HISTORIC AMERICAN ENGINEERING RECORD

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MOUNTAIN DELL DAM
PARLEY'S CANYON, 10 MILES EAST OF SALT LAKE CITY
SALT LAKE COUNTY
UTAH

PHOTOGRAPHS AND
WRITTEN AND HISTORICAL DATA

Historic American Engineering Record
Heritage Conservation and Recreation Service
Department of Interior
Washington, DC 20243

Historic American Engineering Record

Mountain Dell Dam

UT-16

Location: Near Salt Lake City, NW side of Interstate 80,.3 mi W. of St. RT. 239, 9.2 mi. E. of Salt Lake City.

Date: 1914-1924

Owner: City of Salt Lake City

Condition: Excellent

Significance: Early example of multiple arch dam construction. Designed by John Eastwood.

Historian: T. Allan Comp, PhD, 1972

"THE MOUNTAIN DELL DAM"*

"For the past five years the city engineering department has been engaged, under the direction of the City Commission, in preparing plans for, and carrying out, extensive water supply improvements for this city. At the time the plans were first undertaken, the city was in a serious condition for want of sufficient supply during certain seasons of the year -- particularly in the late summer and in the middle of winter. At other seasons of the year the supply was generally ample for all purposes."

A careful study was made of the city's available supply with a view of conserving a portion of the surplus supply and of securing additional water.

This study, embraced in a report, resulted in the bond issue of 1914, whereby a certain portion of the improvements recommended were undertaken. Since that time detailed plans have been prepared and contracts let for most of the units included in the program.

The Mountain Dell dam is the last of the storage and distributing reservoirs contemplated in the bond issue. With the completion of this unit the city has an available storage reservoir capacity of 850,000,000 gallons, as compared with nothing at all prior to 1914.

* Sylvester Q. Cannon, Monthly Journal: Utah Society of Engineers. September 1917.

In the matter of distributing or equalizing reservoirs, the city now has a total capacity of 24,000,000 gallons as compared with 9,000,000 gallons previously.

The location of the Mountain Dell dam is relatively so near to the city that it can serve as an equalizing as well as a storage reservoir.

In preparing the plans for this improvement, the question of stability and cost were carefully considered. Plans for three types of dam were prepared and bids obtained on each type. These three types were: Arched solid dam, gravity type; reinforced concrete dam of the Ambursen type; and the multiple arch reinforced con crete dam of the Eastwood design.

After a careful consideration of the various types the multiple arch type was accepted. One of the factors influencing this decision was the bedrock condition at the site. The bedrock is a calcareous shale not entirely water-tight and of a nature to decompose somewhat under exposure to air and water. The advantages of the multiple arch type in this connection were considered to be the practical elimination of upward pressure, the practical impossibility of overturning or sliding on its base and the ready facilities for internal inspection of the dam at any time. By making the arches and buttresses of suitable thickness, the unit stresses in the concrete are kept low (the concrete being entirely in compression); and by placing suitable and sufficient strut tie beams the buttresses are thoroughly braced and supported.

The dam is designed for a full projected height of 145 feet above the rock foundation. A provision was made, however, for the building of the dam only to the partial height under the present contract, because of the city's lack of means for the completion of the structure. The partial height brings the top of the dam 105 feet above the foundation. The cost of the structure was considerably increased because of the necessity of going 43 feet below ground level in the bottom of the canyon to secure the bed-rock foundation. The spillway level is 4 feet below the top of the dam, so that the maximum depth of the reservoir is 58 feet to the crest of the spillway.

The dam as planned and as constructed consists of 11 buttresses and 11 arches. The maximum base width of the dam is 132 feet from the face of the arch to the down-stream end of the buttresses. The maximum thickness of the buttresses is 8 feet with a batter of approximately 3 inches in 10 feet vertically. The maximum thickness of the arch rings is 4.1 feet. The thickness at the present top of the dam, 15 inches. The arch rings are 120 degree arcs of circles, with a slope of 10 on 12. The spacing between buttress centers is 35 feet. Three hinges are formed in each arch -- one at the springing line and one at the crown. These hinges were formed by pouring the concrete at the buttress corbels, using curved metal forms for the same, and by the use of the same forms for building up one side or the other of the crown of the arch.

At each of these joints the concrete face was painted with asphalt before pouring the concrete adjoining it. Also, a water stop of galvanized iron was placed in each hinge along the slope. The arches are reinforced with two layers of Clinton Electrically Welded Mesh No. 3/8, 2x18-inch, for temperature changes. The buttresses are reinforced with 1-inch twisted bars for the same purpose, and the strut tie beams are heavily reinforced with 1-inch bars and stirrups for tension. The strut tie beams run through the dam from end to end continuously.

The two sets of outlet gates each consists of two 24-inch pipes with a suitable grating entrance, and with a butterfly and a double-disc gate valve on each pipe.

The spillway has a capacity of 580 second feet, or twice the maximum flood flow of record. The capacity of the outlet gates with the dam full is nearly twice the maximum flood flow of the stream.

The maximum compression in the buttresses for the full height of dam (40 feet higher than the present height) is 146 pounds per square inch; and in the arch rings 300 pounds per square inch.

Frequent tests made of the concrete during construction showed a strength at the end of 28 days of approximately 1500 pounds for the buttresses (1:3:6 mix) and of 2000pounds per square inch for the arches (1:2:4 mix).

Since practically everything is in compression, the factor of safety is approximately 7.

The contractor used the gravel and a considerable part of the sand excavated from the foundation for construction purposes.

... The total quantity of concrete in the dam is 8271 cubic yards.

The cost of the dam was $90,000.

The storage capacity at the present height is slightly over 300,000,000 gallons.

The general design and supervision was handled under the direction of /Sylvester Q. Cannon, City Engineer, Salt Lake City/, John S. Eastwood acting as consulting engineer. Parrott Bros. Co. were the contractors."

John Eastwood

Mountain Dell Dam was one of nineteen multiple arch dams built by John S. Eastwood in his lifetime; none of them has ever failed. "The dams are a series of concrete half-cylinders, each fitted to the contour of the ground at its base to compensate for irregularity of the earth surface. The half-cylinders are placed with their convex sides upstream and are so sloped that the impounded water forces the cylindrical bases more firmly against their foundations as the volume of water, and consequently its weight, increases. It was an application of the principle of the lever to dam design. It made possible economic construction of dams in remote areas otherwise impractical and on terrain unsuitable for conventional types." While it is one of his lesser accomplishments, Mountain Dell bears the mark of both Eastwood's genius and his acquired experience.

John Eastwood was born in Minnesota in 1857. Descended from the family of Arent van Oosterhont, the Royal Dutch Engineer, Eastwood grew up in a family well-versed in the problems and properties of water. He attended the State Normal School at Mankato, Minnesota, and graduated in 1878, going from there directly to a position as assistant construction engineer on the Pacific extension of the Minneapolis and St. Louis Railroad. He worked there for five years, but in 1883 he decided that a supervised position was unsuited to his personality and he left Minnesota for California. At the age of twenty-six he went into "private practice" in Fresno, a town of 10,000 citizens. In 1885 he became Fresno's first city engineer and his main concern in that situation, as well as in his role as chairman for the "100,000 Club" (its goal being to promote that population limit) was to find an adequate water supply for that city. He solved that problem in 1896 when he developed a hydroelectric power plant which transmitted electricity thirty-seven miles to Fresno. In 1902 he completed the largest chain of hydroelectric installations in the United States (the Big Creek Project, in California) which included a tunnel twelve miles long straight through the mountains.

When Eastwood died in 1924, French Strother, editor of World's Week, wrote: "Los Angeles owes its very existence, in large measure, to this man..." Though he practically singlehandedly made the Southwest habitable, and though his innovations preceded similar electrical engineering feats by many years, Eastwood realized very little profit from his endeavors.

In 1912, at the age of fifty-five, he began a new venture: he attempted to design the "perfect dam." The result of this experiment was the multiple arch dam, of which Mountain Dell is an example. Before his death in 1924 he built nineteen such dams; they can be found in British Columbia, Idaho, Utah, Arizona, and California. The design was used after his death and Eastwood's dam can be seen abroad as well as over the continental United States, a tribute to the foresight and engineering skills of this very unassuming man.

T. Allan Comp
Project Historian
August 1972

Bibliographical Note: The foregoing article on Mountain Dell Dam was the only source encountered in research. For Eastwood, the following was most helpful.

Charles Allen Whitney, "John Eastwood: Unsung Genius of the Drawing Board," Montana Magazine of Western History, Summer 1969.

ADDENDUM FOLLOWS...

Addendum to:
Mountain Dell Dam
Interstate Highway 80
Salt Lake City, Utah
Salt Lake County

HAER No. UT-16

HAER
UTAH
18-SALC
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PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
Department of the Interior
Washington, D.C. 20240

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THE JOURNAL OF THE SOCIETY FOR INDUSTRIAL ARCHEOLOGY

John S. Eastwood and the Mountain Dell Dam

by Donald C. Jackson

For further information on John S. Eastwood and multiple arch dams, it is suggested that researchers refer to HAER No. CA-8, the Littilerock Dam.

Volume 5, Number 1 1979

John S. Eastwood and the Mountain Dell Dam

by Donald C. Jackson

Throughout the history of Western America, the key to sustained development has always been the ability to store water. Water is the basic resource required for all human activity, and in many regions, it is utilized for power and irrigation, as well as for domestic purposes. Unfortunately, precipitation in the West can be extremely intermittent, and some means of storing water for future use is essential for any kind of long term economic endeavor.

This paper discusses the Mountain Dell Dam (Figures 3 and 4) near Salt Lake City, Utah, an early reinforced concrete multiple arch dam, and places it within the context of its designer's career. In addition, the basic structural concepts used in multiple arch dam design are explained and a comparison is made with the two other types of dams considered by the Salt Lake City Engineer's Office for the Mountain Dell dam site.

Developed in the early 20th century, the multiple arch dam was intended to provide a safe and economic means of impounding water through the use of reinforced concrete as a structural material. Reinforced concrete presented the engineering world of the early 20th century with a structural medium of unprecedented versatility. However, it demanded engineers of imagination and vision to demonstrate its capabilities in useful structures. In this respect, John S. Eastwood of Fresno and Oakland, California, was one of Western America's most innovative builders. Eastwood built the world's first reinforced concrete multiple arch dam on bedrock foundations at Hume Lake, California, in 1908 (Figures 1 and 2), and the structural form has since been employed throughout the Americas, Europe, and Asia.[1] Because of the material economies inherent within its design, the multiple arch dam played a significant role in the development of the world's water resources during the first half of the 20th century and, perhaps of equal importance, demonstrated the capabilities of reinforced concrete construction to engineers involved in many aspects of structural technology. As this account bears out, Eastwood first developed his reinforced concrete multiple arch dam in direct response to the problems encountered in finding a durable and economical means of storing water high in the Sierra Nevada.

