to date over 350 million kWhr of energy have been used in construction operations.

The system as initially planned and installed has proved to be adequate with a reasonable margin of excess capacity. The cost of the system was low and the construction has proved to be adequate but not too elaborate for the purpose intended. A few changes have been made as the work developed and recently, by minor changes in connections, a complete duplicate power supply has been provided for San Jacinto tunnel to ensure continuity of power service for this important and difficult part of the construction work.

The problems encountered in planning and building the communication system were comparable to those of the power system. Similar studies were made of various plans for serving the work in order to arrive at the best engineering solution of the problem. Consideration was given to service by radio, telephone, telegraph and teletype systems to be built by the District, and to the leasing of facilities from operating companies.

Because of the multiplicity of stations to be served and the requirements of the contractors for service to their respective headquarters offices located in various cities throughout the country a wire line telephone system appeared to be most appropriate for serving the work. The studies also indicated that an annual saving of approximately $60,000 would result during the construction period if the District installed and operated its own system between Lake Mathews and the Colorado River. It was cheaper by some $15,000 a year however to provide service between the Los Angeles and Banning offices of the District over facilities leased from the telephone companies.

San Gorgonio Pass is a natural route for communication lines between Los Angeles and eastern cities, and a large saving in cost was effected by contracting with the Western Union and Bell Systems for wire space on approximately 100 miles of existing lines between Beaumont and Desert Center.

From any telephone on the District's system one can talk to any telephone within reach of the public telephone systems just as easily as this can be done from office or residence. No repeaters are used in the District's system. This excellent service was made possible by adequate design and through a connection with the public telephone system at Banning.

The facilities installed consist essentially of 5 telephone exchange installations with interconnecting trunk lines and local distribution circuits. There is a total of approximately 1300 miles of metallic circuit, 802 miles being carried on poles owned by the District, 400 miles on poles used jointly with utility companies and 38 miles on the District's power poles. The maximum number of telephone instruments connected to the system at one time was 306 and the number of calls transmitted has averaged 13,000 per month. Approximately 25% of the traffic handled was chargeable to the contractors and 75% to the District.

Most of the work of installing the plant was done by contract, with the contractors furnishing materials as well as the labor required. Work was started in December of 1932 and with the exception of the Iron Mountain-Boulder line and minor additions later made by force account crews was fully completed in October of 1933.

(November 25, 1938)
Employment

Employment Methods Used in Construction of the Aqueduct.

By N. F. JAMIESON
Employment Officer

Employment on a project 350 miles long, covering all branches of construction from camps, open ditches, conduits, tunnels, roads, water works, dams, reservoirs, power lines, to pumping plants and pipe lines, with living and climatic conditions to be considered, is a problem of no small magnitude. However, the solution can be more easily understood if it is approached under three main divisions, viz.: (first), requirements of the District; (second), division into classes of positions to be filled; and, (third), the merit system (prescribed in an ordinance of the Board of Directors governing the selection of employees for appointment.)

Requirements of the District:

In the conduct of its affairs relating to employment, the District acted in accordance with the provisions of the Metropolitan Water District Act, which provides that "the Board of Directors shall have the power to prescribe by ordinance a system of civil service." and on August 7, 1931, an ordinance was adopted by the Board which established a merit system of employment.

(First), "To be eligible for employment a person must be a bona fide resident of the District for a year preceding date of employment." (Second), "Not more than one member from a household shall be employed by the District." (Third), "All applicants must pass a medical examination before being accepted for employment." (Fourth), "Preference shall be given to ex-service men with dependents, where qualified."

Classification of Positions to be Filled:

Class A. Chemical, civil, electrical, mining, mechanical, structural, and sanitary engineers, hydrographers, attorneys, physicians.

Class B. Clerical and accounting: Accountants, auditors, bookkeepers, costkeepers, general storekeepers, secretaries, stenographers.

Engineering: Draftsmen, estimators, computers, instrumentmen, topographers, inspectors.

General: Assistant right-of-way solicitors, title searchers and escrow officers, public information agents, assistant personnel officers and investigators, accident investigators and claim adjusters, trained nurses.

Class C. Clerical and accounting:
General clerks, typists, comptometer operators, bookkeeping machine operators, junior costkeepers, file clerks, storekeepers, storekeepers' assistants, telephone operators, timekeepers, messengers.

General: Stewards, watchmen, junior Conductors, chauffeurs.

Engineering: Chairmen, rodmen, recorders.

Class D. Skilled trades: Positions, the duties of which require ability or skill in a trade, craft, or useful art, or special manual or mechanical training.

General construction: Electrical assistants, electricians, foremen, chief dragmen, and chief steam shovel operators, powerhouse and pumping station chief operators, superintendents, and master mechanics.

Methods of Selecting Applicants by Merit System:

On August 7, 1931, the Board of Directors adopted an ordinance prescribing a merit system to govern the selection of employees for appointment. Under this system the ability and fitness of the applicant is determined by a rating under the following four general qualifications with a predeterminant weight in each class as shown. To be eligible for appointment, an applicant must receive a rating of not less than 60 on education and experience combined and not less than 60 on references, and an average rating of not less than 75 for all qualifications. The weights to be given each qualification under each of the several classes listed are as follows:

<table>
<thead>
<tr>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
<th>Class D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>30</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Experience</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Character and</td>
<td>25</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Personality</td>
<td>40</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Physical Condition</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

Education. Credits for education will be allowed for each year of work satisfactorily completed under each of the several classes as tabulated in Schedule 1 up to the limits shown by the figures in parentheses:

<table>
<thead>
<tr>
<th>Schedule 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>High School or equivalents</td>
</tr>
<tr>
<td>College or equivalents</td>
</tr>
</tbody>
</table>

Maximum possible | 48(16) | 96(64) | 96(64) | 16(64) |

In lieu of any high school or college credits not attained under Schedule 1 but in no case in excess of the limits shown therein, applicants may be given credits for other satisfactorily completed work as shown in Schedule 1-A.

SCHEDULE 1-A

<table>
<thead>
<tr>
<th>High School Credits</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
<th>Class D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business College per term</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Correspondence school courses completed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Accounting</td>
<td>9</td>
<td>32</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>General</td>
<td>8</td>
<td>32</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>College Credits</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Normal college per year</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Technical correspondence school course completed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Business college or secretarial course in addition to 4-year high school course per year</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Maximum possible under Schedule 1-A</td>
<td>36</td>
<td>32</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

Experience: Maximum credits for experience in work of an identical character will be allowed as shown under each of the several classes listed below. In lieu of credits for identical work proportionate credits will be allowed for similar or related work.

SCHEDULE 2

<table>
<thead>
<tr>
<th>Schedule 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
</tr>
<tr>
<td>Over 10 years</td>
</tr>
<tr>
<td>6 to 10 years</td>
</tr>
<tr>
<td>4 to 5 years</td>
</tr>
<tr>
<td>2 years</td>
</tr>
<tr>
<td>1 year</td>
</tr>
<tr>
<td>Graduate university</td>
</tr>
<tr>
<td>Graduate high school</td>
</tr>
<tr>
<td>Apprenticeship</td>
</tr>
</tbody>
</table>

Character and Personality: Ratings will be determined from reference letters of former employers on forms furnished by the District, advising as to employee's character, initiative, ability, personality and judgment; and upon personal interviews. Each of these attributes will be further subdivided into the following classifications: poor, fair, good, and exceptionally good. Poor will have a rating of 50; fair, 65; good, 80; and exceptionally good, 90. These ratings will be given relative weight in making up the final rating as follows:

<table>
<thead>
<tr>
<th>Schedule 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
</tr>
<tr>
<td>Initiative</td>
</tr>
<tr>
<td>Ability</td>
</tr>
<tr>
<td>Personality</td>
</tr>
<tr>
<td>Judgment</td>
</tr>
</tbody>
</table>

Average ratings will be made on education, experience, and personality and character, and if the average rating on these qualifications is over 75, and if the applicant is selected for appointment he will then be required to pass a medical examination.

Physical Condition: Medical examination must demonstrate that the employee is physically able to perform the duties to which he would be assigned if employed.

District Takes Over Employment Problem on May 1, 1930

On May 1, 1930, the District took over control and operation of the Colorado River Aqueduct Project from the Department of Water and Power, City of Los Angeles, which Department had been carrying on engineering and surveys for a period of eight years. At the
time of the District’s assuming control, many of the employees who had been working on the project for the city were incorporated into the District’s organization.

With regard to preference being given to "ex-service men with dependents, where qualified," the District has consistently carried out this tenet for, from the start of construction of the Aqueduct to the present time, one-third of all employees have been ex-service men. This includes all persons employed by Aqueduct construction contractors, as well as those employed directly by the District. This ruling was made effective by requiring all contractors to employ only such persons as had made application through the District's employment offices, and who had been certified as bona fide residents, and as to their military service.

Many of the contracting firms had home offices in localities far distant from the District's territory. In such instances the District exempted a few key positions from its residence requirements, but such exceptions were extremely few in number.

Following the bond election of September 29, 1931, the District has been accepting through its Personnel and Labor Employment offices applications for both classified and unclassified positions. In March, 1931, Mr. Ezra B. Rider, one of the District's engineers, was placed in charge of forming and starting the Personnel Office and remained in charge until January, 1933, when he was transferred back to the Engineering Division, being followed by Mr. H. A. Beall, as Personnel Officer, who remained with the District until October 31, 1938.

In December, 1932, when construction work on the Aqueduct was first started, a Labor Employment Office was established and located at 770 South San Pedro Street, Los Angeles, under the direction of the writer as Labor Employment Officer. Branch offices were established throughout the thirteen member cities of the District where labor applications were received and forwarded to the Central Labor Employment Office in Los Angeles.

The Labor Employment Office, from its opening to the present time, has received, checked and graded applications for all classes of construction work up to and including the grade of foreman.

After construction was well under way, to facilitate the employment of qualified residents by contracting firms, the District, early in 1934, instituted a system of issuing identification certificates to those employment applicants found to meet the District's residence requirements. This certificate was issued to the applicant in the shape of a small card that certified as to the applicant's being a bona fide resident of the District, indicated whether he was a veteran or non-veteran, and carried on one side the applicant's photograph, name of city of residence, and his signature, and on the other side his right thumb print and physical description.

The use of this identification certificate allowed the contractor to employ the applicant directly without calling upon the Labor Employment Office. It also gave the applicant the opportunity of rustling for a job without returning to the Labor Employment Office in Los Angeles. Up until October 31, 1938, there had been issued 26,077 of these identification certificates to veterans and non-veterans.

Up to and including October 31, 1938, there had been received in the Personnel Office a total of 25,760 applications for positions. During this same period approximately 138,000 applicants were interviewed, and 2379 were employed in classified positions.

In the Labor Employment Office there had been received 131,842 applications for skilled and unskilled construction work. 206,139 interviews had been held, and a total of 19,261 men had been sent out to District jobs plus 28,001 to contract jobs.

The peak of employment on the District operations was reached in July, 1936, and for the contractors in October of the same year. Approximately 35,000 individuals have been employed directly on the Aqueduct construction work, without taking into consideration the number employed by transportation companies, manufacturers, and other concerns supplying equipment and materials for the Aqueduct.

In both the Personnel and Labor Employment Offices, the established merit system of employment has been very closely followed, thereby assuring impartiality and fairness in employee selection. By this method the District secured exceptionally well qualified employees in the classified service and a very high type of laborer in the skilled and unskilled classes.

We can be proud that there has been so very little trouble with the peace authorities in all the communities through which the Aqueduct has been constructed. The high standard of personal conduct that has been maintained by the employees since the start of the work is an indication of the good character of the average Aqueduct worker. We feel this is also a commentary on the method of selecting men for both classified and unclassified positions.

(December 25, 1938)
BUILDING AN AQUEDUCT SIPHON

A view of siphon construction as seen from the inside of a section of covered conduit on the Colorado River Aqueduct. The main line of the aqueduct includes 54.1 miles of these 16-foot diameter concrete conduits which have a capacity of 1500 cubic feet of water per second, or approximately one billion gallons of water per day. The water seen on the floor of the conduit was placed there for curing purposes during the construction period. Construction of the conduits alone on the Colorado River Aqueduct involved the excavation of nearly 12 million cubic yards of earth and rock, and the placing of 1,200,000 cubic yards of concrete.
Conduits

Methods Used in the Construction of the 54.1 Miles of Conduit on the Colorado River Aqueduct.

By O. J. SCHRIBER
Division Engineer, Division 6

The Colorado River Aqueduct includes 54.1 miles of cut-and-cover conduit distributed in the length from the west portal of Whipple Mountain Tunnel to the east portal of Valverde Tunnel.

Briefly described, the conduit is an unreinforced arch structure of horseshoe section with inside dimensions of 16 feet high by 18 feet 10 inches wide at the base, with a minimum thickness of 14 inches of concrete at the crown, increasing to four feet at the invert line. The invert is 12 inches thick at the center line, increasing to 22 inches at the edges. The complete section contains 427 cubic yards of concrete per linear foot. The structure is built in an open trench and then backfilled with a minimum of three feet of cover along the crown. The following major items of construction give an idea of the volume of work involved in the construction of this 54.1 miles of conduit: 10,700,000 cubic yards of common and 1,000,000 cubic yards of rock excavation, 7,000,000 cubic yards of backfill and 1,200,000 cubic yards of concrete.

The conduit work was advertised in the fall of 1934 and contracts were awarded to seven firms along with siphon and canal work. This included all of the conduit except a section 8,985 feet in length at Pan Hill Canyon on the Coachella Division which was done by Distinctive Trenching Company.

The material encountered in the excavation was mostly an alluvium of varying degrees of solidification and cementation. This material varied from fine sand to hard cemented sand and gravel which required blasting. Approximately 10 per cent of the excavation was classified as rock. The major portion of this consisted of the hard cemented material and the balance was ledge rock which was encountered in the crossings of small ridges, side-hill cuts and the approaches to tunnel portals. Where the topography was uniform the depth of cut varied from 16 to 25 feet. In rougher terrain and in the tunnel approaches cuts ran up to 65 feet and for one short ridge reached a maximum of 90 feet.

Steel Forms

For the concrete work steel forms of heavy construction were developed by the various contractors. These were similar in design on the various jobs. The principal problems involved in the design of the forms were ease in handling and setting, and facility for introduction and placing of concrete.