Born of Dutch ancestry in 1857, Eastwood graduated from the University of Minnesota as a civil engineer in 1880 and immediately went to work on railroad construction projects in the Pacific Northwest.[2] In 1883, he moved to Fresno, California, where he established a private office as a civil engineer and surveyor. At this time, California was barely thirty years removed from the heyday of the gold rush, and Eastwood was among the second wave of pioneers who came not merely to extract mineral wealth, but also to develop the region's resources in a more lasting manner. At first engaged primarily in surveying, he became Fresno's first City Engineer in 1885, but he discovered he was not suited to the life of a bureaucratic engineer and soon resigned. His attention focused on the Sierra Nevada east of Fresno, where he recognized the great potential of the swift-flowing mountain streams. Beginning with the construction of a seventy-mile-long wooden lumber flume, he became involved in controlling the mountains' water resources. Soon afterward, he commenced work on the first major project of his life.[3]

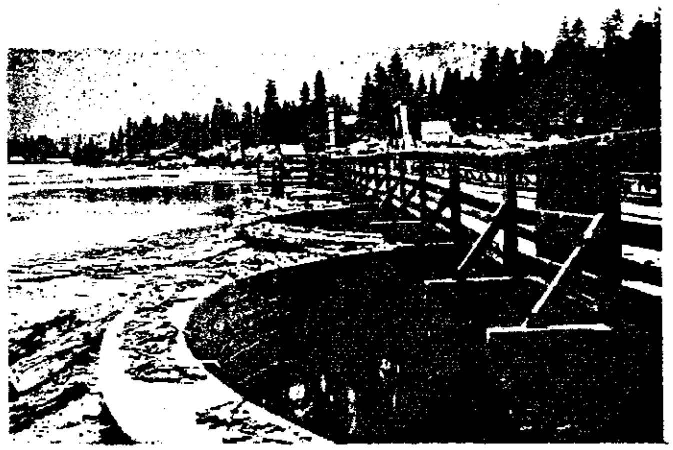


Figure 1. *Hume Lake Dam as it looked in June 1931. Constructed in 1908-1909 for the Hume-Bennett Lumber Company, it, along with the surrounding forest land, came under the control of the U.S. Forest Service in 1935. (Courtesy of Water Resources Center Archives, Berkeley, Calif. W.L. Huber Collection)*

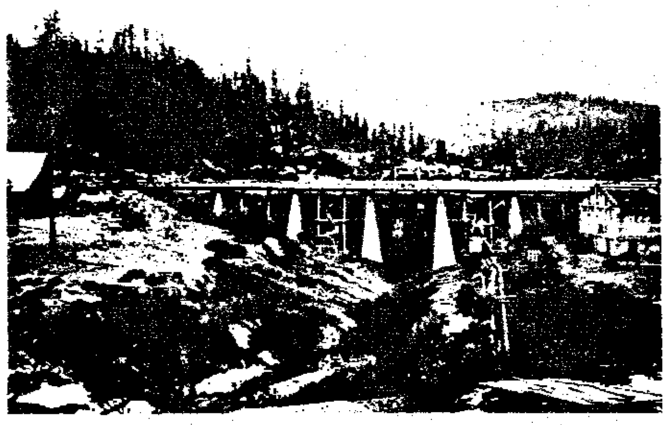


Figure 2. *Downstrean side of the Hume Lake Dam as it looked in June 1931. The building on the right was part of the original mill complex. It burned in 1917. Except for a recoating of the dam's upstrean face in the late 1950s, the structure has remained unaltered. (Water Resources Center Archives, Berkeley, Calif., W.L. Huber Collection)*

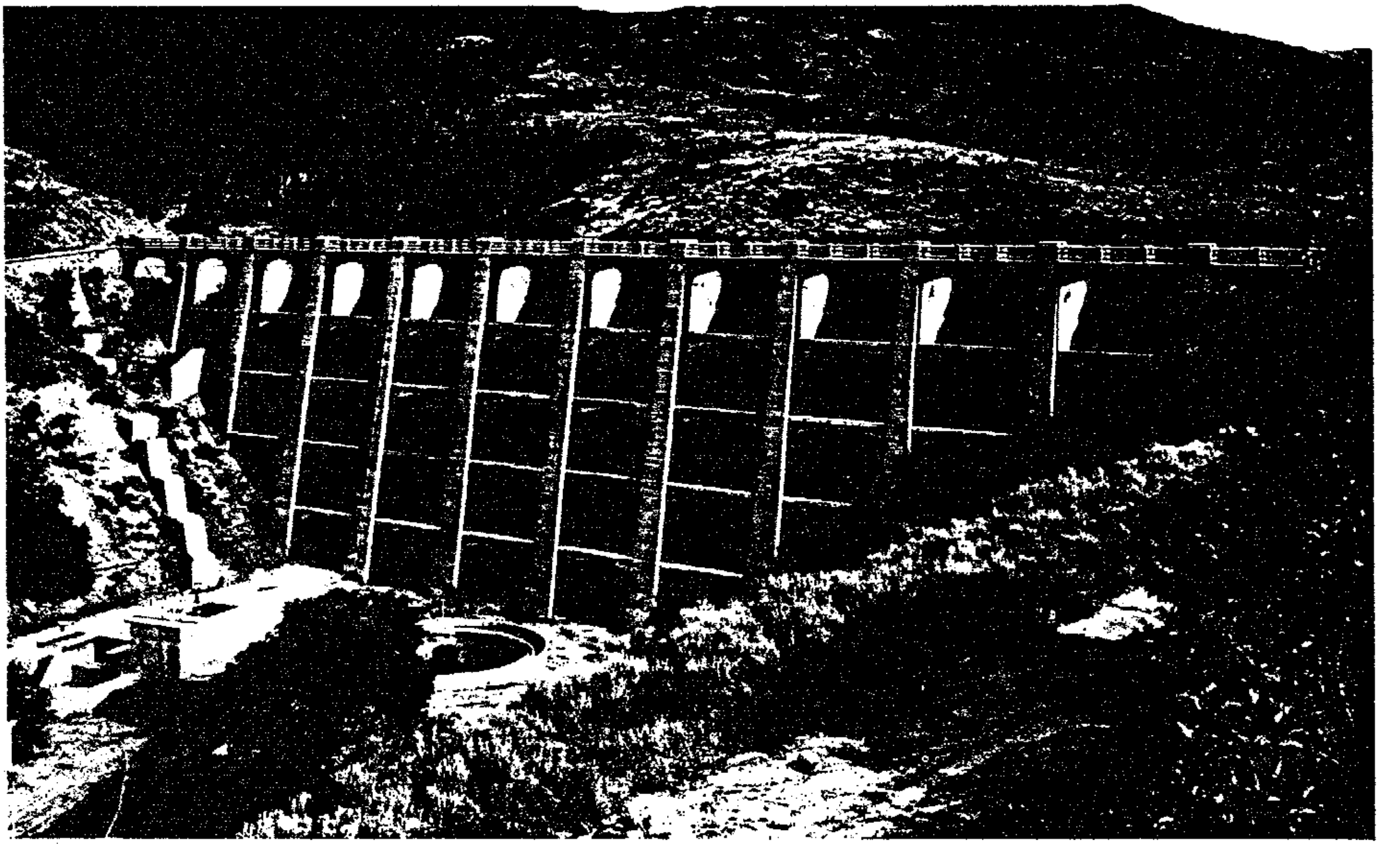


Figure 3. *Downstream face of Mountain Dell Dam. Covered spillway is on left and water treatment facilities are in foreground. 1973. (Courtesy of Jack E. Boucher)*

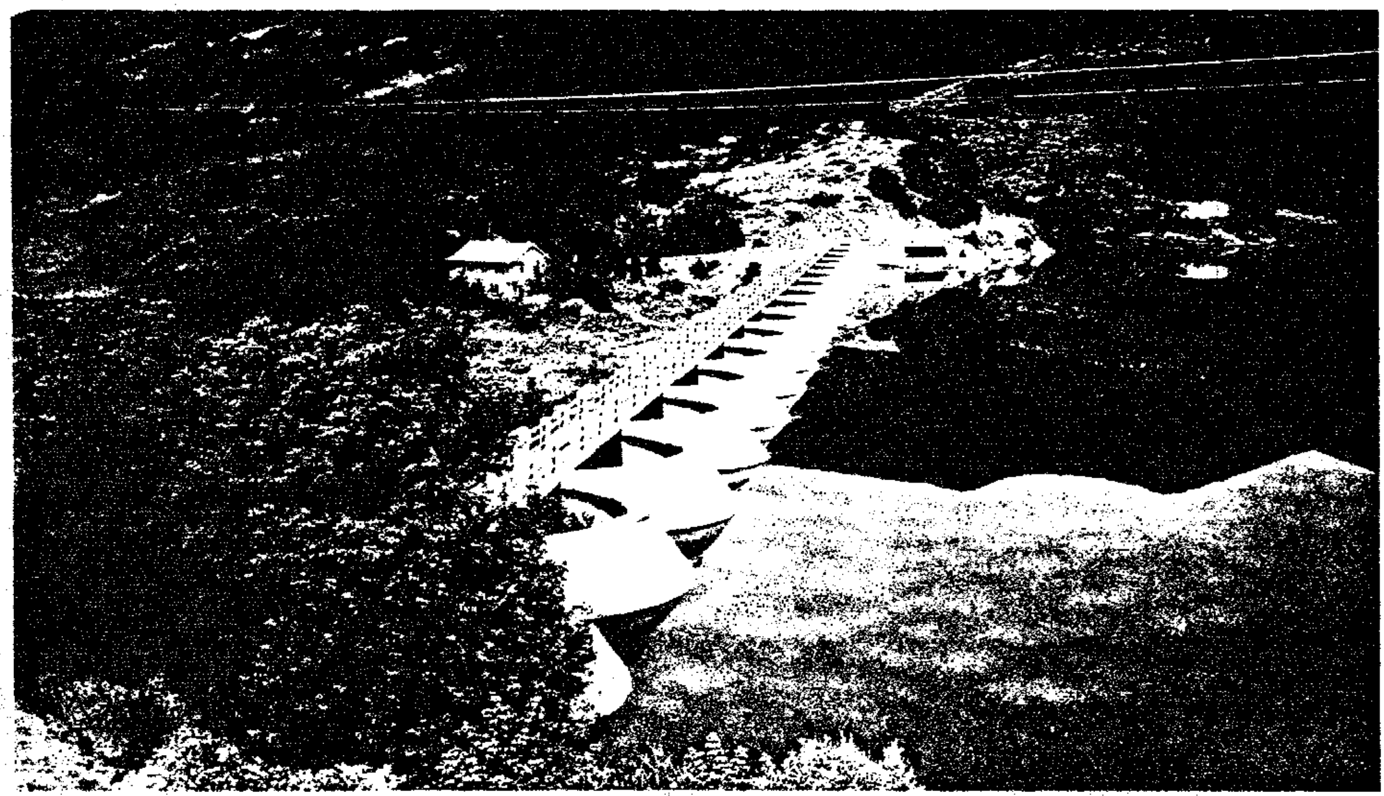


Figure 4. *Upstream face of Mountain Dell Dam with reservoir filled. Spillway opening is visible on the far side of dam. 1973. (Courtesy of Jack E. Boucher)*

In early 1895, Eastwood became chief engineer of the San Joaquin Electric Company, and responsible for the design and construction of one of California's early hydroelectric plants. As described by George Low in the April 1896 *Journal of Electricity*, Eastwood employed the nascent technology of long-distance alternating current power transmission in creating a hydroelectric power system for the Fresno area.[4] Unfortunately, the financial capabilities of the company proved insufficient to meet the great cost of constructing a dam in the remote reaches of the mountains, and, as a result, Eastwood was forced to rely on an undammed, natural supply of water to drive the turbines and generators. It was this inability to impound and store runoff that led to the demise of the San Joaquin Electric Company in 1899 after a long drought dried up the North Fork of the San Joaquin River and brought the company's power production to a standstill.[5]

Shortly after the San Joaquin Electric Company went bankrupt, Eastwood became engaged with the Pacific Light and Power Corporation as engineer in charge of designing a large hydroelectric project on the South Fork of the San Joaquin River. This has since become known as the Big Creek Complex.[6] The Pacific Light and Power Corporation was controlled by the famous financier and electric railroad magnate, Henry Huntington. Eastwood had great hopes for the project, and he planned it to include storage dams to insure that a drought could not stop its power production.

Although Big Creek was for the most part designed prior to 1905, financial difficulties precluded its construction for several years. During this time, Eastwood developed an inexpensive type of reinforced concrete dam design in which the water face consisted of a series of arches supported by buttresses resting on bedrock. This was a design which minimized the amount of material required and, consequently, reduced the transportation costs. In 1908, while waiting for construction of Big Creek to begin, he designed and built the Hume Lake Dam for the Hume-Bennett Lumber Company. This structure is located about forty-five miles south of Big Creek, and it demonstrated the practicality of multiple arch design. Shortly thereafter, Eastwood received the contract for the design of a multiple arch dam to supersede the 1884 Big Bear Valley Arch Dam near San Bernardino in Southern California.

Eastwood envisaged the use of multiple arch dams in the construction of the Big Creek project, but these hopes were dashed when, in November 1910, he was dismissed from all association with the project. He still held stock in the Pacific Light and Power Corporation, but even this financial interest disappeared when Huntington, as majority stockholder, assessed all owners of Pacific Light and Power Corporation stock to pay for the construction of Big Creek. Eastwood was, in essence, forced to sell his stock to pay this assessment.[7] Following this abrupt separation from the Big Creek Project at the age of 53, Eastwood was left practically penniless and, as a means of survival, he began actively pursuing a career devoted to the design of multiple arch dams.

In the early 20th century, Salt Lake City regularly experienced severe water shortages in mid-winter and late summer. To alleviate this condition, bonds were floated in 1914 to finance the construction of three storage dams. The largest of these was to be the Mountain Dell Dam in Parley's Canyon, a site about ten miles east of the city.[8] In the summer of 1915, Eastwood received a letter from the Salt Lake City Engineer, Sylvester Q. Cannon, inviting him to submit a design of a multiple arch dam for their consideration. Included was a large amount of pertinent geological data gathered from test borings made at the dam site. The letter explained that the Park City branch of the Denver and Rio Grande Railroad passed adjacent to the site, and that sand and gravel deposits in the vicinity were readily available for use in the dam's construction. Cannon also stated that delivery of construction materials by gravity would be possible and that the nearby transmission lines of the Utah Power and Light Company could supply electric power for construction purposes. In describing the proposed project, Cannon stressed that the reservoir would be "...about 8 miles above a portion of the city that is rather thickly settled..." and that safety would be a concern of paramount importance in the selection of a design.[9]

Earlier, Eastwood had built four dams in California, and his reputation as dam designer was growing. He had written several articles in *Western Engineering* describing his Big Bear Valley Dam, Los Verjeles Dam and Kennedy Dam, and had also published a four page promotional "supplement" distributed with copies of the March 1915 *Western Engineering*.[10] His primary source of income was from dam design commissions, and he sought work anywhere he could get it.

Eastwood knew that reinforced concrete could resist both compressive and tensile forces; however, he also knew that if reinforced concrete is placed in sufficient tension, the concrete surrounding the reinforcement will crack. In a dam, this could precipitate disaster, as cracks in the dam's face could allow water to penetrate the structure, rust out the steel reinforcement, and in time destroy the dam. Consequently, it was his object to design a structure subject only to compressive loadings. Because the concrete would be placed only in compression, the danger of serious cracks occurring in the dam would be entirely removed. Eastwood was also aware of the tensile stresses set up in concrete structures due to temperature fluctuation, and he realized that some steel reinforcement to resist these stresses was essential, especially in the concrete comprising

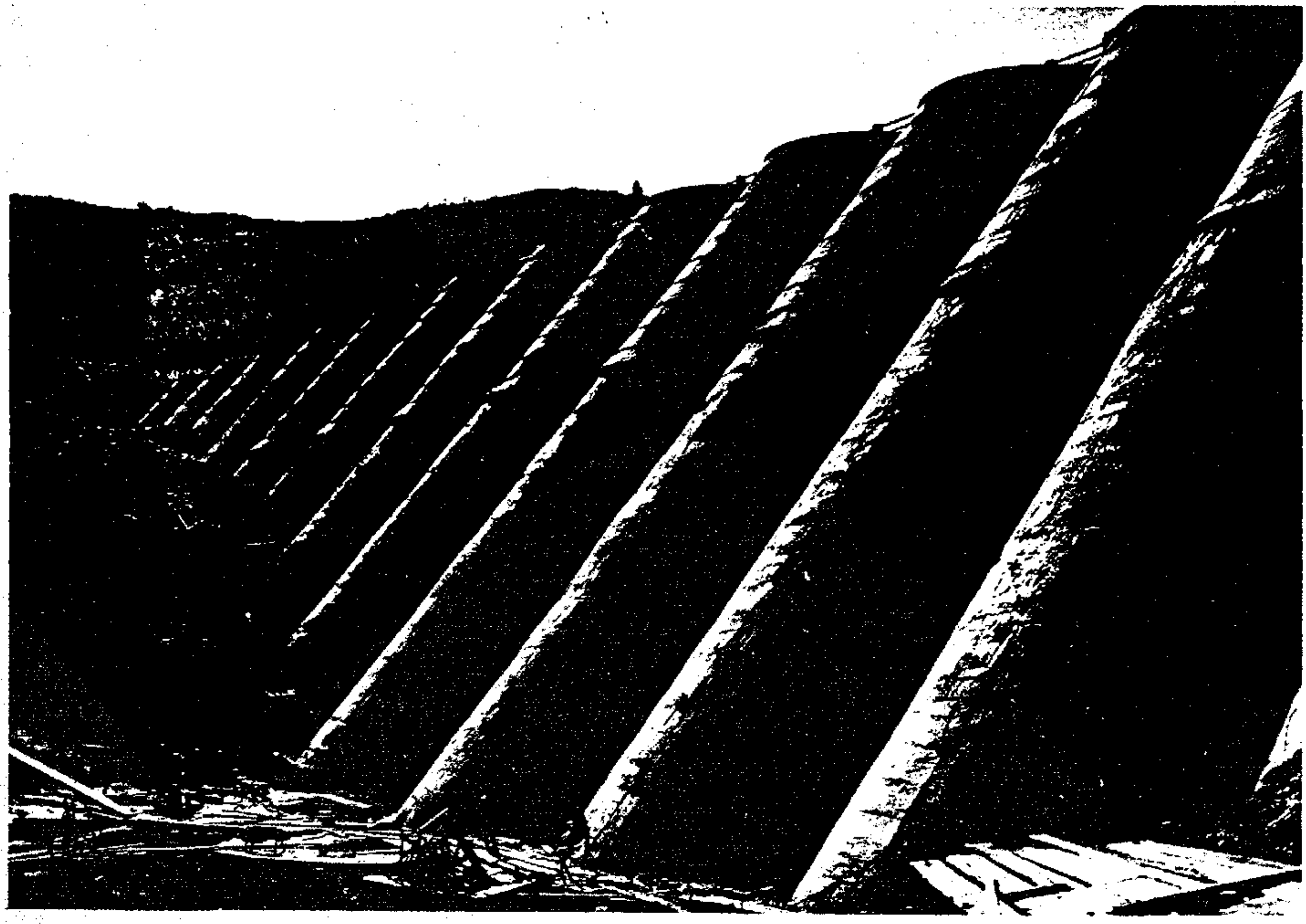


Figure 5. *Upstream face of the Mountain Dell Dam as it looked in 1926. (Courtesy of the Utah Historical Society)*

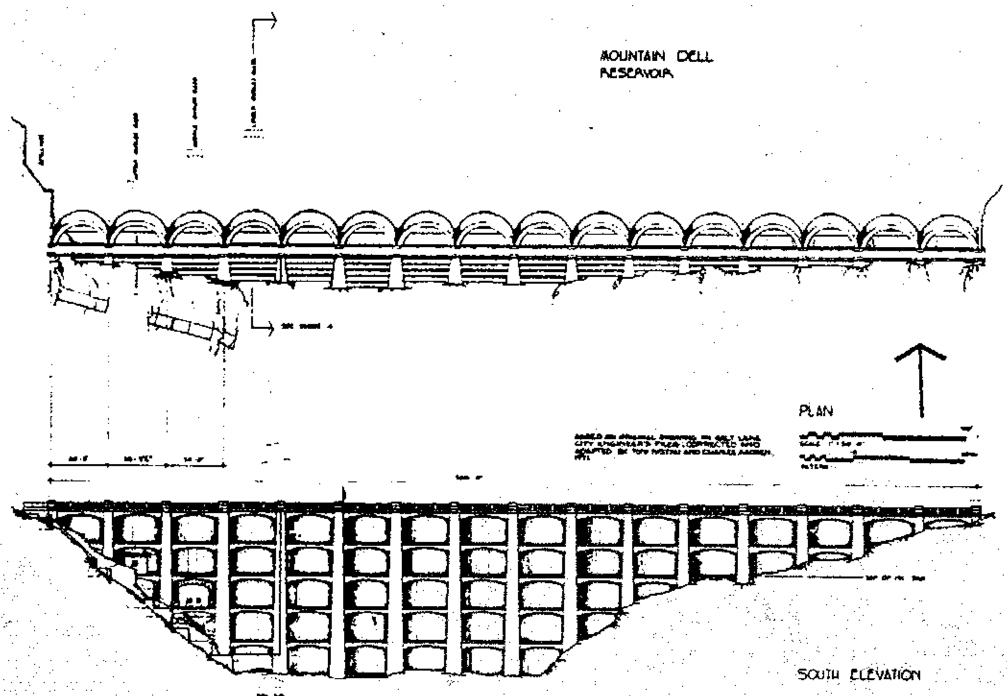


Figure 6. *HAER drawing of plan and downstream elevation.*

the dam's water face. For maximum conservation of materials, Eastwood used the structural form of the arch, or more specifically, the arch ring.[11]

Figure 5 shows the Mountain Dell Dam shortly after completion of construction. The series of reinforced concrete arch rings which form the structure's water-face can be clearly seen. These arch rings vary in thickness from four feet at the bottom of the dam to one and a quarter feet at the top, and are inclined upstream at an angle slightly greater than fifty degrees. To calculate the arch thickness needed at various elevations, Eastwood used what he referred to as Rankine's Ring Formula, an equation relating thickness to pressure, radius, and allowable stress.[12] Usually expressed as "thickness equals pressure times radius divided by allowable stress" or $T = PR/Q$, the formula provided a mathematical basis for determining the dam's structural dimensions.

The dam is 145 feet in height, but, as shown in Figure 6, only the arch rings near the middle of the canyon have this great a depth. The canyon walls are sloped, and the arch rings at the end of the dam are only about twenty feet deep. Each of the arch rings has a span width of thirty-five feet with the extrados (upper curve of the arch) encompassing a 120° circular arc. The vaults formed by these arch rings are supported by trapezoidal shaped buttresses firmly anchored into bedrock. The buttresses vary in thickness from eight feet at the foundation to two feet at the top, and carry the thrust of the water load to the dam's foundation. When the reservoir is filled with water, the hydrostatic pressure is exerted directly on the cylindrical vaults. Through their "arch" action, the water pressure is concentrated on the buttresses which support them. Because the spans of the arches are all equal, their respective sideward thrusts due to water loadings cancel one another out, and the only forces the buttresses are required to sustain are those perpendicular to their upstream faces.