The inside forms differed very little for the various contracts. The outside forms, however, differed in the arrangements for introducing the concrete and in providing access for working the concrete. The form lengths were in multiples of 35 feet to coincide with requirement for the spacing of dummy and construction joints at this interval. Forms were provided for daily pours varying from 70 feet for the shortest contract to 210 feet for the longest contract. These lengths of pour required double the length of inside forms due to the requirement that the inside forms remain in position a minimum of 16 hours.

The inside forms were made of steel plates varying from 3/16 to 5/16 inch in thickness, welded to steel ribs, and fabricated in sections 7 feet or 11-1/2 feet in length to make 35-foot lengths corresponding to the spacing of the dummy joints. These sections were hinged at the top and on a line three to four feet above the invert on each side for ease in collapsing and moving.

Outside forms were made of 3/16-inch or 1/4-inch steel plates welded to steel ribs in sections corresponding in length to the inside forms. The ribs of these sections were hinged at the top and the entire form was supported on 1/2-inch bolts set horizontally, on two to six foot centers, in the edges of the invert.

One type of the outside form had fixed chutes built between the ribs for delivery of the concrete into the forms with rows of doors at three levels between these chutes for access and operation of vibrators in placing the concrete. Concrete was delivered to these chutes by a power-driven hopper car operated on a track along the top of the form. A second type used the three rows of access doors but replaced the fixed chutes with movable chutes delivering through the access doors. The chutes were either supported by trolleys operating on a steel rail along the top of the form or by a gantry moving back and forth along the length of the pour. This gantry also supported the hopper car for distributing the concrete to either side of the form.

A third type of the outside forms, and the last developed, had exterior stiffening trusses which provided greater rigidity in maintaining the forms in proper shape and alignment without the use of tie bolts between the inside and outside forms. With this arrangement the top eight feet of the form on each side was hinged so it could be opened out to facilitate the introduction of the concrete into the forms. This type required only one row of access doors about four feet above the invert. Articulated closed chutes supported on the stiffening truss delivered the concrete into the forms from a hopper car travelling on top of the form trusses. As the concrete raised in the forms, sections of the chutes were removed and when the concrete reached the hinge, the top sections of the form were lowered into final position and the balance of the pour was made through the top opening in the forms which was about six feet wide on all of the forms.

Steel girders or fillers were used between sections of both the inside and outside forms for construction on curves.

The outside forms were moved, two or three plates at a time, by means of an overhead gantry which was provided with hydraulic or screw jacks for raising and lowering the forms. This gantry, self-propelled, travelled on steel rails laid along the edges of the invert. The inside forms were moved by a jumbo, or form carrier, which travelled on a track laid on the finished invert. This carrier was provided with hydraulic jacks for raising and lowering the forms and ratchet arms, or hydraulic jacks, for collapsing and setting the wings or aprons of the form.

Equipment for mixing of concrete was about equally divided between transit mixers and paying mixers. The transit mixers, which were of four cubic yard capacity, were charged at the batching plant and mixed en route to the forms.

The invert was placed from three to seven days ahead of the arch to insure sufficient strength in the invert concrete to support the weight of the arch forms and concrete. Concrete delivered to the invert subgrade was vibrated and then screeded to the required section by a slip-form.

All arch concrete was adequately vibrated with either electric or pneumatically operated vibrators. The invert and outside of the arch were protected with two coats of coal tar sealing compound, followed by a coat of whitewash, for curing. The invert shoulders were kept wet until the placing of the arch and the inside of the arch was water cured for 14 days.

The use of steel forms providing for rapid moving and setting, and facility in the placing of the concrete, and the adoption of standard equipment for efficient use on the conduit construction resulted in rapid progress and excellent workmanship at an economical cost.

(January 25, 1939)
CROSSING ROUGH COUNTRY

Monolithic siphon construction on the main aqueduct. This particular siphon section has an inside diameter of 12 feet 4 inches. The main line of the Colorado River Aqueduct includes 144 separate inverted siphons which vary in length from 175 feet to five miles, and have a combined length of approximately 29 miles. These inverted siphons are of three distinct types: single circular barrel, as shown above; double parallel circular barrel; and three-compartment rectangular.
Siphons

Problems Involved and Methods Used in the Construction of the 144 Inverted Siphons on the Main Aqueduct.

By J. B. BOND
Division Engineer, Division 5

On the 242 miles of main aqueduct between the Colorado River and Lake Mathews, 144 inverted siphons are required in crossing drainage channels, ravines and other depressions and to create artificial waterways for cross-drainage in flat country. In length, the individual structures vary from 175 feet to 5 miles. Their combined length is approximately 29 miles, or 12 per cent of the total distance along the aqueduct from intake to terminus. These siphons are all of reinforced concrete construction with operating heads varying from about 9 to 138 feet. The structures are of three distinct types: single circular barrel, double parallel circular barrel, and three-compartment rectangular.

All siphons are monolithic, except the Little Morongo Canyon crossing where a prefabricated barrel 12 feet in diameter and 660 feet long was constructed as an advance experiment.

The single circular barrel siphons, 16 feet in diameter with designed capacity of 1605 second feet, are used where short low-head structures are required in crossing drainage channels between tunnels and cut-and-cover conduit. Eleven of this type, with a combined length of slightly less than 0.9 of a mile and single lengths varying from 175 to 435 feet, were constructed. The additional cost of the complicated transition structures at each end of the double barrel siphons overbalances the cost of the full-capacity single barrel structure where the crossing is short and the head is low.

All of the long high-head siphons are the double barrel type. In numbers they represent about 39 per cent of all of the main aqueduct siphons. In length they cover 80 per cent of the structures required for crossing drainage channels or other depressions. Only one barrel with a capacity of 806 second feet is being constructed at the present time; the second barrel is to be added when the demand for water justifies the additional expenditure.

In the desert section where the aqueduct traverses smooth, gently sloping alluvial areas, the construction of open lined canal is desirable from an economic standpoint. The precipitation in this region is scant. Many months may pass without measurable rainfall. When storms do come, they are often in the form of cloudbursts. There are few well-defined drainage channels across the even slopes. The storm runoff escapes in the form of sheet drainage, carrying with it large volumes of sand, gravel, and desert vegetation. Without adequate protection, the open canal which runs transversely to this storm flow would quickly fill with debris. This protection has been supplied by short box siphons dipping beneath artificial waterways, spaced along the canal at intervals determined by the character and the size of the area contributing to the runoff.

The three-compartment rectangular siphons were built as a single unit between sections of open lined canal. Each barrel has a rated capacity of 335 second-feet. The three barrels are designed to carry the total canal flow of 1605 cubic feet per second. In length the 81 box siphons total 5 miles; individual structures vary from 260 to 610 feet. All operate under very low heads.

The construction of the single barrel circular and rectangular box siphons did not involve any unusual problems. The short low-head structures were for the most part located on smooth ground. The excavation was in dry, firm material which did not require special treatment to form a suitable foundation.

After extensive studies, the economical size for the two parallel circular barrel type of siphons was determined to be 12 ft. 9 in. and 12 ft. 4 in. The first mentioned diameter was used in crossing drainage channels and depressions between sections of canal where on account of the required length and head the construction of a rectangular box type structure was too costly. The 12 ft. 4 in. diameter barrels were placed between conduit or tunnel sections. Two departures were made from the standard sizes. The 660-foot precast siphon installed for experimental purposes at Little Morongo Canyon crossing has an inside diameter of 12 feet. On this type of construction an exceptionally smooth surface can be obtained which justifies the use of a lower coefficient of roughness.

Between Whitewater Tunnels Nos. 1 and 2, the monolithic siphon has a diameter of 11 ft. 5 in. At this point, aqueduct location made it advisable to introduce additional slope in the structure thus permitting a decrease in the size of the barrel.

Some of the problems encountered in the design and construction of the two parallel circular barrel type of siphons were: steep rough ground; crossing earthquake faults classed as active; and preparing a stable foundation on soft yielding ground.

In crossing canyons and washes, several of the double barrel siphons were constructed on very steep, rough slopes. As a rule, the difficult sections were short and did not require unusual type of anchorage or placing equipment. An exception to this is the Eagle Mountain siphon which is located on very rough terrain for the entire 1439 feet of its length. On account of the steep and broken character of the ground, the trench excavated for the siphon was inaccessible to trucks or mobile equipment. A portion of the barrel was laid on an incline of 25 degrees. The contractor tackled the job by installing a cableway to handle forms, reinforcing steel, concrete, and other materials and supplies.

The slope of the Eagle Mountain siphon was steep enough to require some means of holding the reinforcing steel in place. This was accomplished by diagonal anchor bars wired to the hoops. In addition, it was necessary to extend a cable from the reinforcing to an anchor placed on the slope above.

Three earthquake faults classed as active are crossed by Big Morongo, San Andreas, and Casa Loma siphons. To provide flexibility and to confine the damage to a short section should an actual rupture occur in these three siphons with respective lengths of 6411, 3400, and 26315 feet, the monolithic construction was broken at about 20-foot intervals by joints capable of transmitting shear but no tension. To provide for possible vertical displacement of the ground, an additional drop of 2.5 feet over that required by siphon losses was provided at each of the above structures.

Casa Loma siphon extends across San Jacinto Valley for a distance of about 5 miles. In many sections of this stretch ground water stands within a few feet of the surface. Considerable water was encountered during siphon excavation. For about 30 percent of the length of the structure, the material at subgrade was soft and yielding. The foundation was made stable by excavating from one to three feet below the established grade and filling this space with crushed rock, thoroughly compacted. Water was held below the foundation by pumping until concrete was placed.

In the long circular siphons, manholes for access to the interior of the barrel were located at regular intervals and blowoff structures with valves were built at low points to permit draining. Air release and vacuum valves are installed on high points of siphons.

The concrete per linear foot, including transitions and structures, averages 1.95 cubic yards in the 12-foot 4-inch circular, 3.3 in the box, and 3.37 in the 16-foot circular siphons.

(January 25, 1939)
SAN JACINTO TUNNEL IS HOLED THROUGH

The final holing through of the 13-mile San Jacinto Tunnel. This tunnel became famous because of the tremendous amount of underground water that was encountered during its construction, and it is said to have been the most difficult tunnel that has ever been driven. The San Jacinto Tunnel, however, is but one of 42 separate tunnels on the Colorado River Aqueduct.
Tunnels

Problems Involved and Methods Used in the Construction of the 92.09 Miles of Tunnels on the Main Aqueduct.

By J. L. BURKHOLDER
Assistant General Manager

Twenty-nine tunnels varying in length from 338 to 96,605 feet comprise the 92.09 miles of tunnel on the main aqueduct. Of this total, contracts were awarded for 58.35 mi. and 33.74 mi. was scheduled for construction by District forces. The contractor on the 13.04 mi. San Jacinto tunnel, after having excavated 2.37 mi., was seriously behind his program and completion of this work was added to the District's force account program.

The District awarded contracts for the 58.35 mi. of tunnel to thirteen well-known contractors from various parts of the United States. With the exception of the San Jacinto tunnel (holed through Nov. 19, 1938) all tunnels were completed by July, 1937, well in advance of schedule. Tunnel driving was carried on from 60 headings.

With the exception of the tertiary sediments, characteristic of the Whipple Mountain range near the Colorado River, which required very little support, all other formations penetrated required support varying from 25 to 100 per cent of the length. The granite formations were found to be loosely jointed and to have a tendency to air slack when exposed. The metamorphic rocks were normally closely fractured and most of the "heavy ground" was encountered in these materials. The gravels and other alluvial materials required support throughout, but were usually coherent enough to permit excavating without spiling or breastboarding.

Numerous dead faults were encountered with crushed zones varying from a few inches to several hundred feet wide. These zones usually required heavy support and enlargement of the section for extra heavy lining. In the dry tunnels it was unusual to find fault zones extremely difficult. In wet tunnels, however, notably the San Jacinto and the Val Verde, water encountered in open seams and in crushed areas gave rise to difficulties that seriously impeded progress.

In driving 71.85 mi. of "dry" tunnels, the outstanding over-all average progress of 7.04 ft. per shift or 21.12 ft. per day was attained with maximum monthly advances as high as 1,101 ft.

Plant units that were of material aid in attaining this excellent progress were: (1) well designed drill carriages planned to facilitate full-face driving; (2) improved mucking equipment, used in conjunction with large capacity cars and time-saving switching devices; (3) automatic feed drills with longer carriages (30 in.) requiring fewer changes of steel; (4) improved ventilating plants; and (5) the use of standby units to prevent loss of time due to equipment breakdowns.

As an average, each round blasted out of the tunnel headings yielded an advance of 7.3 ft. The average shift per heading required for the various surface and underground operations connected with tunnel excavation numbered 27 men.

Typical drill carriages provided two decks from which the drillers, by use of swivelled arms and columns supported at the front end of the carriage, spaced and directed drill holes to conform to adopted blasting rounds. From five to eleven drills were thus mounted as required by the rock conditions; to drill 25 to 80 holes. The pipe framework of the carriage was used for delivery of air and water to facilitate speedy connections to each drill. The old screw-feed type drills were not used; instead, automatic feed, and pneumatic drills were standard equipment because they gave the advantage of constant pressure on the bit, thus permitting maximum drilling speed.

Blasting was done with 40 to 60 per cent gelatin powder (using 1/2 x 12 in. cartridges in distinctive red wrappings) of which an average of 2.7 lb. per cu. yd. of solid rock was used. Some rock required as much as 7 lb. per cu. yd. The powder was detonated electrically from a 440-volt circuit used exclusively for this purpose.

Mucking machines of two types were used: the shovel type and the conveyor type. The latter greatly predominated, although there were five 3/4-yd. crawler-mounted shovels which had been especially designed for this work.

Because mucking machine operation is so frequently interrupted by the switching of muck cars, tunnel men were continually trying to save time by improving the ear switching devices. Many new ideas were tried out in the course of this work but the well-known California type switch was the most successful because of its simplicity.

Tunnel tracks built to 36-in. gauge with 40-lb. rails were adopted as standard. Traffic protection was provided by automatic or hand-operated block signals at intersections and control points. Power units for haulage were 8-ton battery or trolley type electric locomotives. The all-metal side-dump cars, of either the Western or mine type, were used with capacities of 4 to 6 cu. yd. Excellent ventilation was maintained by surface-operated fans (arranged to exhaust or to blow) through 22-in. metal pipe.

With 62 per cent of the tunnels requiring temporary support, three types were used to suit varying conditions: timber, metal-lagged steel and timber-lagged steel. Shotcrete was put on extensively to prevent air slacking and spalling of the rock; its early application to walls and arch often saved the cost of more expensive supports.