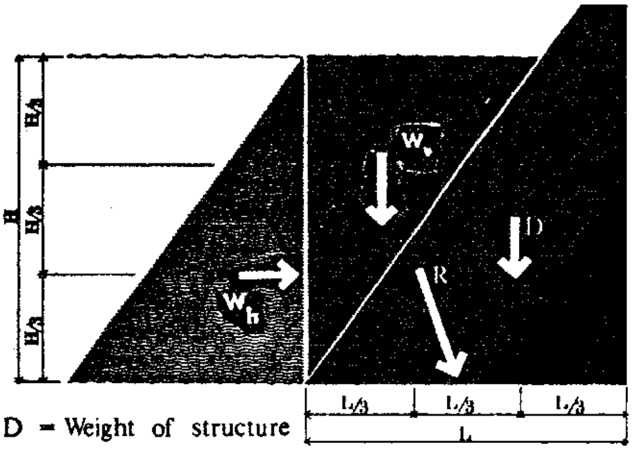
Because of the upstream inclination of the dam's facing, the resultant of the water pressure combined with the structure's weight passes almost directly through the center of the dam's foundation. Figures 7 and 8 show cross-sections of dams which use the force of gravity to retain water. In Figure 7, the inclined upstream face of such a dam is represented in black. It inclines into the stored water, signified by the light and dark gray areas. The horizontal component of the water pressure is represented by the light gray triangle. Because of the inclined face, there is also a vertical component of water pressure pushing down on the dam, as represented by the dark gray triangle. Together, the weight of the dam, the vertical force exerted by the water, and the horizontal force exerted by the water form a resultant force 'R' which acts on the dam's foundation. In this case, it intersects the foundation almost at its centerpoint. Comparing this to the vertically-faced dam shown in Figure 8, it may be seen that a vertically-faced dam is not acted upon by any vertical component of water pressure. Consequently, the resultant 'R' for this dam intersects the foundation much closer to its downstream edge. If the resultant falls beyond the downstream edge of the foundation of a gravity dam, then the dam will fail by overturning. There is a greater chance of this occurring in a vertically-faced dam. Eastwood was by no means the first person to build dams with inclined upstream faces, as many 19th century mill dams used this structural feature to great advantage.[13]

As a result of the Mountain Dell's inclined face, the buttresses are placed in compression, and this stress is distributed over the entire width of the dam. Eastwood calculated the maximum stresses to be 146 pounds per square inch in the buttresses, and 300 pounds per square inch in the arch rings. Tests made on the original concrete used in the dam indicated an average strength of about 2,000 pounds per square inch, which prompted Cannon to proclaim the dam had a safety factor of seven.[14] A recent structural analysis of the Mountain Dell Dam by Glenn L. Enke, consulting engineer and Professor Emeritus of Civil Engineering at Brigham Young University, confirms the accuracy of Eastwood's calculations in terms of average stresses within the dam, though modern mathematical analysis indicates some parts of the dam to be stressed slightly more than 300 pounds per square inch.[15]

In deference to the great height-to-width ratio of the buttresses, they were reinforced laterally to prevent any possible buckling or toppling (Figures 9 and 10). This reinforcement is supplied by strut-tie beams which connect all the buttresses. The twenty-three strut-ties (thirteen are visible, ten are below grade) in the Mountain Dell Dam each contain steel reinforcement approximately four square inches in section, run continuously through the buttresses, and are grouted into bedrock on both sides of the canyon. They were specifically designed to reinforce the dam against stresses resulting from earthquakes and other vibrational shocks.[16]

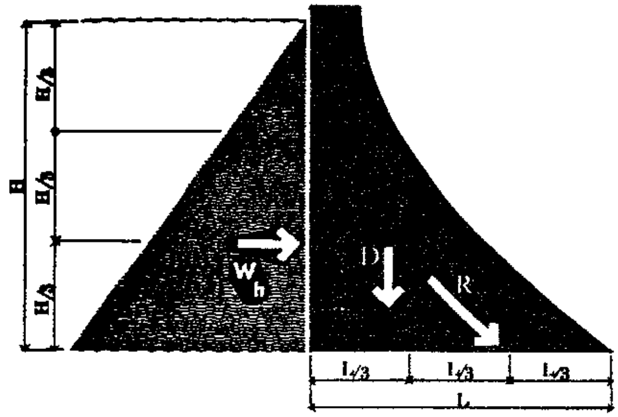
A spillway exists at the west end of the dam with a capacity of approximately 400 cubic feet per second. According to the Salt Lake City Water Department, the spillway, in conjunction with the outlet gates, has always proved sufficient in handling floods, and the dam has never been overtopped.

In September 1915, City Engineer Cannon gave notice that bids from contractors would be accepted for Eastwood's Mountain Dell Dam design. Eastwood's design was to be placed in competition with a concrete curved gravity design and a reinforced concrete Ambursen flat slab buttress design. Both of these types of structures had been built previously in many parts of the United States.



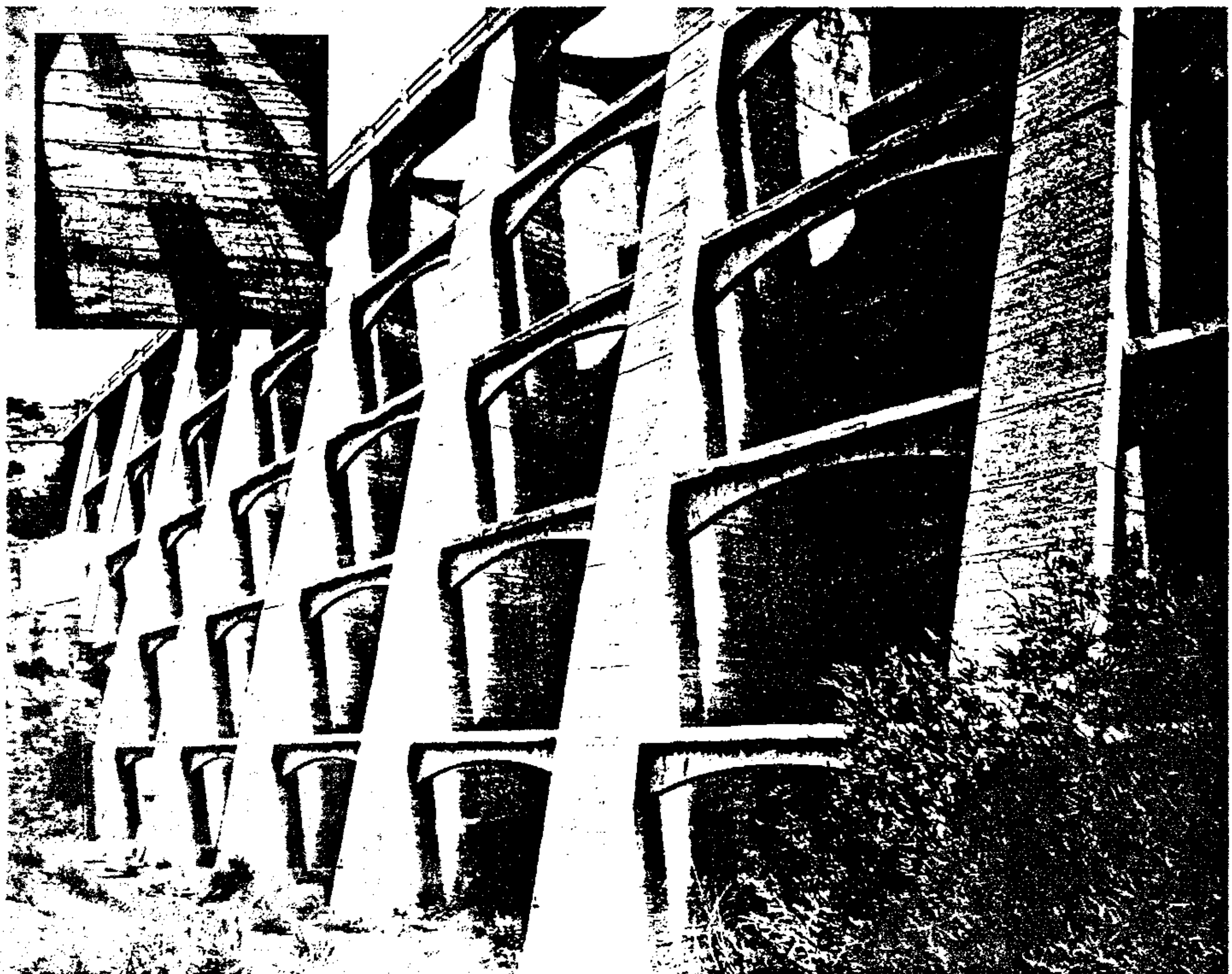
D = Weight of structure
W_h = Horizontal thrust of water
W_v = Weight of water above inclined face
$R = D + W_h + W_v$

Figure 7. *Cross Section: Gravity or Buttress Dam with inclined upstream face.*



D = Weight of structure
W_h = Horizontal thrust of water
$R = D + W_h$

Figure 8. *Cross Section: Gravity or Buttress Dam with vertical upstream face.*



Figures 9 and 10. *Detail of buttress walls and strut-tie beams. Impressions of form work on the concrete are clearly visible. 1973. (Courtesy of Jack E. Boucher)*

A curved gravity dam, often referred to as a "gravity arch" dam, is a structure built with such ample dimensions that the hydrostatic thrust of the stored water can be resisted solely by the great weight of the material in the dam. In essence, it is a gravity dam which is built on an upstream arc, or curve, supposedly to provide it with greater strength. In certain instances, like the Buffalo Bill Dam (formerly Shoshone Dam) shown in Figure 11, it is possible to build a "true arch" dam with such slender dimensions that the "arch action" of the dam is *required* to resist the hydrostatic thrust, i.e., its cross section is less than that required for a gravity dam.[17] True arch dams can be built safely only where there are strong foundations, not at relatively porous sites like the location of the Mountain Dell Dam. At these sites it is impossible to depend on the "arch action" of the structure. Consequently, Cannon asked for bids on a conservatively designed, curved gravity dam.

Eastwood had reservations about this kind of design because of the possibility of its failing as a result of "upthrust."[18] Upthrust is a hydrostatic phenomenon affecting dams which, because of its complex nature, has come to be only vaguely understood since the beginning of the 20th century.[19] Essentially, it is the result of water seeping under a dam and then pushing upwards on the foundation. If sufficient water "percolates" under the dam and pushes up, the dam will float free of its foundation and, because of the horizontal component of the water pressure, slide downstream, thus destroying the integrity of the structure, and possibly everything below the dam as well.

The solid base of the curved gravity dam makes it susceptible to upthrust, unless special means of draining the foundations are provided. The solid base does not allow for a natural and convenient means of seepage dispersal. Because a multiple arch dam is buttressed, the effect of such pressure is, in almost all cases, negligible.[20] Any water seeping under a buttressed dam will harmlessly rise to the surface in the area between the buttresses.

Eastwood believed arch dams were only suitable for narrow canyons with strong rock walls capable of withstanding the compressive thrust of the dams' arch. The Buffalo Bill Dam site is a perfect example of this.[21] For a wide valley with porous foundations, such as the site of the Mountain Dell Dam, he believed the amount of material required in a curved gravity dam, and consequently its expense, would be excessive, and because of upthrust, could be dangerous as well.

The second design competing with Eastwood's was an Ambursen flat slab buttress dam. First built by Nils F. Ambursen of New York in 1903, the Ambursen dam may be regarded essentially as the application of reinforced concrete slab construction to dams.[22] Figure 12 shows the Stony River Dam in West Virginia, as it appeared in January 1915. Due to faulty construction work, this Ambursen dam failed, and the flat slab facing is clearly evident.[23] In an Ambursen dam, the upstream facing is supported on triangular buttresses which carry the hydrostatic thrust to the foundation. The only difference between the flat slab dam and the multiple arch dam is in the structural shape of the dam's water-face. Both are buttress dams, but Ambursen designed the upstream facing as a series of flat slabs instead of arch rings.

In a letter sent to City Engineer Cannon in July of 1915, Eastwood outlined the advantages of his design over that of Ambursen.[24] He related it directly to the arched upstream forms of his design and their necessarily compressive loadings. A dam must retain standing water for long periods of time, and it is imperative this water be kept from corroding the steel required to reinforce against tensile stresses. When a series of flat slabs supported by buttresses is uniformly loaded, the section of the slabs at midspan will necessarily deflect away from the loading. In the case of an Ambursen dam, this would mean that the slab facings would deflect downstream. Consequently, the concrete on the downstream side of the slab would be placed in tension, and cracking in the concrete resulting from these conditions could allow moisture to seep in and corrode the steel reinforcement. This water could seep through from the reservoir, or it could result from condensation; in either case, the structural integrity of the dam could be seriously threatened. Eastwood stated that the only way to prevent this cracking was to reduce the loading on the concrete, and the only way to do this was to increase the amount of concrete in this dam. Because of this, Eastwood predicted that the cost of an Ambursen dam would be much greater than an equally secure multiple arch dam.