The metal-lagged steel support consisted of arch ribs supported on wall beams and columns and lagged with pressed steel liner plates bolted to the ribs. In this combination costs were high for both material and labor. Early experiments made by the District led to development of an independent steel rib type of support which effected savings in time and cost. This support, which became standard for the job, consists of two-segment I-beam ribs rolled to proper shape and bolted together at the arch center. Steel rods and timber collar braces were used to bind the sets together.

In most of the tunnels concrete lining was placed by the continuous pour method, utilizing 200 ft. of telescoping steel arch forms, moved ahead in 20-ft. sections as the work advanced. Lining was begun at the point farthest removed from the tunnel access and was advanced toward that point. Concrete was pumped or shot through a single pipe and allowed to flow down the form until side slopes of about 3:1 had been built up and the initial section of the form was completely filled. By moving the discharge pipe laterally, concrete was distributed alternately in the side walls of the arch. The important operation of filling the crown was performed by directing the concrete so as to form nearly horizontal shoulders at the quarter points of the arch, and then subjecting the fresh concrete in the crown section to pressure by keeping the end of the discharge pipe well buried.

In this manner, overbroken areas in the crown were filled to heights of 6 ft. or more above the forms. Staggered lines of test holes were drilled in the finished arch to test the filling of voids. Good compaction and smooth surfaces were secured by hand spading the concrete.

Concrete batching plants were located near the tunnel entrance where the weighed materials were placed, dry, in especially designed batch cars for transporting into the tunnel.

(February 25, 1939)
AN AQUEDUCT CANAL SECTION

A concrete lined canal on the main line of the aqueduct filled with Colorado River water on its way to the coastal plain of Southern California. There are approximately 63 miles of lined canals on the aqueduct, all of which are enclosed by steel wire fences. The canals are 55 feet wide at the top, taper down to 20 feet in width at the bottom, and are approximately 12 feet deep. Construction of these canals attracted wide interest because of the many new types of equipment that were especially designed and built for this particular kind of construction work.
Canals

Methods Used in the Construction of the 62.8 Miles of Concrete Lined Canals on the Colorado River Aqueduct

By G. E. ARCHIBALD
Resident Engineer, Division 1

Canal is the oldest and simplest form of man-made waterway, and its construction might well be expected to excite little interest. The construction of 62.8 miles of concrete lined canal for the Colorado River Aqueduct, however, attracted widespread attention because of bold design of special machines, which permitted placing of the canal lining at a rate too high for three times as fast as by any former methods, and with better results.

The Colorado aqueduct lined canal in earth has a finished bottom width of 20 feet, a top width of 35.13 feet and a depth of 11.71 feet. In general, the canal was not set in the ground to full depth, part of the excavated material being used to build an embankment on each side to form the upper part of the canal, similar to familiar irrigation practice. A portion of the excavated material also went to form a dike on the uphill side to protect the canal from storm water. A roadway was constructed on the other side. Where the aqueduct crosses washes which are part of the natural drainage of the country, canal is replaced by closed conduits known as 'siphons' which are constructed below the beds of the washes and do not obstruct the run-off of storm water.

The five firms awarded contracts which included canal construction were: Barrett & Hulp and Macco Corp.; Jahn and Bressi Construction Co.; Wood and Bevanda; Utah Construction Co. and Aqueduct Construction Co. The first canal lining was placed by Wood and Bevanda in January, 1935, and the last by Aqueduct Construction Co. In March, 1937. Activity was at its height on all contracts during the winter of 1935-36, when a practically unbroken line of construction equipment extended from Cooch Mountain to Vidal, and ribbons of concrete crept across the desert as though by magic.

Rough excavation for canal offered no new problems and was particularly suited to the dragline type of excavator. Machines of sizes in common use predominated, with 134 and 2 cubic yard buckets and powered with gas or diesel engines. Usually two of these machines were operated in echelon, each digging one-half of the trench as they progressed.

On each of two of the contracts, however, the bulk of excavation was accomplished by a single electrically driven machine of larger size with 5 cubic yard bucket. Power was transmitted to this machine through 1,000 to 1,500 feet of armored cable from a substation mounted on a trailer and connected directly to the District's 33,000-volt transmission line along the aqueduct right of way. Excavation by dragline was made as close as possible to finished lines since trimming must be done by more expensive methods. A grade man equipped with hand level and rod kept constant check on this condition.

The chief problems confronting the contractor were those of trimming the earth slopes and placing the 6-inch to 8-inch concrete lining accurately to designed lines, and at the same time rapidly and economically. Road grading and paving types of equipment could be used for the bottom of the canal but not for the side slopes. Hand methods were used, but slow and costly. On the other hand, attempts at mechanization meant fairly heavy expenditures for special equipment without certainty of success. As it happened, most of the experiments that were unsuccessful failed because of compromise in design due to efforts to avoid heavy first costs.

Machines were designed, however, which were successful from the outset. The first trimming machine, pioneered by Wood and Bevanda, resembled two ladder-type ditching machines placed back to back, each completely trimming one-half of the bottom and one side wall of the canal as the machine advanced. The whole assembly was supported by a steel bridge, the ends of which rested on railway trucks traveling on rails on each side of the canal. These rails were carefully set to the proper line and grade and controlled the accuracy of the trimming. The machine was driven forward as it excavated by means of power winches operating cables anchored ahead. The excavated material was carried clear of the canal by belt conveyors.

Another type of machine was developed by Jahn and Bressi Construction Company. This machine also had a heavy-trussed steel frame or bridge which traveled on rails on each side of the canal trench. Instead of endless chains of digging buckets, however, it was equipped with buckets similar to that of a road grader, which were lifted, lowered or tilted by an elaborate system of hydraulics and screw jacks. The machine was hauled forward and backward by a tractor in the canal trench, making a light cut on each forward run until the finished grade was reached. The excavated material was pushed to the bottom of the trench by the blades and was carried away by bucket elevators and belt conveyors.

Each of these machines operated satisfactorily and economically. Machines developed by other contractors were built on the grader principle.

Reinforcing steel for the lining was placed by hand — practically the only hand operation entering into the canal construction. The steel was laid on precast concrete blocks placed on the sub-grade.

The type of canal paving machine finally adopted by all of the contractors was also pioneered by Wood and Bevanda. Stripped of operating and auxiliary mechanisms, it was rather more nor less than a giant trowel, formed of steel plates fastened to a heavy steel framework and shaped exactly to the dimensions of the finished lining. This machine traveled on the same tracks as the trimmer and was drawn by winch and cable at the rate of about one foot per minute. Two paver-type concrete mixers fed by a fleet of batch trucks kept pace on the roadway alongside the canal and a gasoline-driven car shuttled back and forth across the deck of the paving machine receiving concrete from the mixers and distributing it along the forward edge of the "trowel." A ribbon of completed lining flowed from under the trailing edge of the machine, requiring in general only finish steel troweling to produce the smooth, hard, water wearing surface desired. Several light wooden frames were usually drawn behind the paving machine to support the concrete finishers on this work.

(February 25, 1939)
HUGE PIPE SECTION ON DISTRIBUTION LINE

A section of precast concrete pipe being lowered into a trench where it became a part of the distribution system of the Colorado River Aqueduct. This particular section of pipe has an inside diameter of 10 feet 3 inches. Other sections of this line have inside diameters as great as 12 feet 8 inches. Some of these huge sections of pipe, which were 12 feet in length, weighed as much as 42 tons.
Distribution

Problems Involved and Methods Used in Construction of Distributing Works of the Colorado River Aqueduct.

By R. B. DIEMER
Distribution Engineer

The main aqueduct of the Metropolitan Water District has been designed and constructed to provide an unyielding supply of water from the Colorado River for use in the Coastal Plain of Southern California to supplement the supplies obtained from present sources. The aqueduct terminates at Lake Mathews, situated ten miles southwest of Riverside and near the easterly edge of the Coastal Plain. In order to provide for delivery of Colorado River water to service areas within the Coastal Plain a distribution system has been designed and is being constructed, leading westerly from Lake Mathews.

The primary purpose of this distribution system is to meet the needs of the present thirteen member cities in the District. However, as it is expected that additional areas and cities will join the District from time to time, and since the growth in water demand cannot be definitely predetermined as to time and location, it has been deemed advisable to keep the development of the distribution system as flexible as economically feasible in order to meet the needs for additional water supply when and where they may develop. This is to be accomplished by means of construction in progressive stages, providing an initial system to serve the requirements of all of the present members for a few years and later constructing such additional features as may be required, until delivery of the full 1500 second-foot capacity of the main aqueduct is taken care of. Water is to be delivered to the member cities in wholesale quantities with distribution to individual users to be made by the various city water departments.

There are many design and construction problems encountered on the distribution system which are not involved on the main aqueduct. While the main aqueduct will deliver water at a fairly constant rate to one point, Lake Mathews, the distribution system will deliver water under pressure to meet the varying requirements of thirteen cities, all at different elevational zones, and of such potential areas as may join the District in the future. On the distribution system numerous right-of-way and construction problems are encountered as a result of the high development in the areas through which most of the features are located.

Terminal Storage

As the construction of the Lake Mathews reservoir is to be covered in a separate article, little space will be devoted here to this feature. Briefly, the present construction at this site provides for a storage capacity of approximately 100,000 acre feet, with the works so designed and constructed as to be suitable for future enlargement up to an ultimate capacity of about 225,000 acre feet. The principal construction features include an earth dam across Cajalco Creek, an earth dike along the northerly rim of the reservoir, a diversion tunnel around the site of the dam, an outlet tower, and an outlet tunnel leading to the headworks of the distribution system. The outlet tunnel has a finished diameter of 14 feet and sufficient capacity to take care of the ultimate needs of the distribution system.

In addition to Lake Mathews, the principal features of the initial distribution system consist of a high line from the lake to Eagle Rock, known as the upper feeder, a main cross feeder extending southerly from the upper feeder at Eagle Rock together with laterals and an operative reservoir, a line to Orange County, and a lateral from the upper feeder westerly to Glendale and Burbank. Beverly Hills and Santa Monica are to be served by a pipe line extending southward from the Glendale-Burbank feeder.

In order to have a substantial amount of storage on the distribution system closer to the points of use than Lake Mathews, the District has entered into a contract with the City of Pasadena to acquire Morris reservoir in San Gabriel Canyon. This reservoir, which has a net storage capacity of 88,000 acre feet, will be connected to the upper feeder.

Headworks for the distribution system have been constructed adjacent to the north portal of the Lake Mathews outlet tunnel. Although the initial purpose of these headworks is to regulate withdrawals from the reservoir into the upper feeder by means of valves and a small forebay, provision is being made at small cost for a future extension to a lower feeder to extend westerly from Lake Mathews. Hydraulic head in the reservoir in excess of that required in the upper feeder will be dissipated at valves in the headworks.

Upper Feeder

The upper feeder, which is now completed, has a capacity of 750 c.f.s. from Lake Mathews to San Dimas, a takeout point for a future auxiliary line to the central portion of Los Angeles, and 510 c.f.s. from San Dimas to Eagle Rock. Full flow hydraulic grade elevations range from 1280 at the headworks to 940 at Eagle Rock, and all of the line is designed to operate under pressure. The feeder consists of 10.3 miles of welded steel pipe, with diameters from 9 feet 8 inches to 11 feet 6 inches; 35.7 miles of prestressed concrete pipe with diameters from 9 feet 8 inches to 12 feet 8 inches; 0.023 mile of cast-in-place concrete siphons 10 feet and 7 feet in diameter; and 15.7 miles of circular pressure tunnels, mostly 10 feet in diameter. All construction work on this line was done under contracts.

Most of the pipe line portion of the upper feeder traverses highly developed areas where right-of-way was expensive and numerous improvements were encountered. In general where the line passed through private property, easements were taken to avoid the excessive severance damages appurtenant to fee purchase, and the lines were buried a minimum of 4 feet below the ground surface for protection against erosion and to permit owners to use the ground for agricultural purposes after the construction work had been completed. The easements through cultivated areas provided for the replacement of three feet of topsoil.

Steel Pipe

Steel pipe is used on the upper feeder for the high head siphon extending north across the Santa Ana River from a point two miles south of Arlington to a point in the Jurupa Hills, a distance of 10.3 miles. Hydraulic head on this siphon will range from 20 to 485 feet. This stretch of steel line was constructed under one contract.

The line crosses the Santa Ana River on a bridge composed of eight 50-foot approach spans, and three 181-foot steel truss bridge spans supported by piers 43 feet high with footings varying in depth from 30 to 50 feet. Due to the conservative design and construction of the bridge no damage was caused by the disastrous flood of March 2, 1938.

Steel pipe was fabricated at the contractor's plant in Los Angeles in sections 33 feet 4 inches long from plates 100 inches wide and varying in thickness from 17/32 to 31/32 inch. All shop joints and seams were butt-welded using automatic electric machines. Where plate thickness exceeded 5/8-inch the welded pipe was placed in a closed furnace and annealed to eliminate welding stresses. Upon completion, each section was tested hydraulically to a stress of 22,000 lbs.
per square inch which is approximately 150 per cent of the working stress.

**Steel Pipe Coating**

For protection against corrosion, the pipe was given a 3/32-inch coating of coal tar enamel on the inside and a 3/4-inch outside coating of gunite reinforced with steel wire mesh. Where very corrosive soil conditions existed, an outside coating of coal tar enamel was also used underneath the gunite. For best results in obtaining a bond between the enamel and the steel, it was found necessary to preheat the pipe to a temperature of about 190°F for the enameling operation. All enameled surfaces, both inside and outside, were carefully inspected for imperfections by means of an electrical detector.

After the enameling had been completed in the Los Angeles plant, the fabricated pipe sections were shipped by rail to a centrally located field plant, near the trench, where the gunite coating was applied and cured for seven days. In curing the gunite a water spray was used for a period of 4 to 8 hours, after which two coats of coal tar cut-back were sprayed on, and covered with whitewash for temperature control. An exterior coating of whitewash for temperature control also was used when the enameled pipe was shipped from Los Angeles to the field.

A specially designed tractor gantry handled the pipe in the field yard. This gantry was very mobile and did not require the use of tracks. The gunited pipe sections weighing from 18 to 30 tons were transported from the field yard to the trench side on trucks constructed especially for this purpose, and were unloaded from the tracks and placed in the trench by a heavy duty crawler-type crane which traveled along the roadway beside the trench.

All field joints were lap welded with portable arc welding machines. Each welded joint was tested by forcing a soap solution under 100 pounds pressure into the space between the inside and outside welds. After this test, the enamel and gunite coatings were completed at the joints, and the pipe was backfilled by puddling.

Good progress was made on the installation of the steel pipe. Average daily advance using about twenty welding machines was six pipe sections or 200 linear feet.

**Precast Concrete Pipe**

The precast concrete pipe portions of the upper feeder were constructed by three separate contractors under a total of five contracts, varying in length from 4.5 to 11 miles. Nine and a half miles of line with hydraulic heads under 75 feet were built with bell and spigot mortar type joints, while 26 miles were built with steel and lead lock joints. All precast concrete pipe was cast in sections 12 feet long. Heads range from 25 to 290 feet.

Reinforcement was computed for a combination of external and internal loading. For heads less than 80 feet, a combination of circular and elliptical bar cages was used. For greater heads, a thin steel cylinder was added to the
was placed per day. In general, concrete materials were transported into the tunnels and mixed at the point of placing. As it was not possible to remove lagging and spiling prior to concrete operations in the alluvium, due to danger of caving and runs, voids behind the lagging and spiling were filled with grout after the concrete lining had cured sufficiently.

Excavation in the rock tunnels involved the usual cycle of drilling, blasting, and mucking. In most cases only light support was required, consisting of steel ribs and timber lagging, although timber sets were placed in faulted or soft ground where greater support was required. Average excavation progress in all of the rock tunnels (working three 8-hour shifts) was about 30 feet per day or 800 feet per month for each heading; greatest monthly progress at one heading was 1210 feet in Monrovia No. 3 tunnel east of the adit.

Concrete was placed in the rock tunnels in a manner similar to that employed in the alluvial tunnels, excepting that in Monrovia No. 3 west of the adit, the placing of the invert concrete in advance of that in the sides and arch, with resulting longitudinal construction joints, was permitted in order to take care of the flow of water. Reinforcement steel was used in the concrete lining of the rock tunnels where the depth of cover was less than twice the pressure head, or where soft unstable ground was encountered.

In the westerly 2856 feet of Monrovia No. 4 tunnel, where the hydraulic head will range from 110 to 260 feet, a steel cylinder of 94 to 9.16 inch plates was used for reinforcement and water tightness. This cylinder has 13 inches of concrete behind it, while the inside is lined with a 2-inch coating of gunite to protect the steel and improve flow conditions.

**Auxiliary Structures**

Appurtenant structures required for the satisfactory operation of the line have been installed at various places along the upper feeder. Blow-off facilities have been placed at low points for draining the line when necessary for inspection or maintenance; air and vacuum valves have been installed at high points; outlets have been provided at points convenient for supplying present member cities and probable future service areas; and two major overflow spillway structures have been constructed at drainage channels near points where the upper feeder is reduced in capacity. One of these spillways is situated at the Puddingstone flood control channel near San Dimas, while the other is at the westerly side of the Arroyo Seco. A third spillway is being constructed in San Gabriel Canyon near Morris reservoir.

**Palos Verdes Feeder**

The Palos Verdes cross feeder extending from the upper feeder near Eagle Rock to its regulating reservoir near San Pedro, is being constructed to serve a part of Los Angeles and member cities in the southwestern part of the metropolis area. Appurtenant to this main cross feeder are laterals to Long Beach, Torrance and Compton. All of these lines are of welded steel pipe, coated on the inside with a 3/16-inch thickness of cement mortar, centrifugally applied by a spinning process, and coated on the outside by a 3/16-inch thickness of gunite reinforced with wire mesh. A layer of coal tar enamel is used underneath the external gunite coating where corrosive soils are encountered.

Pipe lengths, sizes and plate thicknesses for the cross feeder and laterals are as follows:

<table>
<thead>
<tr>
<th>Length (Miles)</th>
<th>Dia.</th>
<th>Plate Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eagle Rock to Palos Verdes Reservoir</td>
<td>25.1</td>
<td>31&quot;</td>
</tr>
<tr>
<td>Long Beach Lateral</td>
<td>4.7</td>
<td>31&quot;</td>
</tr>
<tr>
<td>Torrance Lateral</td>
<td>1.2</td>
<td>31&quot;</td>
</tr>
<tr>
<td>Compton Lateral</td>
<td>1.3</td>
<td>31&quot;</td>
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</tbody>
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The maximum normal operating head on the main cross feeder may vary between 340 and 450 feet.

These lines are located to a large extent in city streets. In congested areas excavation is accomplished with a ladder type trenching machine producing vertical trench walls which generally require sheeting. In open, undeveloped areas trenches are excavated by dragnie. Work on these city lines is hampered by restricted working space, urban traffic, and the necessity of avoiding or moving previously installed utilities.

To prevent deflection of the pipe and cracking of the mortar lining as a result of the heavy load of unconsolidated backfill, temporary steel bulkheads are placed at each manhole, about 1,000 feet apart, and the pipe line maintained full of water under pressure during the backfilling operations, and thereafter until the backfill becomes consolidated.

**Palos Verdes Reservoir**

The Palos Verdes reservoir site is in the Palos Verdes Hills west of San Pedro, at the end of the cross feeder. At this location, a small and irregular natural basin is being enlarged and impounded in shape by excavation. The excavated material is used to close the outlet from the basin and to construct compacted embankments which will increase the capacity. The entire surface of the reservoir is to be lined with 2 inches of reinforced gunite. The reservoir will have a capacity of 1000 acre feet, a water surface of 28 acres, and a maximum water depth of 50 feet. Structures appurtenant to the reservoir are an inlet and outlet tunnel, an outlet tower, and a storm water drain around the site.

(March 25, 1930)
FABRICATING A STEEL PIPE SECTION

Plate steel (1) is delivered in paper wrapping from eastern mills; heavy rollers (2) form it into cylinders; and the center seam is hand welded (3) to complete the circle. A steel cage of reinforcing bars is wrapped around the cylinder (4); which is then upended in a steel form (5) and the seven-inch wall of concrete is poured. M.W.D. Inspector (6) makes a final check.
COPPER BASIN DAM

Blocking a deep narrow outlet in Copper Basin, this dam creates a beautiful reservoir of blue water in the heart of the desert. The Copper Basin Reservoir is one of two operating reservoirs located near the aqueduct’s intake on the Colorado River. The dam shown in this picture reaches into the air 210 feet above the desert floor. More than 250 feet long at its crest, the base of the canyon that it blocks is less than 20 feet in width.
Reservoirs

Problems Involved in Construction of Gene Wash and Copper Basin Reservoirs.

By W. E. WHITIERT
Division Engineer, Division 1

Gene Wash and Copper Basin reservoirs, located near the Colorado River, serve to regulate and equalize the discharges from the Intake and Gene pump lifts and to remove any small amount of silt that may result from local flood flows into Parker reservoir.

Preliminary topographic surveys of both reservoirs, including alternative dam sites, were completed in 1930 to a scale of 1 inch equal 1,000 feet. After more detailed study of possible locations for the two dams, additional topography was taken on a scale of 1 inch equals 20 feet to permit final fixing of the locations of the dams and to furnish data for arch analysis and calculation of contract quantities. This work, which was started November 2, 1936, and was completed December 8, 1936, proved extremely hazardous, due to the precipitous side walls of the canyons. It was necessary to erect a cable line across each canyon, from which men could be suspended on bosun's chairs to paint and number. The position and elevation of each of these points was then determined by cutting them in with transit set up at previously established points of control. The locations and elevations of the painted points were plotted to scale and five-foot contours sketched in.

The contract for the construction of the two dams and their appurtenant works was awarded to J. F. Shea Co., Inc., March 26, 1937, construction started March 29, 1937, and was completed August 15, 1938, with the exception of cooling the concrete and grouting the contraction joints of Copper Basin dam. This work was done by District forces after the return of cool weather.

At the time the contract was let there were no suitable construction roads to the various features of the work except the District highway from Earp, California, to Division No. 1, and the contractor was forced to undertake the widening and straightening of about 10 miles of old survey trails and prospectors' roads to facilitate the transportation of construction material and equipment.

At Gene Wash dam good rock was encountered at about 7 feet below the natural stream bed. The side wall abutments were stripped an average of 16 feet of rock normal to the original ground surface. At Copper Basin dam good rock was found at 23 feet below the natural stream bed. The side wall abutment stripping averaged about 20 feet.

Mass concrete for the two thin arch dams and two spillways was started October 24, 1937, and completed April 29, 1938. Approximately 40,000 cubic yards was placed at an average rate of about 6,400 cubic yards per month. In each dam concrete was placed in vertical blocks about 50 feet in length along the axis of the dam. Vertical keyways were provided at the radial joints between blocks. Concrete in the blocks was generally placed in five-foot lifts, but some ten-foot lifts were placed in the Copper Basin dam. The top of each lift was cleaned with an air-water jet under a pressure sufficient to remove laitance at a time between the initial set and final set when the cement film can be washed clean from aggregate without damage to the surface. At first these horizontal contraction joints were cured by being kept wet under heavy water-soaked burlap. This practice was later discontinued in favor of covering the top of the lift with a layer of wet sand about 1/4 of an inch in thickness. Wet sand was adopted in place of burlap in order to prevent the fine red-brown dust, produced by evaporation of the red-brown country rock, from passing through the burlap and staining the surface of the concrete. The sand was a decided improvement over the burlap, as it prevented the undesirable red stain and kept the concrete surface more uniformly wet with less labor; and, in effect, gave the surface an additional clean-up when the sand blanket was removed.

Concrete aggregate was obtained at the Parker dam aggregate plant, located in the valley of Bill Williams River on the Arizona side of the Colorado River, hauled to the site where cement was added, mixed in a one-yard paver at Gene Wash dam and a two-yard stationary mixer at Copper Basin dam, and transported from the mixer to the point of placement in 2-cubic yard bottom dump buckets by high line cable ways.

The mass concrete was cooled to an average temperature of about 50 degrees Fahrenheit by pumping refrigerated water through 1-inch diameter thin-walled steel cooling coils located in a horizontal position at 5-foot vertical intervals throughout the mass. After the concrete had been cooled to the desired temperature, water under pressure was introduced into the contraction joints in order to separate the blocks slightly and allow free passage of the cement grout when applied. When all joints were known to be free, batches of approximately 2 cubic feet of cement grout, composed of 1 part of cement to 1 part water, were injected into all adjacent joints from the bottom of the dam upwards and from abutment to abutment in rotation, so that the level of the grout in joints was maintained at the same elevation at all times. As the grout entered the joints the pressure was gradually increased in the lower grout lifts as the upper lifts were being filled. The pressures were finally raised to about 65 pounds per square inch at the bottom of the dam and 25 pounds at the crest. These pressures were maintained for one hour, when grouting was considered complete. As some radial and axial deflection was expected in the dam as pressure grout was introduced into the contraction joints, arrangements were made to record even the slightest movements. The radial deflection was found to be zero and the axial deflection to be only one-hundredth of a foot.

(April 25, 1939)
BUILDING MATHEWS DAM

Four power shovels were required in the borrow pits to feed the constant stream of trucks which carried material to the earth-fill construction of the Mathews dam and dike. This work went ahead twenty-four hours a day, and at times more than 100,000 cubic yards of earth per week were placed and compacted on the structures.
Lake Mathews

Methods Used in the Construction of the Mathews Reservoir.

By R. B. WARD
Resident Engineer, Mathews Dam

Lake Mathews, the main storage unit of the Aqueduct distribution system, is situated between the terminus of the main aqueduct and the head of the distribution lines, about 60 miles easterly from Los Angeles. The purpose of this reservoir is to insure an ample supply of water near the points of use as a safeguard against interruptions of flow through the main aqueduct and to regulate the uniform flow of the aqueduct to meet the fluctuating demands on the distribution system.

In addition to the fact that the site was conveniently located and suitable for the economical creation of a reservoir, another factor influencing the selection of this site was that full development to 225,000 acre feet storage could be accomplished in stages.

The work of forming the reservoir for storing 107,000 acre feet of water was completed in February, 1938. This work was done under one general contract and involved the excavation and lining of a diversion tunnel and an outlet tunnel, the construction of two earth-fill embankments, namely, the main dam across Cajalco Creek and a dike on a low ridge along a portion of the northerly side of the reservoir, and the construction of a spillway and an outlet tower.

The diversion tunnel, which was used as a by-pass for storm water during the construction of the dam, is 9 feet in diameter, 2000 feet long, and lined with concrete having a minimum thickness of 8 inches.

The outlet tunnel through which water will pass to the distribution line is 14 feet in diameter and 2,348 feet long. Lining in the outlet tunnel consists of a welded steel membrane, backed with at least 8 inches of concrete and covered on the inside with a protective coating of 2 inches of gunite reinforced with welded steel mesh.

Mathews dam and dike were constructed of earthy materials thoroughly compacted in layers 6 inches thick and have an 8-inch slab of reinforced concrete on the upstream slope for protection against erosion from wave action.

Before any materials could be placed in either of these embankments, considerable preparatory work was necessary. This work at the site of the dike consisted of clearing and grubbing all trees and other vegetation and then removing from the entire foundation area an average of about 3 feet of top soil material to be redeposited later. This material was not sufficiently dense in its natural state and would have afforded an easy path through which water might escape and possibly impair the safety of the structure. However, most of this material was suitable for use in the compacted embankment after it had been brought up to the proper moisture content. The depths to which it was necessary to take up this top soil material were determined by testing samples taken at various depths from open pit excavations put down at approximately 200-foot intervals over the entire foundation area. As the excavation progressed the depths of excavation were checked, and usually about 10 inches of the material was left on the foundation where it was compacted by rolling 16 times with the sheeps'foot rollers, the same as redeposited or borrow pit materials.

The work preparatory to placing material in the dam embankment was much more extensive than for the dike. First, there was the draining of Holmes Lower Lake; next, the removal and washing of about 27,000 cubic yards of muck from the lake bed; then the removal to bed rock of the remainder of the lake bed material which ranged from 5 to 18 feet in thickness. Considerable of this latter material was suitable for use in the compacted embankment, but some of it contained rocks in quantities and sizes that would interfere with the compacting action of the sheep's-foot rollers. The rocky material was passed over grizzly bars spaced 4 inches apart, and the rocks were then deposited in the pervious section of the dam and the fines were compacted in the rolled section. Excavation for dam foundation in areas other than the lake bed portion consisted of the removal of material to a depth of 4 to 65 feet.