On November 24, 1915, the bids on the Eastwood, Ambursen, and curved gravity designs for the Mountain Dell Dam were opened in the Salt Lake City Engineer's Office. Over ten different contracting firms submitted bids, and most bid on all three designs. The results clearly bore out the validity of Eastwood's claims concerning the economy of the multiple arch dam for the Mountain Dell Dam site. For the 145-foot-high structure, the low bids (rounded off) were as follows: Eastwood multiple arch dam: $139,000; Ambursen flat slab buttress dam: $217,000; concrete curved gravity dam: $230,000.[25] Breakdowns of the contractors' bids indicate Eastwood's multiple arch design was more economical because it required less excavation and less concrete than its competitors.[26]

Following opening of the bids, final approval of Eastwood's design by the State of Utah was required before construction could begin. Utah Governor H.M. Wells received an endorsement of Eastwood's designs from G.P. McGillicuddy, president of the Los Verjeles Land

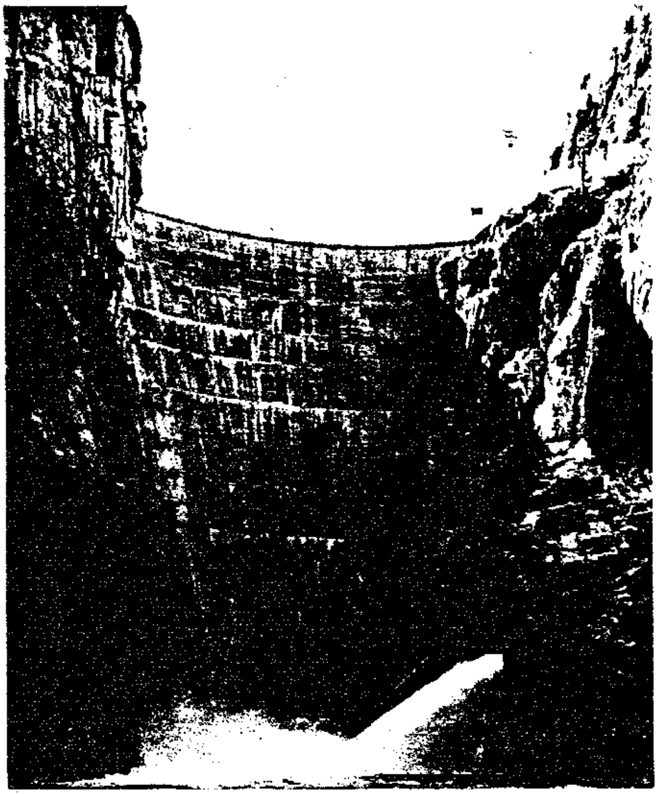


Figure 11. *Buffalo Bill Dam (formerly Shoshone Dam) near Cody, Wyoming, built by the Reclamation Service between 1905-1910. Over 300 feet tall, its crest length is only 200 feet. This was one of the first arch dams built by the Reclamation Service (later Bureau of Reclamation). 1974. (Courtesy of Jack E. Boucher)*

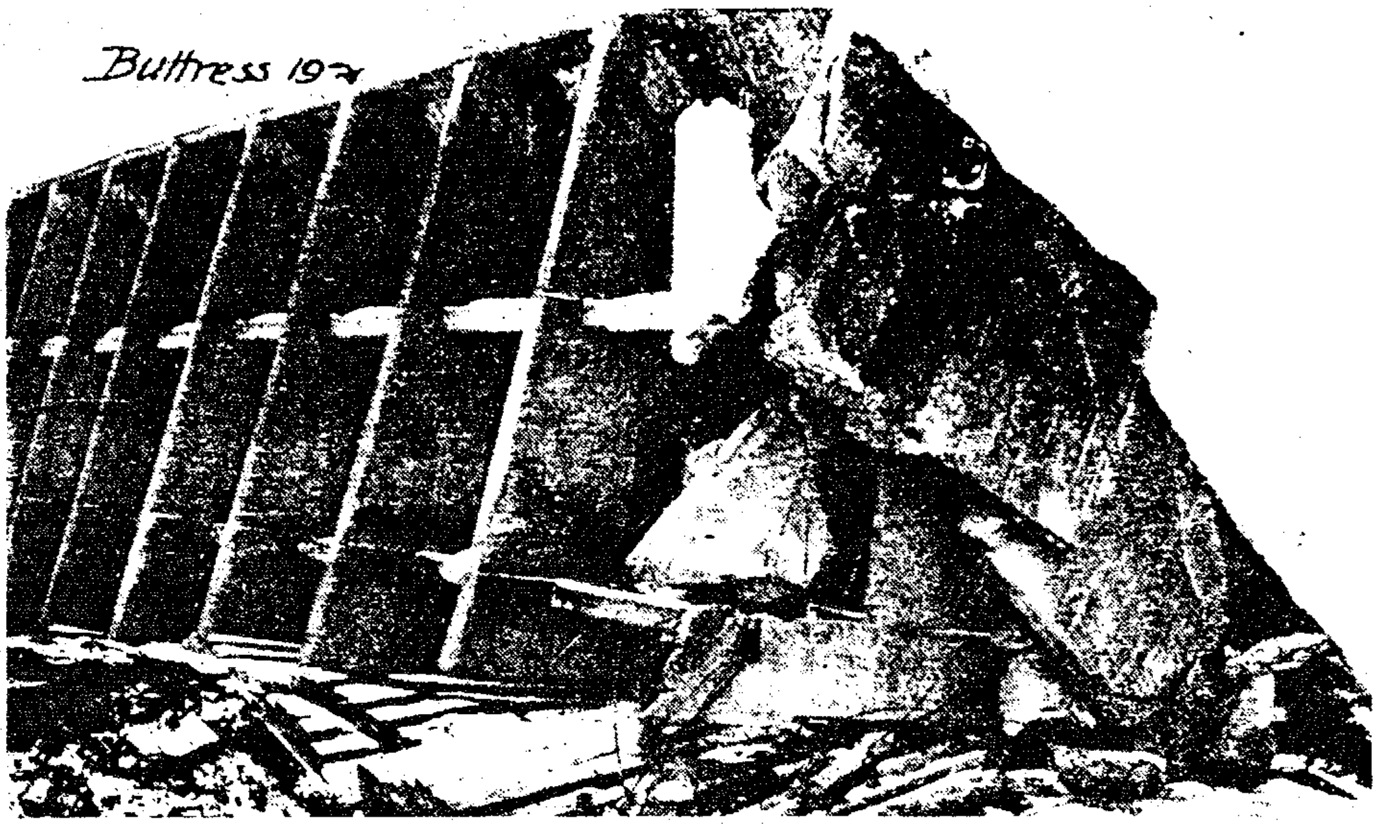


Figure 12. *The Stony River Dam in West Virginia following collapse. Investigators blamed the catastrophe on a failure to properly key the dam into its foundation. January 1914. (Courtesy: "The Reconstruction of the Stony River Dam," F.W. Scheidenhelm, ASCE* Transactions, *Paper No. 1397, page 914)*

and Water Company, of California, stating that his company had obtained excellent service from Eastwood's Los Verjeles dam. Going so far as to say, "For weeks at a time last winter, flood waters had to pass over its entire crest length to a depth of three feet, carrying over logs and debris with no injury or cost for repair," McGillicuddy expressed complete satisfaction with Eastwood's work and recommended his dams without reservation.[27] In mid-December, Eastwood made minor alterations in regard to the dimensions and reinforcement of the buttresses, per request by Cannon, and by the end of the month, the initial contract had been let to Parrot Brothers Contractors of Salt Lake City.[28] For construction of the first 105 feet of the dam, Eastwood was to receive $3,168.00, an amount slightly less than five percent of the initial contract price, for his services. Upon construction of the final forty feet, Eastwood was to receive an additional $2,672.00.[29]

Construction of the dam was a straightforward operation using standard methods of placing concrete in wood forms. For the buttresses and the outsides of the arch rings, sectional panel forms approximately five feet square and built up on 2" × 4" timbers were used. The inner forms for the arch rings consisted of trussed liners eight feet apart supporting vertical 2" × 4" ribs spaced every two feet around the arch. Two layers of heavy sheeting were then laid horizontally over these ribs to provide the contact surface for the poured concrete. To insure that the outside panel forms did not bulge during a pour, cables were attached to the buttresses, strung around tbe outer forms, and then cinched tight with a turnbuckle.

The concrete in the arch rings has a cement:sand:gravel ratio of 1:2:4, while the concrete in the buttresses has ratios of 1:2:5:5 and 1:3:6. The porosity of concrete is in large part determined by the amount of cement within the concrete mix. Because concrete with a higher percentage of cement is more watertight, it was specifically stated that the arch rings be constructed using a richer mix than the buttresses. Reinforcement of the arch rings consists of Clinton wire mesh, while some reinforcement of the buttresses is provided by one-inch twisted eyebars. The pouring of the concrete was facilitated by the use of a 125-foot-high distributing tower which delivered the concrete through chutes directly to the forms.[30]

Some struts have required patching due to deterioration, and the concrete in the structure can only be considered, at best, average in quality. A small amount of efflorescence, a phenomenon often affecting concrete, has deposited on the dam. This is evident on the whitish patches of calcium carbonate which have formed on the downstream face of the arch rings (Figure 13). Because concrete is slightly porous, water from the reservoir has, over the years, seeped through the facing and in the process dissolved lime present in the concrete. When this water subsequently evaporates upon reaching the downstream face, the lime reacts with carbon dioxide in the atmosphere to form a calcium carbonate deposit. Eastwood was aware of this phenomenon and believed the solely compressive loading within the arch ring minimized its occurrence and effect. If efflorescence is excessive, it can seriously weaken concrete. On the Mountain Dell Dam, it is not extensive and the structure's integrity is not impaired.[31]

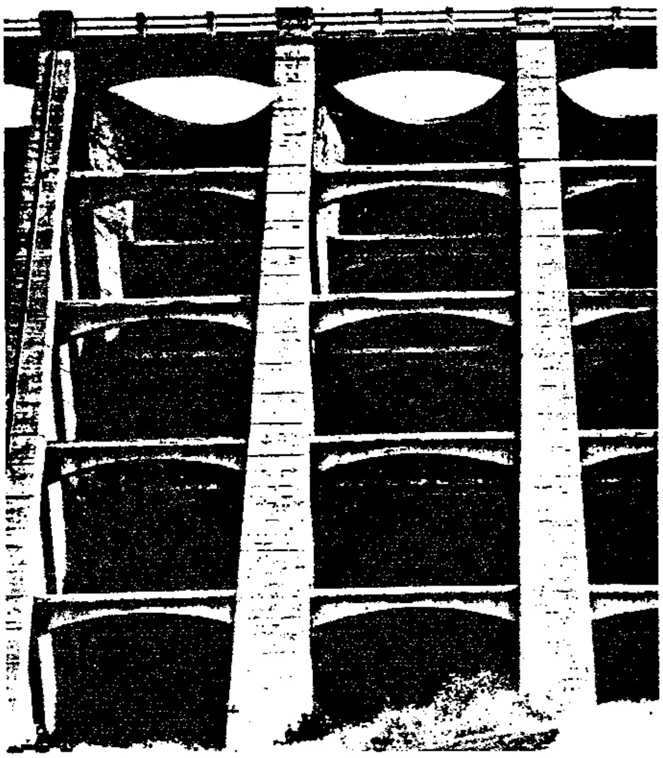


Figure 13. *Detail of buttresses, strut-tie beams, and the downstream face of arch-ring walls. Efflorescence is evident in the white patches and streaks on the arch rings. 1973. (Courtesy of Jack E. Boucher)*

In 1916-1917, the dam was constructed to its initial height of 105 feet above bedrock. Figure 14 shows the downstream side of the dam as it looked upon completion of the initial construction. The buttresses were stepped to insure a tight bond upon completion of the final forty feet.