In order to utilize to the best advantage of the District those materials excavated from the dam foundation, 552,000 cubic yards, and also those from the spillway channel, 124,000 cubic yards, it was necessary for an inspector to be present at all times directing the disposal of each truck load. From an economical standpoint, proper utilization and disposition of these materials was one of the most important problems in connection with the construction of Mathews Dam because every cubic yard of earth removed from the dam foundation or spillway channel and used in the rolled fill embankment of the dam meant a direct saving to the District, as such use reduced the amount of material which had to be obtained from borrow pits or quarries at considerably higher unit prices.

Material placed in the embankments other than that obtained from parts of required excavation, was hauled one-half to two and one-half miles from borrow pits located within the reservoir. Excavation in the pits was usually accomplished by four 2½-cubic yard shovels and hauling was done by a fleet of thirty 10-cubic yard trucks equipped with pneumatic tires and using butane fuel.

In general, compaction of the material in the embankments was effected by six 30,000-pound sheep's-foot rollers drawn by tractors. Usually 16 roller trips over each 6-inch layer were necessary to obtain the desired compaction. On parts of the embankment inaccessible to the roller units, pneumatic tools or tampers were used to compact the material.

In order to obtain the desired compaction in the embankment it was essential that the materials contain the proper amount of moisture. The materials were all too dry in their natural condition to use in the embankments and were brought up to approximately the proper moisture content in the borrow pits prior to excavation by means of overhead sprinklers or by flooding small diked areas. Tests for moisture were made prior to any working in the pits and after each wetting; on the subgrade of each layer in the embankment; and after the material had been dumped and spread. Any deficiency in moisture was made up through hoes during excavation and also by sprinkler trucks on the embankment.

Results of the moisture control and compaction were determined by density or unit weight tests. These tests were made at the rate of one to approximately each 1700 cubic yards compacted. The average dry weight of the compacted material in the dam and dike was found to be 126.3 and 121.9 pounds per cubic foot respectively. The effectiveness of the compaction methods employed is indicated by the small amount of settlement which has occurred in the fills. The maximum settlement which has taken place in the dike is 0.10 of a foot and in the dam is 0.25 of a foot.

Means of releasing water from the reservoir into the distribution system was provided by the construction of a reinforced concrete outlet tower, connected directly to the outlet tunnel. The tower is circular in shape, 20 feet inside diameter and 145 feet high. Fifty control valves were installed in the tower at six different levels. These valves are double disc type, 30 inches in diameter and hydraulically operated. (April 25, 1939)
THE FIVE AQUEDUCT PUMPING PLANTS

Upper left, Intake; center left, Gene; center right, Iron Mountain; lower left, Eagle Mountain; lower right, Hayfield. The interesting geometrical design in the upper right is a section of the indirect lighting fixture in the ceiling of the Intake plant control room. Similar fixtures are in all of the plants. These plants will lift a billion gallons of water a day a total of 1617 ft.
Pumping Plants

Problems Involved in the Design and Construction of the Colorado River Aqueduct Pumping Plants.

By J. M. GAYLORD
Chief Electrical Engineer

The water delivered through the Colorado River Aqueduct must be lifted across the divide separating the Colorado River watershed from the coastal plain area where the water is to be used. The total pumping lift is 1617 feet, divided among five pumping plants located at favorable sites along the aqueduct between Parker reservoir on the Colorado River and Shaver's Summit about forty miles east of Indio. In their order beginning at the Colorado River, the average pumping heads at the various plants are as follows: Intake, 294 feet; Gene, 310 feet; Iron Mountain, 46 feet; Eagle Mountain, 440 feet; and Hayfield, 444 feet.

The ultimate quantity of water to be pumped, 1605 cubic feet per second, together with the high lift and the total horsepower requirement of about 375,000, all combine to constitute a pumping problem of greater magnitude than ever heretofore undertaken. There are some existing installations of larger capacity, but for very low lifts; also of high lifts, but of low capacity; and there are in Europe a few single pumping units with both higher heads and capacities. In the United States, however, no pumps have been built which combine the high lift and high capacity required for the aqueduct. It became evident at an early stage in the study of the pumping problem that there were many important questions to be decided, to which theory alone gave inconclusive answers and existing installations offered no satisfactory precedent. Some of the most important problems relating to the pumps were: what was the most suitable size for the individual pumping units; are single stage pumps satisfactory for the higher lifts; what are the proper rotating speeds; what suction conditions will give the best performance and freedom from operating troubles.

The selection of size of pumping unit was governed by the need for adding pumps to the initial installation to meet the growth of water demand, by limitation of practicable motor size, and by economical construction. Considering all factors involved, pumps of 200 cubic feet per second capacity were decided upon, with an initial installation of three such pumps in each plant, similar units to be added as required up to an ultimate of nine pumps per plant.

The other problems in pump selection directly affected the efficiency and station design. The amount of electrical energy to be used was so large that even with the low cost power from Boulder Dam, a small increase in pump efficiency means a very large saving in the District's power bill. The importance of the proper selection of pumping equipment led to the construction of a complete pump testing laboratory at the California Institute of Technology. Experts in hydraulic research from the faculty of the Institute cooperated with the District's staff in the construction of the laboratory and in the testing program. For nearly two years prior to the issue of final pump specifications tests were conducted on models of the various applicable types of centrifugal pumps, covering the entire range of pumping conditions at the various plant locations. Precision instruments for measuring flow, power and pressure were especially constructed for the laboratory work and the test results were of much greater accuracy than would have been possible in any commercial laboratory. Several leading pump manufacturers cooperated with the District in the design of test models and in analyzing the tests.

Specifications for the full sized pumps were based largely on the model tests, and after bids were taken the award of contracts was made contingent on the satisfactory performance in the District laboratory of a model pump submitted by the bidder. After contracts were awarded, each contractor was required to submit for additional laboratory tests a model of the particular pump which he was to build. Each full sized pump will be tested after it is installed, and as a further incentive to the manufacturers the specifications provide for a substantial bonus for any increase in efficiency above the guarantees. It is believed that the knowledge gained from the extensive testing work will result in considerably higher efficiencies than would otherwise be obtained. The first series of models tested showed maximum efficiencies of nearly 89 per cent. The final contractors' models, incorporating improvements suggested by the earlier tests, showed efficiencies as high as 92.5 per cent.

The pump testing laboratory has been used also for the investigation of other hydraulic apparatus. Models of varying pump inlet passages have been studied. Models of the valves used in connection with the pumps were extensively tested to assist in determining the most suitable design and to obtain essential information on throttling effect and the proper timing to be used to limit pressure surges and water hammer when power is shut off.

The electrical system which serves the aqueduct pumping plants is unique and will operate under requirements quite different from those of a commercial power system. The District's generating units at Boulder Dam will not be connected to any other system while they are being used to supply energy to the pumping plants, and the only load other than the pump motors will be a small amount for camp lighting and minor auxiliaries. Thus the usual commercial requirements for extremely close voltage and frequency regulation do not apply to the District system. The main pump motors vary in horsepower rating from 4300 hp at the Iron Mountain plant up to 12,500 hp at the Eagle Mountain and Hayfield plants.

The control system for the motors and auxiliary apparatus is arranged so that each plant can be operated with a small operating crew. The main control room is separated from the plant itself, and the operator stationed there can start and stop the pumps without leaving the room. An annunciator system warns the operator of trouble with any of the apparatus and tells him its location. Meters and dials in the control room keep the operator informed of the operation of the equipment and of the water levels in the aqueduct and reservoirs.

The pumping plant buildings are each built large enough to accommodate five pumping units, of which three have now been installed. For the ultimate nine units to be installed at each plant, the buildings may readily be extended. Foundations and aqueduct connections have been constructed for the ultimate number of pumps. The buildings are all of reinforced concrete and steel construction. The design is simple and pleasing, without undue ornamentation and harmonizes well with the desert country along the aqueduct.

The pumping plant buildings, the outdoor switching stations, the connections to the aqueduct, and the delivery pipes to the top of the pump lifts, and other appurtenant minor structures, were all built by contract. Installation of all pumping machinery, motors, electrical and control equipment was done by District forces. At the present date all construction work on the pumping plant is practically completed and all plants except Hayfield have been put in operation. Pump efficiency tests are in progress and water from the Colorado River is actually on its way to the thirteen cities of the District.

(May 25, 1939)
A TRANSMISSION LINE TOWER

Construction crews erecting one of the tall steel towers on the 237-mile electric power transmission line which carries electric energy from the Boulder Dam power plant to the five Colorado River Aqueduct pumping plants. This transmission line operates at 230,000 volts, and will eventually carry 36 per cent of all the power generated at Boulder Dam.
Transmission System


By VERNE D. ELLIOTT
Engineer, Electrical Division

Electrical energy required for operation of the District pumps is generated at Boulder power house 133 miles distant from the nearest pumping plant. Hence the design and construction of a transmission system to carry 200,000 hp over the desert from the power house to the five pumping plants became one of the jobs to be completed before water could flow through the tunnels, conduits and canals leading from the Colorado River to the Thirteen Golden Cities.

Preliminary engineering studies of this important feature of the aqueduct were begun early in 1932 and actively continued to completion in 1935. During this time a location for the line was chosen and surveyed; a line was designed, specifications prepared, and contracts for material and construction awarded. Actual construction began December 1, 1935, and was completed in September, 1937.

The line extends from Boulder switch rack southerly, roughly parallel to the Colorado River, for a distance of 84 miles to a switching station located 22 miles from Needles on U. S. Highway No. 66. This switching station, known as Camino, is the beginning of the Gene line which extends 60 miles southeasterly to Gene pumping plant. The main Boulder-Hayfield line continues on to Iron Mountain, Eagle, and Hayfield plants. Two hundred and thirty-seven miles of high voltage transmission lines and two miles of medium voltage lines are required to serve the five plants.

Location

The major portion of the transmission lines lies in desert valleys flanked on either side by mountain ranges, but there are notable exceptions to this condition. For three or four miles out of Boulder switch yard the topography is very rugged and rough and about twenty-five miles of the Gene line crosses the eastern slope of the Whipple Mountains. As an aid in selecting the most advantageous location for the line through this mountainous area adjacent to Gene, a reconnaissance flight was made over the country by airplane and photographs of the ground taken from the air.

The Whipple Mountains area presented many obstacles to the location and survey of the line. No roads or trails were available through the most inaccessible portions of the country where the line was to go. During ground reconnaissance of this part of the line, survey crews carried bed rolls, food and water, and camped on the line. Later, "station-wagon trails" were cleared through the washes and along the ridges, enabling the surveyors to drive to points near the work and return to Gene camp at night.

After the exact location of the line had been fixed, "hubs" were set in the ground and "flags" or "signs", erected to mark the alignment. The entire center line was then "chained" and elevations of the ground determined by transit and level. From these field data profiles of the ground surface, one under each wire, were plotted in the office. “Paper locations” for towers were made on these profiles by means of a cellular template shaped to the catenary curve which the wire assumes when hanging in a span. This method of office study, now considered standard for transmission line work, enables the designer to really compare different combinations of tower height and spacing and thus arrive at the lowest cost arrangement which will keep the wires the desired height above the ground.

Another important part of the survey was to determine the location of the line with reference to land parcels, for the purpose of preparing maps and descriptions of the right of way. Measurements were taken from the line to land corners wherever these could be found. A major part of this work consisted of looking for these old corners which were often described in the original land-survey books as stones with identifying notches cut into them, or small pits filled with charcoal and marked with juniper stakes.

In a few instances a careful search of the ground and study of the original notes revealed that no corners had been set and that the notes were a fraud. Except for this condition the stones or charcoal pits were almost always found as described. Marking stakes were usually missing or badly rotted away.

Rights of way over the public domain were secured by filing maps with the Federal Land office, showing the lands desired and requesting their allocation for this purpose. Rights of way over private lands were obtained by securing easements from the land owners.

Road Construction

As soon as the transmission line location had been surveyed through the Whipple Mountains, road-location crews were started through the same area locating and surveying a road to be built for line-construction purposes and to be used later for patrol and maintenance of the line. A mountainous road 17 miles long, characterized by 450 sharp curves, covers the most rugged section of the mountains. This part of the road was built by contract at a total cost of $393,000, including District engineering. One hundred and twenty miles of "single-track", natural surfaced road was constructed by District forces along portions of the line where it traversed relatively flat country. These roads, completed prior to the beginning of line construction, were available to prospective transmission line contractors and were an important factor in securing very favorable bids.

The power to be transmitted to the pumping plants for the initial installation of pumps is 340,000 hp, an amount sufficient to supply the electrical needs of one-half of the homes in the City of Los Angeles. Many types of construction were studied but the design chosen for the main line was one utilizing steel towers and steel reinforced aluminum conductor operating at 230,000 volts. From Gene pumping plant to Intake plant, power is transmitted over a double-circuit 69,000-volt line with copper conductors. For about ten miles north of Iron Mountain pumping plant, the 250-kv line is subject to severe corona conditions caused by alkaline dust in the air and salts in the bed of Danby Dry Lake. In this section hollow stranded copper conductors were used, and tower footings were especially designed to resist corrosion. Wood piling, thoroughly impregnated with creosote, was utilized as a foundation for twenty-six towers crossing this area. Treated wood was the only material that did not show deterioration from the action of the alkaline salts. Three twenty-five foot piles were driven into the ground for each of the four legs of the tower. The three piles were tied together at the top with a reinforced concrete cap. The cap rests on a concrete sub-base which has a layer of bitumen mixture similar to road pavement above and below it. This asphaltic material is intended to prevent creepage of the salts up through the concrete to the steel, which is about two feet above ground. In all other parts of the line the tower foundations are composed of large steel members encased in reinforced concrete.

Steel Towers

The towers are of galvanized steel. The standard tower is 82 feet high and 23 by 26 feet at the base. The point of conductor support is 72½ feet from the ground. The type and design of tower finally chosen was determined from the
results of many months of engineering study and by comparison of prices quoted by various manufacturers. It was gratifying therefore, but not surprising, when tests of the completed tower proved the design to be adequate and efficient. Towers were fabricated at the Bethlehem Steel shop in South San Francisco and shipped direct to the job in carload lots. The total weight of tower steel was nearly 12,000,000 pounds.

The structural design of towers followed conservative and proven practice. Various conditions to be met throughout the line made it economical to utilize five different classes of towers. Each class is of a strength and weight adapted to the stresses to be met. By limiting the number of types of towers, a reasonably close fit to the varying field conditions was economically maintained. The standard, or “S” type is most prevalent and was used on straight line and for turning very small angles. The “A” type, slightly heavier, permitted angles up to 10 degrees; another known as “R” and very much heavier was used at railroad crossings. The “D”, about the same weight as the “R”, was used for heavy angles and at terminals of the line. Still another type, the “H”, provided the necessary electrical clearance between tower and wires in the alkaline dust sections of the line where longer strings of insulators were used.

Towers were so designed that the lower portion of any or all of the four legs could be constructed 3 or 6 feet shorter than normal as required by the topography. Also extensions could be added under “S” and “A” towers which added 6, 12, 18 or 24 feet to the normal legs. The upper part of the tower, (approximately 3/4) called the constant portion, was not affected by differences in the lower part.

Electrical Conductor

Extensive studies were made and actual bid prices compared for various types of electrical conductor. Steel-reinforced aluminum was chosen as the most economical and best adapted for the purpose, except on the 10 miles of line previously referred to where corrosive dust conditions influenced the decision to use the more expensive conductor. The aluminum conductor manufactured by The Aluminum Company of America is composed of 26 strands of pure aluminum around a seven-strand galvanized steel core. The diameter of the core is 0.4 of an inch and that of the complete cable 1.1 inches. The weight is 1.093 pounds per foot.

The operating voltage of 230,000 requires a conductor with a minimum outside diameter of approximately one inch in order to keep the corona or electrical stress around the wire within the limit of good engineering practice. The aluminum conductor easily meets this requirement, but a one-inch copper conductor which does not contain more material than needed to carry the current must be hollow; that is, have air space inside. This problem has been met in different ways by different manufacturers. One manufacturer offered a cable made up of small strands of solid copper wire and strands of copper tubing like spaghetti. Another offered a more or less flexible copper tube formed by interlocking spiral segments. Still another offered a conductor with a twisted copper 1-beam supporting core upon which were stranded two layers of small solid copper wire. A sample of each of these conductors several thousand feet long was installed upon towers of the Southern California Edison Company under supervision of District engineers with erection conditions and mechanical performance under careful observation. All these types appeared acceptable and prices were approx-1.004 inches whereas that of a solid copper wire with the same amount of material would be only 3/4 of an inch. The weight is 1.6 pounds per foot.

Insulators

The only type of insulator suitable for service on a line of this class is that known as the suspension insulator. This is composed of several units linked together into a string which suspends the conductor from the cross arm of the tower. This type of insulator, as designed and built by several manufacturers, was given electrical and mechanical tests at the high-voltage laboratory of the California Institute of Technology.

Insulator units are of the “cap and pin” type and consist of a metal cap and pin separated by a porcelain insulator. Except at heavy angles, line terminals and points where the conductor tension is changed, conductors are supported from the tower cross arm by a single string of insulators, composed of 13 units. This string is about six feet long. On a few miles of line where additional insulation is required, two or four units are added to each string. On the “D” type towers where wires are “dead-ended,” the insulators hold the entire pull of the wire and two parallel strings are required. These lie out in a horizontal position from the cross arm in line with the conductor.

The District furnished towers, conductors, insulators, and cement to Contractor Fritz Ziebarth who constructed the 13.6 kv line. The 60-kv line from Gene to Intake was constructed by Dist. forces.

Line Construction

Hauling of construction material from railhead to the job was an important part of the contractor’s work. The average haul was 24 miles and the maximum 60 miles. Holes for tower footings were dug by hand methods in all but 60 miles of line where a gasoline engine driven excavator was used. This excavator was fairly successful in ground not too hard or too rocky. Footings were set in position in the holes and surrounded by a steel form into which concrete was poured from wheelbarrows. After the concrete had set, forms were removed and a coating of an asphaltic compound applied to prevent rapid evaporation of water while curing. Earth was backfilled and firmly tamped around the concrete, which was then allowed to harden for a minimum of 21 days before tower erection.

The lower panels and a few other parts of the towers were assembled on the ground and raised to position as a unit, but the main portion of the steel was put together piece by piece in the
The work was specialized and divided between two crews. One worked mostly on the ground and erected legs and extensions. The other erected the tower proper. A good ground crew of 8 men completed an average of 4 locations per day under ordinary conditions. A good day’s work for a tower crew of 12 men was 2½ standard towers.

Aluminum conductor was shipped on reels containing approximately 4000-ft. lengths. These reels were distributed along the line at appropriate locations and mounted on a spindle or shaft through the center, which permitted them to revolve during the stringing operation. The cable was pulled from the reels by a caterpillar tractor. As each tower was reached it was threaded through large roller-bearing sheaves attached to the bottom of the insulator strings. Ordinarily three reel lengths were pulled out and spliced together before pulling to final tension. Conductors were installed with a tension of about 7500 pounds at ordinary temperatures. The maximum tension will be 9,000 pounds if conditions assumed in the design are encountered; namely, a temperature of 25 deg. F. and a wind blowing 60 miles per hour. The breaking strength of the cable is 31,000 lbs.

The guiding thought during design and construction of the transmission line was to build a line which would be as permanent as the rest of the aqueduct, but which would be low in cost.

The result of this effort is a transmission system embodying conservative, proved features, designed to withstand weather conditions more severe than any of record in the territory, which was completed at a total cost of $2,423,000. This is equivalent to $10,000 per mile of 230-kv tower line and includes not only the main line construction, but all engineering, rights of way, road construction, the 69-kv line, telephone line, and switching station with patrol headquarters at Camino. So far as is known this is the lowest cost for which a system of this character and capacity has ever been constructed.

**Telephone Line**

During the transmission line survey period a telephone line location and survey was also made from Boulder to Iron Mountain. Construction began December 10, 1935, and was completed May 27, 1936. It was substantially parallel with the transmission line and about one mile distant. This separation is necessary to keep the troublesome high voltages from occurring on the telephone line during fault conditions on the transmission line.

The telephone line connects with the District telephone system at Iron Mountain plant and is used for power dispatching and general communication between Boulder, Camino and the pumping plants. It is built of butt-treated ceder poles equipped with cross arms and carries two No. 6 copper wires. A position is left open for the addition of two more wires in the future. Although the telephone circuit was built for operation of the transmission line and pumping plants, its early completion made it very useful for communication between construction camps and from the transmission field headquarters to the Los Angeles office during construction of the transmission line.

*(May 25, 1939)*
Testing Laboratory

The Purposes and Functions of the Testing Laboratory.

By LEWIS H. TUTHILL
Testing Engineer

With definite selection of the Parker route for the Colorado River Aqueduct there immediately arose the question of availability of suitable material for making the vast quantity of concrete that would be required to line and protect the channel that was to carry this great stream of water over the desert and through the mountains between the Colorado River and the coastal plain.

In most of the area through which the aqueduct is located little or no concrete work had ever been done and there were no nearby concerns producing sand and gravel from well graded deposits that could be called upon to serve the work. Importation of the millions of tons required from outside sources was economically out of the question. Consequently it was necessary first to locate all promising deposits of material and excavate test pits in them to determine their depth and the approximate proportions of the different sizes of material.

With the necessity of making a thorough investigation of the suitability and concrete making properties of samples of sand and rock from these test pits, together with the need for preliminary study of appropriate cement types and curing problems, and later acceptance tests of these materials, it was recognized that there was ample justification for the establishment of a materials testing laboratory. Temporary facilities were set up in Los Angeles in 1931, which were moved to Banning in 1933, where complete equipment was installed for this work.

During the investigation of prospective deposits of sand and gravel, examinations of material from some 60 deposits were made. A few were found unsatisfactory but the majority were found capable of making a very good grade of concrete that would be entirely adequate to meet the requirements of such an important structure, provided proper precautions were taken in the preparation of the materials and in making them into concrete. When specifications for doing the work were written these precautions were included as essential requirements.

Materials from each deposit to be used were made into concretes of various proportions, and from observation of the workability and tests of the strength and other properties of these mixes it was determined before commencement of the work what results could be dependably expected when certain sufficient combinations of cement, sand, rock and water were put together.

Hence there was eliminated before work started any possibility that concrete placed in the work would fall very far short of the quality required. Nevertheless, whenever concrete was mixed, at least one sample of it was taken each 8 hours. This was cast in a tin cylinder 6 inches in diameter and 12 inches high and later sent in to the laboratory where such specimens were capped, stripped, and cured until they reached the standard age of 28 days and were then tested to determine their compressive strength.

Another activity of the laboratory has been in connection with the cement. As this is the active element in the most important ingredient in the concrete, it was especially important that a kind of cement best suited to the particular requirements and exposure of the aqueduct be specified, and that only cement fully meeting the specifications was delivered on the job.

Studies of cement types were carried on simultaneously with the preliminary aggregate tests and extensive investigations were made which were carried on in the field as well as in the laboratory.

Results of these experiments indicated that the benefits of finer ground cement in better workability and strength far outweighed any tendency it might have toward greater shrinkage, and that limitation of a compound in the cement called tricalcium aluminate would considerably improve its general quality and durability. The slight premium of 4¢ per bbl. for these modifications was considered amply justified considering their benefits, and these requirements were placed in the purchase specifications for the cement.

Facilities were established in the laboratory for making complete chemical and physical tests of cement. Inspectors were placed at the mills. When a mill had filled a bin with cement for the aqueduct, the District inspector sampled and sealed it. The samples, each representing 300 bbl. of cement, were forwarded to the laboratory and subjected to specification tests. It found to meet the requirements the bin was released for shipment as needed; it not, it was rejected and turned back to the mill for correction or other disposal. When cement was being loaded for shipment to the job, the District inspector was on hand to see that only cement from released and accepted bins went into the cars. He placed a signed certificate in each car which served as the credentials for the cement on its arrival at the work to show that no error had been made during shipment.

An important branch of the cement investigations prior to construction was the development of a cement comparatively resistant to sulphates. In certain portions of the location of the aqueduct and distribution system soils and soil waters contain aggressive alkali salts. The determination of the composition of a cement appreciably more resistant to these conditions than ordinary cements, or even the modified cement for the aqueduct, was accomplished in time to be used in these dangerous sections. In this manner the possibility of weak links was eliminated, and equivalent security and probability of durability was made available for the entire line.

Although the concrete is correctly proportioned of proper materials, and successfully placed in the structure in a workmanlike manner, unless it is properly cured for a period immediately afterward it will fall considerably short of developing its maximum strength, durability and water-tightness. Curing is simply a matter of preventing the concrete from losing its moisture and becoming dry.

It was evident that, for great areas of exposed concrete such as in canal linings and the outside of conduits and siphons before they could be backfilled, in this often dry, sunny, arid region, great difficulty would be encountered in an endeavor to keep such concrete wet for two weeks after it was placed, which was considered the minimum essential curing period. In addition the supply of water was limited and expensive, and its application would be subject to many human and delivery failures at which times the concrete would be in serious danger of damage from early dryout.

Consequently it was decided that probably most effective, dependable, and economical curing of such concrete surfaces could be accomplished by sealing in the original moisture in the concrete immediately after it had set or after the forms were stripped by means of application of some effective form of sealing compound.

During the summer seasons prior to commencement of construction dozens of materials submitted for this purpose were tested for their sealing value under actual field conditions. This problem was solved by the use of two coats of a coal tar pitch cutback thin enough so that it could be sprayed on the concrete. A final coat of fairly durable white wash was added to keep the temperature of the concrete at a minimum. (June 25, 1939)
Special Equipment

Special Types of Construction Equipment Invented and Developed During the Building of the Aqueduct

By EZRA B. RIDER
Engineer, Construction Division

Early in the preliminary investigations of the Colorado River Aqueduct project, provision was made in estimating the costs of construction for the use of the most modern plant and equipment. It was assumed that, as on previous large projects, necessity would be the mother of invention, new machinery would be developed to fit the need, and existing equipment would be enlarged and improved to increase both power and capacity. The next step was to lay out for good-sized units the plant and equipment necessary for efficient operations, based on time for completion of the project, assumed rates of progress, and most economical final cost of the many features.

For example drill carriages and mucking machines were included in the earliest lists of tunnel-driving equipment in order to permit the drilling of the full face. Both were known to tunnel men but not as equipment that had outstanding advantages over the old methods of drilling from bar or column and mucking by hand.

Drilling.—On this project a radically different drill carriage was developed with the folding wings on the sides and extensible center platform in the front so that when in operation at the face with the wings up, no staging or other set-up was necessary. Since the drills were kept on their mountings, except when repairs were required, heavier and more powerful drills could be used without undue strain on the operators. The combination of carriage and heavy drills, mounted, connected to manifolds and serviced ready to go, enabled tunnel crews, when mucking of the previous round had been completed, to move into a clean heading and begin drilling the new round in about 10 minutes. To drill the full round required from 1 1/2 to 4 hours, dependent upon type of rock, depth of round, and number of holes.

When the Coachealla work was started in December, 1932, standard drifter drills were of the hand-feed type, and many of this kind were purchased and used by the District and by contractors. Automatic feed and pneumatic feed drills were introduced and generally adopted with very satisfactory results from the standpoint of both the drill runner and his employer. These new drills maintained a uniform rate of feed with a minimum of effort on the part of the mechanician, and retracted the drill in less time when the full run had been made.

Mucking.—Progress in tunnel driving depends largely upon how quickly the blasted rock can be removed. Where mechanical muckers are used mucking speed is affected not only by the capacity of the mucker itself, assuming a skilled fast operator, but very greatly by the time consumed in pulling away the loaded cars and pushing up an empty. A great deal of effort was expended in developing car-passers, from "cherry pickers," set up near the face, which lifted the empty above the track so that the loaded car could pass beneath, to the combination machine, a drill carriage and overhead car-passer with ramps up which empties could be pulled from the rear and lowered to the front, while the loaded car went through below, and the combination drill carriage and conveyer loaded, long enough to load out a full train of cars without cessation of mucking. Probably the simplest and most practical of all was the "California switch," a portable double track with switches at both ends which was moved along the tunnel track as the excavation proceeded, being kept as close to the face as desired.

Various small muckers played a part in opening aqueduct tunnel excavation, but were displaced by the heavy Conway and Bucyrus machines, the latter being installed by two contractors and used in four tunnels only out of the thirty-seven on the main aqueduct and distribution system.

The Bucyrus was a miniature of the well-known shovel used on surface work and was an effective mucker, though somewhat cramped for room in the 18-foot tunnel section. Electrically operated, it had a 1 1/4-yard bucket and on the rear end a crane for transferring empty cars to the loading track.

The original Conway mucker was a light machine invented for mining work in the lead and zinc mines of the Tri-State district in the Mississippi Valley. The first Conways on the aqueduct came from the Edison Big Creek job and were equipped with air motors procured from the Hetch Hetchy Coast Range tunnel because electric power was not yet available. They were 30's, and were dwarfs compared with the 50's and 60's which soon followed. At San Jacinto and the Conways were equipped with 75 h.p. motors, other parts of the muckers being strengthened accordingly.