Following the initial construction, Eastwood continued his career in water resource development and dam design, becoming involved in projects in California, Idaho, Arizona, Mexico, and British Columbia. Figure 15 is a photograph of Eastwood, his wife, and associates taken during an inspection of the 117-foot-high Murray Dam near San Diego in late 1917. He was not an "armchair" engineer, and he spent much of his life in the field working on practical problems of water control. Figure 16 shows him around 1900 involved in gauging the flow capacity of a stream in the Sierra Nevada Mountains during the design of the Big Creek hydroelectric project. He worked as a practicing engineer until the end of his life, when, in August 1924, at the age of 67, he drowned attempting to save a woman swept into the Kings River.[32]

Figure 14. *Downstream view of dam prior to construction of the top 40 feet. This photo group indicates the large amount of excavation required to facilitate construction of the buttresses on bedrock. March 1925. (Courtesy of Utah Historical Society)*

Figure 15. *Eastwood (foot on rail), his wife, Ella (on his right), and a group of associates inspecting the Murray Dam in San Diego County. ca. 1918. (Courtesy of Charles Allen Whitney)*

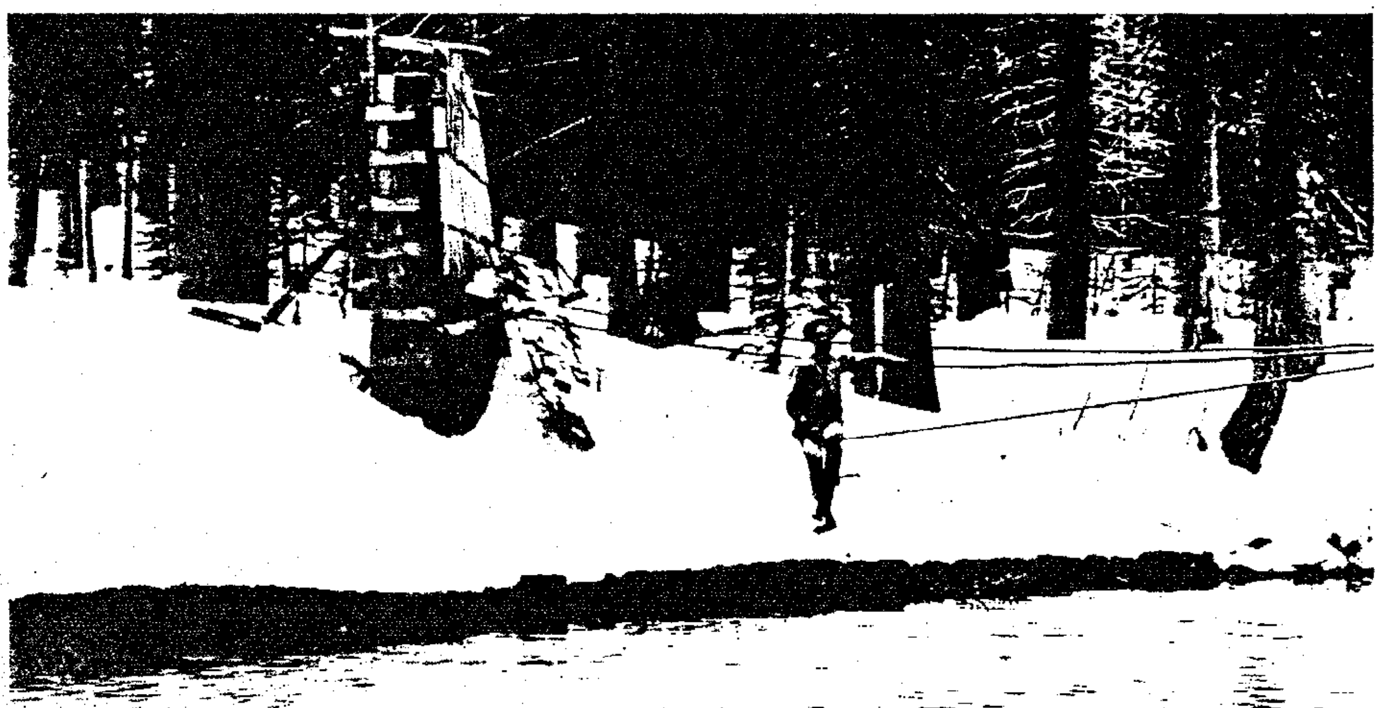


Figure 16. *John Eastwood involved in gauging the flow capacity of a stream high in the Sierras. ca. 1900. (Courtesy of Charles Allen Whitney,*

Late in 1924, Salt Lake City decided to complete the Mountain Dell Dam, and with Eastwood not available to supervise the construction, an alteration, simplifying his design, was made. Figures 17-19 show other dams designed by Eastwood, and it can be seen that the upper 10 to 12 feet of these structures' upstream faces is vertical. In using Rankine's Ring Formula, Eastwood determined the thickness of the arch rings according to their elevation. Near the top of the dam, he felt this formula to be inappropriate, as he believed a minimum "mechanical" arch ring thickness was required regardless of the possible water loading. In other words, there was a practical limit to how thin the arch ring should be built, regardless of water pressure. Given a minimum "mechanical" thickness, the construction of a vertical top to the arch rings provided an economy of material compared with construction of sloping arch rings to the same elevation. The vertical top shortened the length of the arch rings, and, consequently, the concrete required in their construction was reduced. The original plans for the Mountain Dell Dam included a vertical top, but they were changed prior to completion in 1925.[33] Many other engineers built multiple arch dams after he introduced the form, but the vertical top facing was an almost exclusive design feature of Eastwood's.[34] After his death, the Salt Lake City Engineer's Office chose to continue the inclined facing to the top of the dam and assume any structural effect resulting from this would be insignificant.[35] By doing so, they simplified the construction of the form work, though the amount of concrete required was increased.

It is important to recognize that Eastwood was a practical, innovative construction engineer and not a theoretical researcher into the properties of reinforced concrete. He considered himself an engineer, not a scientist, but he was proud to declare that he had developed a "scientific" dam design, i.e., one which would provide the safest, most practical, and most economical means of water storage.[36] He understood that every dam site presents a unique set of geological conditions, and, consequently, every site requires a dam especially designed for it. In his multiple arch dam designs, Eastwood varied the span of the arch rings, the arc enclosed by the arch rings, the upstream inclination of the arch rings, the downstream batter of the buttresses, and the maximum allowable stress within the concrete in determining the specific form of each structure, and, of course, these factors were interrelated. For example, the Mountain Dell Dam was originally to have the arch rings inclined upstream at an angle of 45° with a maximum allowable stress of 350 lbs per square inch (psi); however, Cannon later requested the allowable stress to be lowered to 300 psi. Consequently, Eastwood increased the angle of inclination to 50° 11′ because, with a greater percentage of concrete in the dam, less water was needed to provide a vertical component of weight.[37]

Although he considered himself the primary and most prolific designer of reinforced concrete multiple arch dams, Eastwood never claimed he had "invented" the multiple arch form for dams. He was aware of antecedents to his structures, including the vertically-faced masonry, Meer Allum Dam in Hyderabad, India, built by European engineers at the beginning of the 19th century, and the late 19th century, brick and plain concrete, Belabula Dam in Australia, as well as prior theoretical propositions such as Henry Goldmark's 1897 design for the Pioneer Power Plant near Ogden, Utah, and George Dillman's 1902 paper on economical dams.[38] However, Eastwood was the first to construct a reinforced concrete multiple arch dam on bedrock foundations and the first to demonstrate the economic advantage of doing so.

In the years following Eastwood's death, labor costs rose sharply in relation to material costs, and the multiple arch dam never received the widespread use Eastwood believed it warranted. Nevertheless, the structural form has continued to be employed in locations where material transport costs are great and a materially-efficient design is highly desirable. Perhaps the most spectacular example of this has been the 703-foot-high Daniel Johnson Dam (formerly Manicouagan Five) in Northern Quebec, built between 1962 and 1969. After consideration of all types of dams, engineers on the project chose a multiple arch design because of the economic advantages it afforded.[39]

Finally, it is appropriate to recognize the exemplary safety records that Eastwood's dam and all multiple arch dams have compiled. The recent (1976) Grand Teton Dam failure in Idaho, and the near disasters of the Lower San Fernando Dam (1971) and the Baldwin Hills Dam (1963) near Los Angeles, have provided startling proof that dam safety is not something which can be taken for granted. Although alteration of some Eastwood dams has occurred in the last half century, none has failed in any manner or been the cause of any loss of life or property. Dramatic evidence of the strength of Eastwood's dams is provided in Figure 20, which shows the Anyox Dam in British Columbia, Canada, in 1923. Following forty-eight hours of heavy rains, the reservoir behind the Anyox Dam filled up before the final fifteen feet of one arch ring had been constructed. Though water poured through the structure and, upon hitting the strut-tie beams, sprayed for over 200 feet, the structural integrity of the dam remained uncompromised.[40]

Eastwood's reinforced concrete multiple arch dam was a design created to meet a need considered to be inadequately met by other contemporary dams. The Mountain Dell Dam is representative of the seventeen dams built using his designs. The critical role played by economics in Salt Lake City's decision to build Eastwood's dam reflects a major concern of all who attempt to use water in the West. All

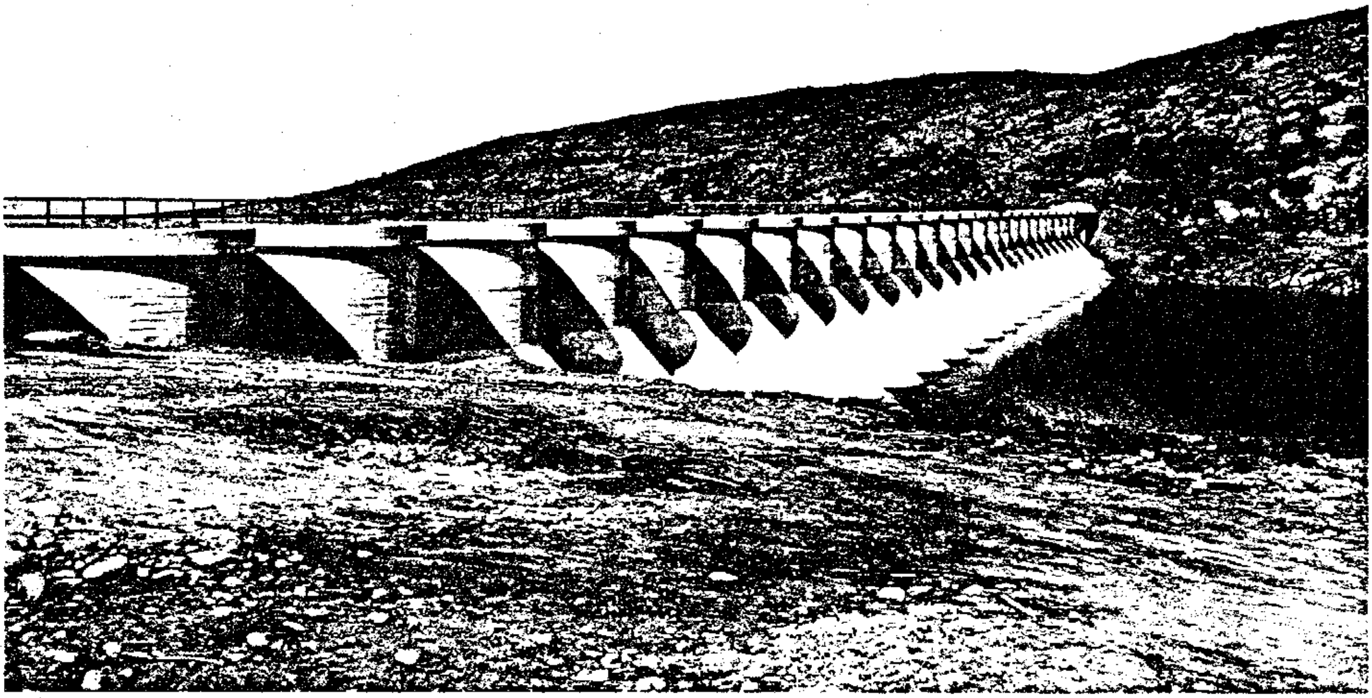


Figure 17. *The 117-foot-high, 900-foot-long, Murray Dam in San Diego County, California. Built for the Cuyamaca Water Company, it was one of four Eastwood dams built in the county during 1917-1918. March 1918. (Courtesy of Water Resources Center Archives, Berkeley, Calif. W.L. Huber Collection)*

Figure 18. *Built for the Bear Valley Mutual Water Company in 1910-1911, this was Eastwood's second dam and the first to include strut-tie beams. It replaced the famous 1884 single-arch masonry dam designed by F.E. Brown, visible in the foreground. The photo is of Eastwood. (Courtesy of Water Resources Center Archives, Berkeley, Calif., John S. Eastwood Collection)*

human activity depends on reliable sources of water, and by far the most expensive, as well as vital, component of any water storage system is the dam. Eastwood's primary objective in developing his multiple arch dam was to minimize the expense of water storage and allow maximum use of available financial resources.

The Mountain Dell Dam was built to serve a small, but growing, mountain community. Though the site was not located in the remote reaches of the mountains, Eastwood's multiple arch design was chosen because of the economic savings it promised local taxpayers.[41] At the time, few in Salt Lake City appreciated the theoretical nature of the design, or the experiences which led to its development, but many appreciated its low cost. Today, the dam (Figure 21) continues in its original capacity as an important component of Salt Lake City's water supply system.[42]

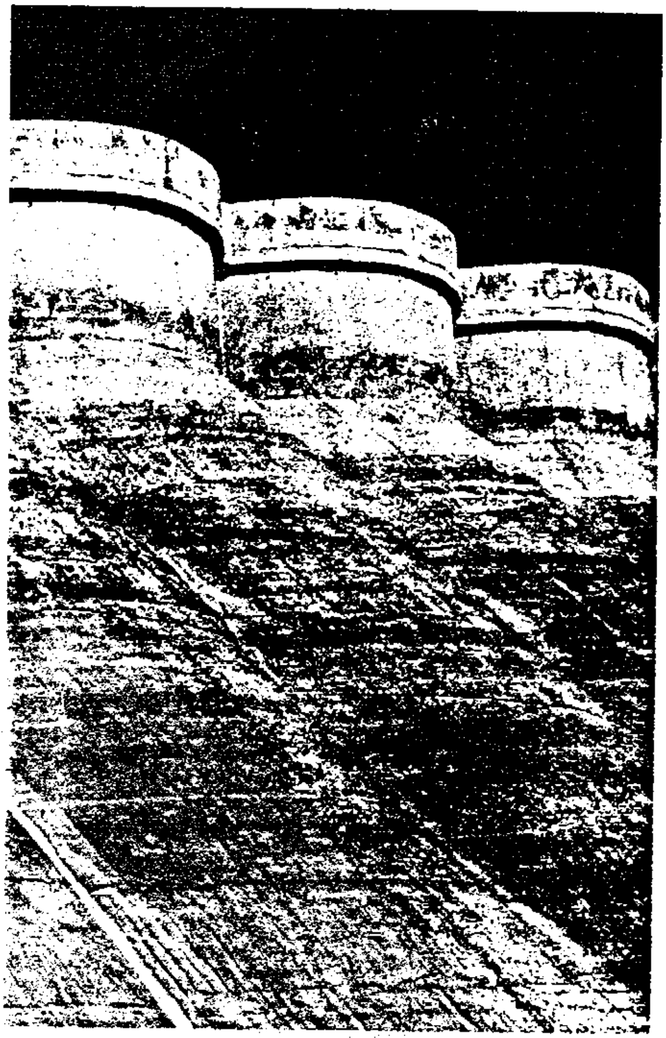


Figure 19. *In 1922-1924, the Little Rock and Palmdale Irrigation Districts built the 175-foot-high Little Rock Creek Dam in the San Gabriel Mountains north of Los Angeles. The tallest of Eastwood's dams, it was the only design feasible to construct, given the limited financial resources of the irrigation districts. (Courtesy of Donald C. Jackson)*

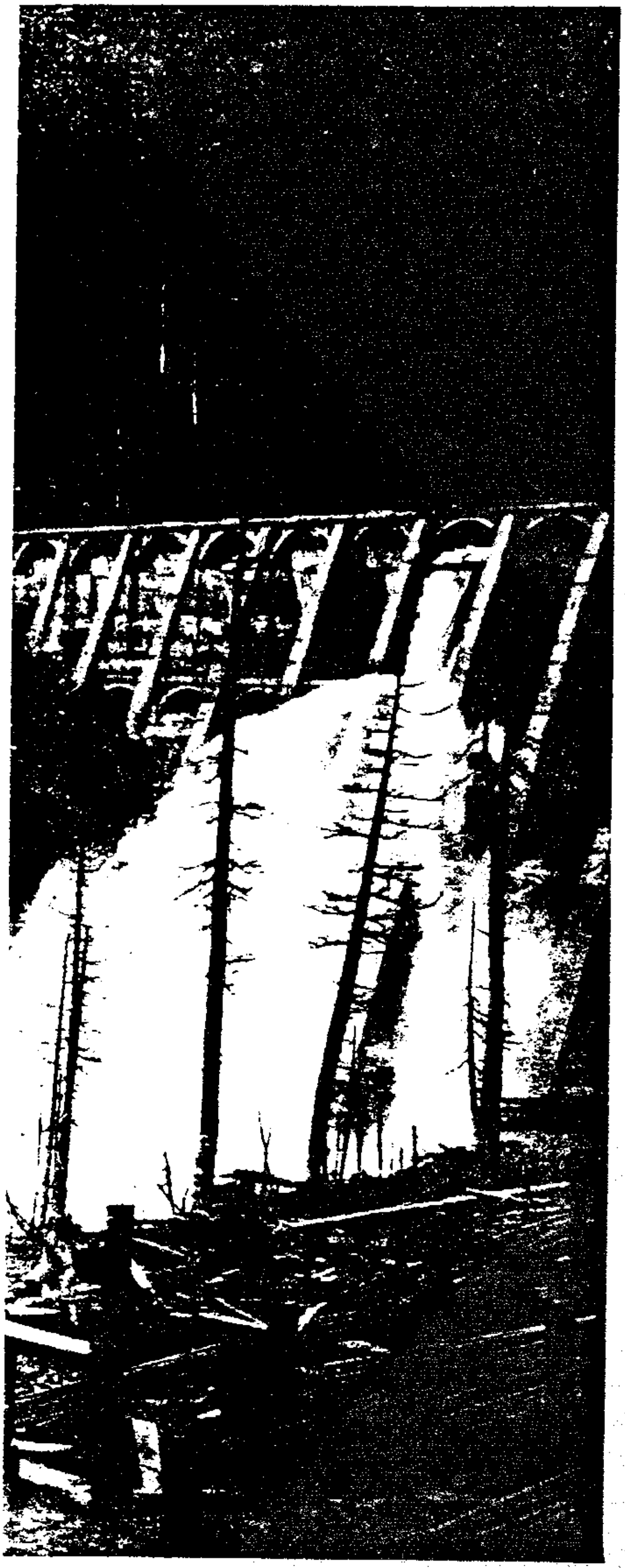


Figure 20. *Following severe flooding, the reservoir behind the 153-foot-high Anyox Dam filled up before completion of construction and water gushed through an open arch-ring. No damage occurred to the dam. December 1923. (Courtesy of Charles Allen Whitney)*

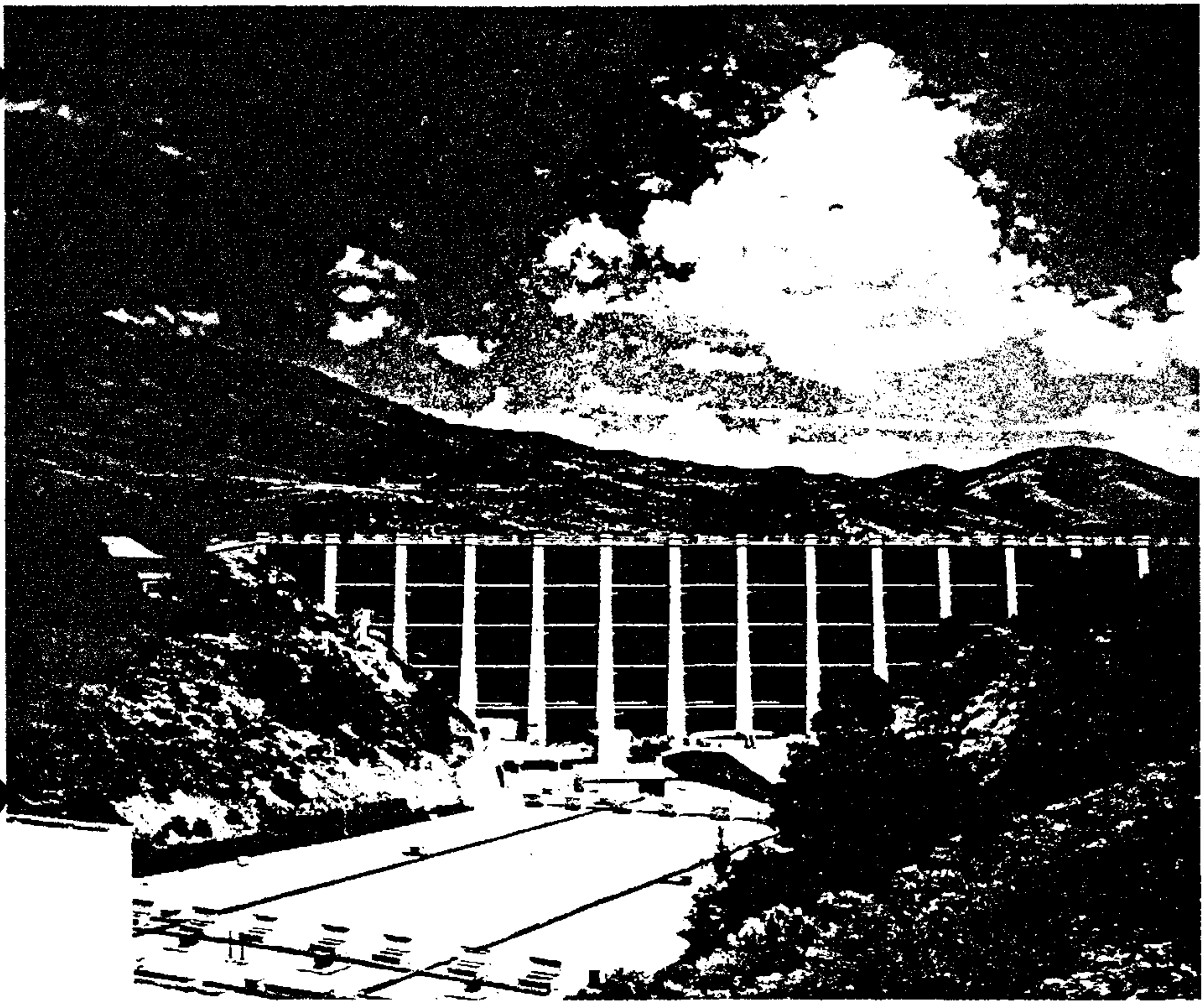


Figure 21. *Downstream face of Mountain Dell Dam with water treatment facilities in foreground. 1973. (Courtesy of Jack E. Boucher)*