The speed of the muckers in well broken material made possible the record advances in a number of tunnel headings. Frequently 5-cubic-yard cars were loaded in 4 to 6 minutes, including switching time.

Haulage.—In tunnel haulage a somewhat radical departure from customary practice was made in equipping a number of tunnels with storage battery locomotives to the entire exclusion of the trolley type. Under severe service conditions, with long hauls, they proved to be safe, reliable, and economical in operation during the entire construction period. In other tunnels the combination of storage battery and trolley locomotives proved distinctly advantageous.

New cars incorporated several improvements, particularly the use of roller bearings, permitting the hauling of longer trains and larger loads.

Concrete lining.—In tunnel lining operations, improvements were made in steel forms, and in travelling for moving the forms in short sections where the continuous placing method was used. Continuous placing was somewhat of an innovation in itself. Pneumatic equipment, so called because compressed air was used in moving concrete from the gun through the discharge line into the forms, was extensively employed but more than half the concrete lining on the aqueduct was placed by a new development of the concrete pump. With continuous supply of aggregate to the mixer on the Pumpcorette machine, provided by specially designed batch cars, rate of placing concrete in the forms was speeded up remarkably. Machines rated at 480 cubic yards per 24 hours pumped an average of 640 yards over periods as long as nine months. Larger capacity machines of the same type placed a daily average of 865 cubic yards during one entire month. The one-day maximum for a large Pumpcorette was 1,387 cubic yards of concrete.

Surface equipment.—On the surface schedules standard excavating equipment was in general use for all rough excavation. This equipment consisted of gasoline, diesel and electric-powered draglines, gas and diesel shovels, tractors with bulldozer attachments, trucks and conveyers. The final excavation to grade and compacting of subgrade for the invert of cut-and-cover conduit and sewers was accomplished with scrapers and rollers and by hand methods. For rapid delivery of concrete from mixers on the bank to a hopper at the center of forms in the trench, extensive and successful use was made of belt conveyors. However, when it came to the final trimming of the typical canal section in earth and placing the concrete
lining therein, important and radically different equipment was developed on the job, namely, the canal trimmer and the canal paver.

In the winter of 1934-35, when construction of the desert schedules of the surface work was begun, contractors generally followed the customary method of trimming the canal sides and bottom largely by hand, and placing concrete in the invert and sides separately, much after the manner of building concrete roads with pavers. Canal construction carried on in this manner proved to be not only slow but altogether too costly. There was one exception to this starting procedure. On Schedule 8 Clyde Wood, one of the contractors, conceived the idea of trimming the canal section by machine and laying the concrete lining with a modified slip form. Considering that in each mile of canal there was approximately 8 acres of surface to be trimmed and finished to close lines and grade, a good deal of money could profitably be spent on equipment to do this type of work rapidly and economically. The Wood trimmer was successful and during the summer of 1935 canal trimmers or subgraders were adopted on all canal schedules but one.

Essentially the trimmer was a rigid framework supporting the cutting and shaping mechanism in the trench. It was made up of end trusses set parallel to the canal center line fitted with wheels resting on track on the canal bank. To the end trusses were attached trusses extending down into and across the canal section to hold the framework and trimming mechanism rigidly in alignment and transfer the entire weight to the track. Methods of completing the removal of material left by the draglines in making the rough excavation varied but included bucket elevators, sometimes with teeth on the cutting edge, and cross conveyors to dispose of material on the canal banks. The final shaping was done by a blade set in the framework to the exact dimension of the trench, the material pushed ahead of the blade being picked up by the bucket elevators.

Weighing approximately 50 tons the trimmers were moved by means of tractors in the trench and under normal conditions completed to exact line and grade from 60 to 75 feet of canal per hour.

The framework of the monolithic paver was somewhat similar to that of the trimmer, which it followed on the same track. The transverse trusses carried a steel plate or slip form whose shape conformed to the inside finished cross section of the canal and whose edges were rolled slightly to avoid damage in passing over finished surfaces. The bottom plates were square with the canal, but the side plates were set on a slight angle to the rear to give support from below to the freshly deposited concrete at the top of the slope. A continuous hopper extended across in front of the slip form into which concrete was
dumped from a shuttle car on top of the machine in such a way as to maintain a uniform head of fresh concrete as the paver advanced. The space between the subgrade and slip form was filled with concrete forced in by pressure of the supply in the hopper above, assisted generally by vibration of the concrete.

The monolithic lining was placed at a rate often exceeding one foot per minute, the forward travel being effected and controlled by two independent winches mounted on the front end with cable attached to the track ahead.

Many special machines were used on the distributing system but space permits mention of only a few. In fabricating the heavy sections of precast concrete pipe the mandrel used at Rochester in making up the reinforcement cages was developed by the contractor to wind continuous rod spirally upon the longitudinal reinforcement. In the construction of the Palos Verdes feeder the trench excavators were built with cutting teeth and buckets arranged to dig a cradle into which, after a minimum of hand work, the gunited pipe could be laid for a snug fit. The spun mortar lining of this pipe was placed by a special machine which rotated the pipe at a speed of 900 r.p.m.

(July 25, 1939)

MOVING HEAVY PIPE

A specially designed portable pipe gantry used in connection with the fabrication and handling of large diameter steel pipe sections on the distribution system. The section of pipe shown being moved by the gantry is 33 feet long, 10 feet 6 inches in diameter, and weighs 33,000 pounds.
BUILDING THE SOFTENING AND FILTRATION PLANT
This construction view shows the concrete crew while it was placing the roof slab on the zeolite softening building at the District’s softening and filtration plant. The zeolite building is one of the three main units of the plant. All water delivered to the thirteen District cities will pass through this plant, and when delivered to the consumer the water will be softer than the water served in most of the District cities from local sources and will be filtered and crystal clear.
Water Softening and Filtration Plant

Problems Involved in the Design and Construction of the Water Softening and Filtration Plant.

By W. W. AULTMAN
Engineer, Design Division

In order that the Colorado River water which will be supplied to the District member cities may be of unexcelled quality, a plant is being built which will both soften and filter the water before it is delivered to the domestic consumers.

The softening process will remove or reduce the dissolved substances which make water hard and cause the formation of boiler scale, deposits in pipes, soap curds, "tattle tale gray," and the familiar "ring around the tub." Filtration will facilitate the removal of the last traces of solid suspended matter such as mud, organic matter, plant and animal life and, if present, harmful bacteria. Initially, the plant will have a softening and filtering capacity of 100 million gallons per day, and it can be increased to an ultimate capacity of 400 million gallons per day.

The hardness in Colorado River water, averaging about 300 parts per million, is due to the presence in solution of calcium bicarbonate, calcium sulfate, and magnesium sulfate. Softening is accomplished by reducing the calcium and magnesium in these three compounds to the point which proves most desirable, taking all factors into consideration, probably about 85 parts per million total hardness. Lime, the least expensive and most efficient softening agent, will be used to remove the calcium bicarbonate from the water but it will not reduce the hardness resulting from the calcium and magnesium sulfates. In this plant, the calcium and magnesium present as sulfates will be removed by means of zeolite.

The zeolite which will be used is an insoluble substance having the appearance of white sand and having the ability to exchange its non-hardness-forming sodium content for the calcium and magnesium present in hard water. Following lime treatment, the partially softened water will flow through beds of this material where complete softening will take place. The zeolite in the softener beds will remove just so much hardness before the material becomes exhausted and when this point is reached, the zeolite does not have to be replaced but will be regenerated. Regeneration is accomplished by allowing a solution of common salt (sodium chloride) to flow slowly through the zeolite, rinsing out the excess salt with filtered water. The salt which is used to regenerate the zeolite, while not as cheap as lime, is the least expensive material which can be used to remove the calcium and magnesium present as sulfates.

A schematic flow diagram and the softening reactions which take place are shown on page 59.

The entire flow of the Colorado River Aqueduct is by gravity after it leaves Lake Mathews, and the softening plant is designed as a part of this gravity system. The plant intake may be said to be located at Lake Mathews, 36 miles away, at an elevation 265 feet above the plant; and the plant had to be designed to handle whatever flow was released, because the 116 to 152-inch pipe line in that section was not designed to withstand the surge pressures which might develop if the flow were suddenly throttled or stopped. As a result, the chemical feeding equipment, filters, and zeolite softeners are all designed to operate in proportion to the rate of flow of water through the plant.

To accomplish this proportional control of the chemical feeding equipment, exclusive of the chlorinators, the water as it enters the plant is measured by means of propeller-type meters. For each 250,000 gallons of water entering the plant, an electrical contact is closed which, by proper electrical control, will cause the feeders to apply the correct amount of chemicals to treat that quantity of water. Lime, coagulant, and other bulk chemicals, will be fed by weight. Activated carbon, ammonium sulfate, phosphates, etc., will be made up in solutions or suspensions of known strength, and measured by volume. The main effluent venturi meter will control the operation of the chlorination equipment in proportion to the quantity of water leaving the plant.

In order to keep the dirt away from the head house, and to eliminate the fire hazard, the activated carbon is to be stored as a water slurry in tanks as far from the main plant as possible. Two concrete tanks are being provided, each to store at least one carload of carbon, and each being equipped with bag opener, mechanical agitator, and dust control devices. Pumps controlled by the raw water meters will transfer the carbon to the points of application.

The bulk chemicals will be handled by pneumatic and mechanical elevating and conveying equipment. As the lime will be received directly from the kiln, provision is made to cool it before it is stored in the head house bins. The lime cooler may be utilized in the future in conjunction with lime reclamation facilities.

It appears probable that some time in the future the calcium carbonate sludge produced during softening will be burned to supply the lime and carbon dioxide required in the softening process. For the first few years of operation lime will be purchased commercially and carbon dioxide will be produced by burning natural gas or oil in a hot water boiler. The hot water produced will be used for lime slaking and other purposes throughout the year, and for heating the buildings in the winter. The carbon dioxide is required primarily for pH correction of the water flowing to the zeolite softeners, which will be automatically controlled by suitable pH regulating equipment.

In the head house will be stored the lime, coagulant, chloride, ammonium sulfate, phosphates, and chemicals other than salt and activated carbon. These will be fed through their respective chemical feeders and the lime and coagulant will be introduced directly into the raw water as it passes through the head house. In this building also will be located the carbonation equipment, a standby butane driven electric generator, and a repair shop.

After the chemicals are added they are thoroughly mixed with the raw water by two turbo flash mixers. This mixed water flows to the flocculating basins, where gentle mixing occurs which conditions the water to facilitate settling of the suspended matter.

The water enters through a tunnel from the flocculating basins to the center of the square settling basins. The sludge removal equipment will be driven from the center column and will have an extension arm which will reach into and clean the center. The sludge from the settling basins will be pumped to the point of disposal by means of pressure-type diaphragm pumps located in a room directly below the center of each settling basin.

The filters, 12 in number, are of conventional design and will not be covered. The troughs are of cast-in-place concrete, the valves hydraulically operated, the underdrain system of perforated clay pipe laterals, each unit with individual rate of flow controller and all units regulated by a master controller to automatically adjust the rate of flow through each unit in proportion to the inflow into the plant. A surface wash system is provided. Both surface and backwash rates are regulated by rate of flow controllers. All used wash water will be collected in a basin below the filters and
pumped back to the incoming water conduit at the flash mixers.

The lime softened, filtered water will be divided into two portions. One portion will return through the head house where chlorination and possible pH correction will be made. The other portion will have its pH corrected and will flow to the zeolite softeners where its hardness will be reduced to zero. The two portions will be so adjusted that upon blending, the water passing again into the aqueduct will have the desired hardness of 85 to 100 p.p.m.

The zeolite softener units, 12 in number, operate upflow in order to conserve head and wash water. Each unit will contain 2205 cubic feet of synthetic gel-type zeolite with a guaranteed exchange capacity of 9000 grains per cubic foot when using for regeneration 0.35 pound of salt per kilogram of hardness removed. The softeners are so provided with interlocking devices that it should be impossible to get brine into the distribution system through careless operation. Provision is made for regeneration by either the regular brining process or by the brine reclamation method, both of which will proceed automatically upon push-button actuation after the manual control of the operation of the raw water inlet and softened water outlet valves.

With the possibility of using cheaper grades of salt containing appreciable amounts of dirt, all saturated brine from the salt storage basins will pass through pressure filters before it is used for regeneration of the zeolite.

The offices and laboratories are located in the administration building. Laboratories will be fully equipped for all kinds of chemical, bacteriological, and biological work incident to water purification practice. Water from the various parts of the plant is provided at a central point in one of the laboratories for sampling and test purposes. Separate laboratories are provided for research and development work, in order that new processes and equipment may be investigated without interfering with the normal routine operation of the plant.

In order to be able to demonstrate the plant processes without disrupting the normal operation of the plant laboratories, a demonstration lecture room is provided which will seat about 70 people. In addition to provision for demonstrating the plant processes, facilities will be available for showing slides and silent or talking motion pictures. From the experience of other large water purification plants, it is expected that from 5000 to 10,000 people will visit the plant annually.

The architectural treatment of the plant has been made with an endeavor to provide an attractive appearance at a minimum cost. The style is modified Spanish colonial with concrete panelled walls and a red tiled roof, which should present a pleasing appearance in the midst of the surrounding orange groves located at the foot of the San Gabriel Mountains.

(August 25, 1939)
FLOW DIAGRAM AND SOFTENING REACTIONS
SWITCH HOUSE AT EAGLE MOUNTAIN PUMPING PLANT

A night view of the switch house at the Eagle Mountain pumping plant, one of the five pumping plants which lift Colorado River Aqueduct water to a total height of 1617 feet. The other four pumping plants are Intake, Gene, Iron Mountain, and Hayfield. These five pumping plants are among the most important operating units of the aqueduct.
Operation

The Colorado River Aqueduct As An Operating Utility.

By JULIAN HINDS
Assistant Chief Engineer

This paper brings to a close the series of articles which have been appearing in the “News” over the past fifteen months, describing the conception, planning, and building of the Colorado River Aqueduct, with its related storage and distribution facilities. It is fitting that the ending of this series should coincide almost exactly with the completion of the final construction task on the main aqueduct, making it ready for the actual transportation of water from the Colorado River to the coastal plain of Southern California.

The big pumps have already been tuned up and tested and Colorado River water has flowed all the way to the San Gorgonio wastewater at the east portal of the San Jacinto tunnel. Soon this wastewater will be closed and a steady stream of Colorado River water will begin pouring into Lake Mathews, building up a reserve that will forever stand as a sentinel to guard Southern California against the ravages of drought.

The ultimate capacity of the aqueduct is 1,500 c.f.s. (annual average), or about one billion gallons per day. Such a flow will double the present water supply of Southern California. Obviously, this entire flow will not be needed immediately, hence the aqueduct will be brought into use gradually.

Each pumping plant will eventually contain nine pumps, each with a capacity of 200 c.f.s. or 130 million gallons per day. Three pumps have been installed in each plant at the present time and others can be added when needed. These pumps will be operated as required to keep an ample reserve in Lake Mathews.

Operation

The functioning of the system will be somewhat as follows:

A meter dispatcher in Los Angeles will keep the chief operator, who will be located at the Gene pumping plant, informed as to the volume of water in Lake Mathews and of estimated future withdrawals. The chief operator will lay his plans accordingly. Before starting the pumps, he must make sure that after allowing for other users below Parker Dam, the water to be pumped is available in the river. If necessary, an order for release of flow will be made on Boulder. Storage in Lake Havasu will afford considerable leeway in the adjustment of flow, making precise, momentary control unnecessary. Following the same starting procedure that has been carefully worked out during the initial tests at the five pumping plants, the intake plant will be put into operation. Water will be drawn from Lake Havasu and lifted through the delivery line and the Colorado River tunnel into the Gene Reservoir.

Unless the water level in Gene Reservoir has been drawn down below normal for some reason, the Gene and Intake plants may be put into operation at the same time. Because of the storage space available in Gene Reservoir, exact synchronization of the two plants is not essential but they will generally be operated in step.

The flow from the Gene plant climbs the mountain in the 10-foot diameter pipe behind the pump house and flows through 24 miles of pipe line and tunnel into the Copper Basin Reservoir.

It will require about 17 hours for the flow to reach Iron Mountain, the next pumping plant 62 miles along the aqueduct from the Copper Basin outlet.

In traversing this long distance, the flow “thins out,” so that the first water arrives as a mere trickle which must be accumulated in a small basin provided for that purpose until the flow becomes sufficient to sustain a pumping unit in operation. When this condition is reached, a pump must be started promptly to prevent a wastage of water, as the storage space is limited. Other units are started, one after another, until the water being pumped at this plant equals the release from Copper Basin Reservoir.

In about 11 hours after the first Iron Mountain pumping is started, the vanguard of the flow will arrive at the Eagle Mountain pumping plant after having traversed 41 miles of tunnel, canal, siphon, and covered conduit.

In another 4 hours the flow will have traversed an additional 16 miles of aqueduct, arriving at Hayfield where the final pump lift is located. Here it may be discharged into the Hayfield Reservoir or pumped directly from the canal. The Hayfield Reservoir, when full, is capable of supplying the full aqueduct flow for many weeks and constitutes an important equalizing basin and a valuable protection against an interruption in flow.

It makes it possible to keep the western end of the aqueduct in operation should it be necessary to close down the eastern end for maintenance or repairs, thus minimizing the demand for emergency draft on reservoirs within the coastal area.

Water from the Hayfield pumps will require about 24 hours to traverse the remaining 116 miles of main aqueduct and reach Lake Mathews, where it will be accumulated or drawn out as required to meet the needs of the District cities.

Terminal Storage

Lake Mathews, when full, will contain 107,000 ac. ft., or 32 billion gallons, of water—enough to supply the present needs of all the metropolitan areas of Southern California for a month without operating the aqueduct pumps, should all other sources of supply suddenly and completely fail. Such sudden and complete failure is of course improbable and any likely partial failure due to drought or other cause could be taken care of for many months from Lake Mathews alone. Adding the reserve storage which the District will maintain in Morris Reservoir (12 billion gallons), and assuming that the aqueduct pumps will be kept going, the menace of drought as far as the 13 District cities are concerned, will be forever banished.

Distribution

Water will be withdrawn through a tunnel leading around the west end of the long earthen dike which forms the north rim of Lake Mathews. For safety, the flow will be controlled by a dual set of valves, one in a concrete tower located in the northwest corner of the lake and one at the outlet end of the tunnel. The latter will discharge into a stilling basin, visible from the road leading to the reservoir, from which the water will enter a long pipe line leading across the Santa Ana Valley and along the foothills to Eagle Rock Canyon at the eastern edge of the City of Glendale. From this huge pipe line, through which a loaded truck might be driven, branches lead to District cities. These branches will be connected to existing distribution systems so that the water from Lake Mathews may flow into the faucets of every home in the 13 cities of the District.

The water stored in Lake Mathews will be good water, safe and usable for every human need. However, in its long journey from the snow-capped peaks of Colorado and Wyoming, it dissolves portions of the limestone and other rock materials over which it flows. These substances are perfectly harmless but impart to the water the quality of hardness. To correct this condition, a water softening plant is being provided on the main distribution feeder line. This plant, located near San Dimas, will both soften and filter all water used for domestic and industrial purposes. Thus Colorado River water when it reaches the District cities will be soft and sparkling clear—the best as well as the most abundant water in Southern California.

(July 25, 1939)
Left, “The Old Chief,” the late William Mulholland, packs his bedroll and heads for the river at the start of aqueduct surveys in 1923. Above, the late W. B. Mathews, first General Counsel of the District.

Left, General Manager Weymouth. Center, the completion ceremony. Right, Chairman Whitsett and Director Rosetti place the last concrete in the main aqueduct.
End of a Chapter

By LYNN DAVIS SMITH
Editor, The Colorado River Aqueduct News

On a day in October, 1923, a small group of men left the coastal plain of Southern California and headed east across the desert toward the distant Colorado River. Informally, and yet with great sincerity of purpose, those men began a new chapter in the Winning of the West.

Sixteen years later, almost to the very day, that chapter was continued by another small group of men who took turns with a shovel placing concrete in a structure located on the edge of the same coastal plain. The scene on October 14, 1939, was marked with the same informality and the same sincerity of purpose as had been the case on that October day in 1923.

It is true that the chapter was closed by a ceremony which was watched by an audience. But the ceremony was brief and simple, and the audience was made up of the people who had worked together to write this new chapter in history. There was no need for a great show of pomp and glory to tell the story to that audience. Reduced to its elements, it is a story of cause and effect that can be briefly told.

Millions of people living in a semiarid area were using more water than the area can supply. As a matter of self-preservation, a large group of these people decided to supplement their water supply by tapping the only remaining source—the Colorado River—which is hundreds of miles to the east of the coastal plain on which they live.

Tapping this river involved the construction of the greatest aqueduct in history. This Colorado River Aqueduct has an initial length of 392 miles, and an ultimate capacity of one billion gallons of water per day.

The job of study, planning, and financing, which started with the first group of men in 1923, required nine years to finish. Seven more years were required to do the construction work which the second group of men completed in 1939. Making that second event possible were more than 35,000 men and women who worked on the project.

Thus, the story in its simplest form will not be forgotten. Each drop of water which flows from the Colorado River to the coastal plain will tell this basic story of cause and effect. But, unfortunately, the details which give life, and color, and romance, to the story—are already becoming dim.

These details were the daily events in the lives of the men who built the aqueduct. Gathered on the speakers’ platform and in the audience at the ceremony on October 14 were the men whose combined experiences would tell the whole story of the building of the Colorado River Aqueduct.

Sitting there were men who had gone out on the desert with the first survey party. Without benefit of air-conditioning, and lacking modern transportation and road and communication systems, these men had done the pioneering job. Roaming over vast areas of unmapped wastelands, they had surveyed 25,000 square miles of territory in order to find a route for the aqueduct.

Out of touch with civilization for weeks on end, their camps were scattered far and wide over a vast triangular area whose apex was on the coastal plain and whose base was a section of the Colorado River reaching from Bridge Canyon clear down to the Mexican boundary.

Only these men could fill in the details of the aqueduct story that have to do with living in fly camps where every drop of water had to be pumped. Of taking “topo” in box canyons where the sun temperature went so high above 100 that the average layman wouldn’t believe men could work under such conditions.

From these “S.I.s” would come the stories of just how far it was actually possible to push the old model T. How the “lizzies” were strong enough to climb ridges that would make a mountain goat think twice, and yet couldn’t buck the winds that blew over Shaver’s Summit.

These surveyors could tell stories about finding the remains of old Indian watch towers, sun altars, and trails, along the banks of the Colorado—landmarks that had been described in the diary of Father Garcés who traveled that way 200 years before.

And while they were speaking of Indians they would certainly have to laugh once more about the time a party of sun-blackened S.I.s came across a stalled car on the road near Homer. In the car was a group of eastern school marms who promptly took to the hill when the surveyors strolled up to see what the trouble was. After fixing the car’s flat tire, the S.I.s were off until the school maids resolutely came back to “make peace talk” with the “savage redskins.”

It seems the Easterners were making a summer tour of the Wild West, and they thought the Apaches had them when the sun-tanned survey party came up to say “How.”

Other tales could be told of the lonely night watches of the light tender who kept their solitary vigil night after night on the top of some desert peak during the triangulation work and of the times when bolts of lightning played tag with theodolite parties set up on the highest peak of Mt. San Jacinto.

These old timers would chuckle about the way the white collar struts from the L. A. office would invariably get stuck in the sand on their desert “bolevards.” And a number of the white collar struts, sitting there on the platform on October 14, 1939, would pointedly refer to at least one time when a “desert rat” had laughed so loud about the predicament of an office stiff that he forgot to watch the road, and as a result ploughed into the same hole with the man from L. A.

Along with the S.I.s would be a hundred and one yarns about the Beaumont gang who manned the field office for the preliminary surveys. Included would be the story of how one of the aqueduct’s famous siphons got its name. It’s a name that didn’t seem appropriate for a structure of concrete and steel, and yet one young draftsman had put that name on so many plans and drawings that it would have caused a costly delay in time and money in order to change it. Today that siphon bears the name of a girl who was the draftsman’s fiancée in the ’20’s, and who later became his wife.

The official record omits all these stories, but it does record the fact that these pioneers laid out more than 100 different routes from the Colorado River to the coastal plain, and in so doing completed the largest topographic survey ever undertaken by any agency other than the Federal Government.

There were white collar men on the platform at the completion ceremony who could tell of another pioneering job which was carried on at the same time. The job of fighting their way through the maze of uninformed, or ignorance, or selfishness, in order to create a new type of governmental unit under which the thirteen cities could fight their common battle with a common effort. These men, too, could tell of working in the “heat,” a heat put on by powerful groups who were opposed to the building of the aqueduct.

And both the field and the white collar pioneers would tell of the never ending battle against those who shouted long and loud that “it can’t be done.”

The official record lacks space for all these details, but that record does show the goal that was reached by these pioneers. It shows that the field men, after comparing their 100 different proposed routes, did find the most practicable, eco-
nomical, and safest route over which to build an aqueduct from the river to the coastal plain. A route 242 miles long, with its intake on the Colorado River 150 miles below Boulder Dam and its terminus on the coastal plain at an elevation from which water can be served by gravity to all those who will use it. They named it the Parker Route, after the little Arizona town which lies in the desert 18 miles below the aqueduct's intake.

The white collar men reached their goal, too. Their achievement was the creation of a new type of governmental subdivision by which a group of cities, not necessarily contiguous, could combine for the purpose of financing building, and operating a water supply system. Their creation is The Metropolitan Water District of Southern California, composed of thirteen cities, which has financed, and built, and will operate an aqueduct from the Colorado River.

With the pioneering work completed, the great construction army moved into the scene. Theirs was a precise mission. They were to build 92 miles of tunnels, 63 miles of concrete-lined canals, 55 miles of concrete conduits, 29 miles of inverted siphons, three dams, five pumping plants, and 237 miles of high voltage electric power transmission lines. Incidental to their main mission, they were to build hundreds of miles of surfaced highways, communications, power, and water systems, and dozens of ultra modern construction camps—each complete in every detail to provide every necessity and convenience for the thousands of men who were to live and work in the "uninhabitable" desert country.

Once again the official record is confined to the essential fact that they did accomplish their mission, and in so doing completed one of the greatest construction jobs in history with an all-time record for speed, safety, and economy.

The first small group of construction men were sent into the field on Christmas Eve, 1932. A new saga in the history of the West began that night. It was a story that contains all of the dash and courage and color of the frontier days, and yet it was enacted within a few hours' drive of one of the world's most modern and sophisticated metropolitan areas.

All the details which make up this part of the story will never be told. Only by gathering together all the individuals who worked on the project would it be possible to even approach the complete picture, for there is a separate bit of history for every mile of the aqueduct, and a separate story for every man who worked on the job.

To the men who were on the job, just the mention of the name of a town or a camp along the line will recall details without end. Names such as Berdoo, Pushawalla, Fargo and Yellow in the Coachellas, other men will promptly think of Indio, Cactus City, Utopia, Rice, and Crossroads. And, a whole book could be devoted to the Jackhammer, the Owl, and the Paradise cates.

And when the talk gets to cafes, it will not take long to get a recount of the meals that were served in the construction camps. Meals that have become legendary because never before had food of such high quality and quantity been served on a big construction job. Out will come the stories about the growing tables at Ben Arp's camp at West Iron, and about the Thanksgiving Day feed at another tunnel camp when the hardrockers averaged the consumption of nearly five pounds of turkey per man. And about the holing through parties.

And speaking of holing through, the conversation would then drift into the epics of the tunnel driving days. Because it was the most difficult of all, the stories about "San Jack" will be remembered longest. But there were many others, such as, chasing the devil out of Whitewater after a woman had been taken into the heading, and about the Valverde shift that took it on the lam when they thought the face was coming in—and it turned out to be a hard hat being sucked down the metal ventilating pipe, and about the time the safety engineer was caught in a skip which was hoisted to the top of the Potrero headframe and "unintentionally" left there for two hours, and the dozen of cases of men from other walks of life—doctors, lawyers, teachers, one even a society playboy—who went to work as hardrockers, and made good.

All these, and countless other details, give life and movement to the chapter in the Winning of the West which has to do with the building of the main line of the Colorado River Aqueduct. A chapter which was closed by the reading of the official report on October 14, 1939, which stated:

"With the pouring of the last concrete on the transition structure at the West Portal of the San Jacinto tunnel, construction of the main line of the Colorado River Aqueduct has been completed." (October 25, 1939)
DISTRICT SEAL OVER MAIN ENTRANCE TO THE SOFTENING AND FILTRATION PLANT
Issued February 1941
by
The Metropolitan Water District of Southern California,
Headquarters
396 West Third Street
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