Post-Publication Note:

Though this article underwent a gestation period of over 36 months between submittal and publication, there was little input from the journal's editor except in a very negative sense. As printed, the article lacks a conclusion that conveys to the reader the complex role of economics in western water resources development. The point is clearly made that multiple arch dams often provided the most economical solutions to water storage problems, but what are not elaborated upon are the reasons why more cities, towns, and government agencies did not build more multiple arch dams in the early 20th century. The Mountain Dell Dam was the first Eastwood dam built by a city government, and out of the 17 built between 1908 and 1924 using his designs, only two were contracted for by a municipal, state, or federal organization. Apparently, private companies were more interested in saving money than governmental entities were, perhaps because the latter could count on the taxpayers to "cough up" as much money as desired. The author also tends to believe there were wealthy interests involved in water development that were displeased with the idea of inexpensive dams because this would allow more people to build dams, and, consequently, centralized control of water would be more difficult to implement. For example, if the people in the Owens Valley had been able to pay for the construction of dams to control the water of the Owens River, then the possibility of Los Angeles being able to gain control and transport the water over 200 miles south would have been less. This article should not be considered the last word on multiple arch dams. It has presented a large amount of basic data on this type of structure but, in terms of historical analysis, much more remains, and is needed, to be said.

Donald C. Jackson 4/23/80

Footnotes

[1] Edward Wegmann with Fred Noetzli, *The Design and Construction of Dams* (New York, 1927); Lars R. Jorgensen, "Multiple-Arch Dams on Rush Creek, California," Paper No. 1396, *Transactions of the American Society of Civil Engineers*, 81 (1917), pp. 850-906. These publications provide clear evidence of Eastwood's claim to be the first builder of reinforced concrete multiple arch dams on bedrock foundations. Wegmann states on page VII, "...it was not until 1908 when the late John S. Eastwood, a California engineer, proved in competitive bids and by actual construction the economy of building multiple arch dams that a number of structures of this type reaching in heights upward of 250 feet have been built, both in this country and abroad." Construction of the Hume Lake Dam was first reported in "The Hume Lake Dam," *Journal of Electricity, Power and Gas*, 23 (October 30, 1909).

[2] "Application by J.S. Eastwood for membership in the American Society of Civil Engineers," Marguerite Eastwood Welch Notebook on John S. Eastwood, Bancroft Library, University of California, Berkeley. Eastwood's niece, Marguerite Eastwood Welch, donated a notebook of personal memorabilia, assorted newspaper clippings, and magazine articles to the Bancroft Library, the contents of which relate to her uncle. Though Eastwood was selected for ASCE membership in Sept. 1913, he never participated in the society's activities.

[3] Charles Allen Whitney, "The Life and Times of John S. Eastwood," unpublished manuscript; Charles Allen Whitney, "John S. Eastwood, Unsung Genius of the Drawing Board," *Montana, the Magazine of Western History,* 19 (Summer 1969).

Mr. Charles Allen Whitney of Santa Monica, California, is an engineer and a leading contributor to many technical and professional publications. In the late 1960's, Mrs. M.E. Welch hired him to write a biography of John S. Eastwood. This partially complete manuscript, which utilized many personal sources including Ella Eastwood's (John's wife) diary, has not been published, though Mr. Whitney did publish a short biography of Eastwood in the *Montana Magazine of Western History*. Mr. Whitney was very kind in assisting the author in the investigation of Eastwood and his multiple arch dams. Many illustrations accompanying this article are from Mr. Whitney's private files, which he allowed to be photocopied by the Historic American Engineering Record. The author is extremely grateful for his help.

[4] George P. Low, "The Fresno Transmission Plant," *Journal of Electricity*, 2 (April 1896), pp. 79-89. Operation of the transmission plant commenced in April 1896. A 4,020-foot-long steel penstock supplied water under a head of 1,411 feet. High-speed Pelton turbines powered General Electric generators, and electricity was transmitted to Fresno over thirty-four miles away. The AC current was three phase with a potential of 11,000 volts. Low stated that the plant operated under the highest head in the world at the time and transmitted power farther than any other commercial enterprise.

[5] Whitney, "Life and Times," Chapter one, pp. 53-56; Chapter three, p. 50; James Dix Schuyler, *Reservoirs for Irrigation, Power, and Domestic Water Supply* (New York, 1909), p. 108.

[6] David H. Redinger, *The Story of Big Creek* (Los Angeles, Calif., 1949), pp. 4-9.

[7] Charles Allen Whitney, "Dollars and Genius Built Southern California; The Story of Henry Huntington and John S. Eastwood," unpublished manuscript on file at the Water Resources Center Archives, University of California, Berkeley. In *The Story of Big Creek*, Redinger writes (page 8), "According to Mrs. Eastwood, he (John S. Eastwood) received only a small salary—just sufficient for living expenses—during the several years he spent on the preliminary work of the Big Creek Project (for the Pacific Light and Power Co.) because the future seemed bright. At last he lost everything." Today, Big Creek is owned by the Southern California Edison Company and supplies approximately six percent of the company's total power production.

[8] Sylvester Q. Cannon, "The Mountain Dell Dam," *Monthly Journal: Utah Society of Engineers, 3* (September 1917), p. 223 (hereafter cited as Cannon, "Mountain Dell"); Mountain Dell Dam Folder, John S. Eastwood Papers, Water Resources Center Archives, University of California, Berkeley (hereafter cited as MDD, JSE papers, WRCA). According to records in the archives, Eastwood's business papers and dam design data were sold after his death by his widow to Mr. Chester Loveland. In 1961, these papers, minus some material which had been inadvertently discarded, were donated to the Water Resources Center Archives. The assistance of head librarian of the Archives, Mr. Gerald Giefer, his head reference librarian, Ms. Mary Deane, and their staff was of great value in the preparation of this paper. Special thanks are due Ms. Deane for her unfailing good humor and kind help.

[9] S. Q. Cannon to J.S. Eastwood, June 10, 1915, MDD, JSE papers, WRCA.

[10] John S. Eastwood "The New Big Bear Valley Dam," *Western Engineering* 3 (December 1913), pp. 458-470. John S. Eastwood, "The Los Verjeles Dam," *Western Engineering* 5 (July 1914), pp. 7-9. John S. Eastwood, "The Kennedy Dam," *Western Engineering* 5 (April 1915), pp. 407-409.

[11] Multiple Arch Dam Folder, John S. Eastwood Papers, Water Resources Center Archives, University of California, Berkeley (hereafter cited as MAD, JSE papers, WRCA).

[12] MAD, JSE papers, WRCA.

[13] James Leffel, *Construction of Mill Dams* (Springfield, Ohio, 1881; reprint ed., Park Ridge, New Jersey, 1972), also in J.A. Garcia-Diego's, "The Chapter on Weirs in the Code of Juanelo Turriano," *Technology and Culture* 17 (April 1976), pp. 217-234, designs for 16th century Spanish diversion dams are illustrated with inclined upstream faces.

[14] Cannon, "Mountain Dell," p. 229.

[15] Dr. Glenn L. Enke, "Investigation of Elastic Behavior of a Multiple Arch Dam," (Ph.D. dissertation, Utah State University, 1972) (hereafter cited as Enke, "Investigation"). To insure that the horizontal thrust of the water did not destroy the buttresses by "shearing" action, Eastwood calculated the area A (in square feet) of a buttress and two half arches at various elevations and divided this by the horizontal hydrostatic force P (in pounds) acting at that elevation. He then made sure that the dam was proportioned so that the ratio P/A was less than 100 lbs. per square foot. This was a simple, straightforward way to approximate the shearing stress in the buttresses, and the use of a conservative allowable stress (100 psi) insured its reliability. MDD, JSE papers, WRCA.

[16] Big Meadows Dam Folder and Big Bear Valley Dam Folder, JSE Papers, WRCA.

[17] H.N. Savage, "The Shoshone Dam, U.S. Reclamation Service, near Cody, Wyoming," *Engineering News* 62 (9 December 1909), pp. 627-628. Readers interested in arch dams are referred to Nikalaus Schnitter's "Evolution of the Arch Dam" published in the October and November 1976 issues of *International Water Power and Dam Construction*.

[18] J.S. Eastwood to S.Q. Cannon, November 7, 1915, MDD, JSE papers, WRCA.

[19] William P. Creager, Julian Hinds, and Joel D. Justin, *Engineering for Dams*, 3 vols. (New York, 1947), 2:260.

[20] Ibid. p. 564.

[21] John S. Eastwood, "An Arch Dam Design for the Site of the Shoshone Dam," *Engineering News* 63 (9 June 1910), pp. 678-680. In this letter, Eastwood criticizes the Reclamation Service's Shoshone Dam for containing excessive amounts of concrete, most of which does not provide any additional safety. In questioning the economic validity of the Shoshone Dam's "constant radius" design, Eastwood proposed an equally safe "constant angle" design which would have required less than half the concrete. In the final years of his life, Eastwood designed multiple arch dams which utilized conic or "constant angle" arches. He built only one of this type of dam, the 90-foot-high Weber Creek Dam in Eldorado County, California.

[22] Wegmann, *Design and Construction*, p. 210. Early Ambursen dams include the 10-foot-high dam at Theresa Falls, New York (1903), the

65-foot-high dam in Ellsworth, Maine (1908), and the 135-foot-high La Prele dam in Douglas, Wyoming (1908).

[23] F.W. Scheidenhelm, "The Reconstruction of the Stony River Dam," Paper No. 1397, *Transactions of the American Society of Civil Engineers* 81 (1917), pp. 907-1024. Failure was blamed on an improperly constructed upstream cutoff wall, which allowed water to undermine the dam's foundation.

[24] J. S. Eastwood to S.Q. Cannon, 26 July 1915; MDD, JSE papers, WRCA.

[25] MDD, JSE paper, WRCA; "High Multiple-Arch Dam for Salt Lake City Water Supply," *Engineering News-Record* 78 (March 7, 1918). Some slight confusion exists concerning the height of the Mountain Dell Dam. Its ultimate height is sometimes given as 145 feet and sometimes as 150 feet. Dam height is measured from the deepest bedrock foundations to the highest part of the structure. Utilizing the geologic data provided by Cannon, Eastwood designed and proportioned the dam for a maximum height of 150 feet, but apparently bedrock was not as deep as originally thought and the structure was built only 145 feet high.

[26] MDD, JSE papers, WRCA.

[27] G.P. McGillicuddy to Governor H.M. Wells, December 9, 1915, MDD, JSE papers, WRCA.

[28] J.S. Eastwood to S.Q. Cannon, December 21, 1915, MDD, JSE papers, WRCA.

As reported in the *Engineering News-Record*, March 7, 1918, the wartime shortage of lumber increased the cost of wood used for formwork to the extent that the cost of the 105-foot-high dam was approximately $90,000 as opposed to the original low bid of $75,000. This cost increase would also have been incurred for the Ambursen and curved gravity designs.

[29] MDD, JSE papers, WRCA.

[30] *Engineering News-Record* 78 (March 7, 1918). Though an accepted practice at the time, chuting of concrete long distances is now considered inadvisable because of the separation of aggregates and cement which can occur. The relatively low strength of the dam's 1916-17 concrete is probably the result of chuting.

[31] Stephen Branauer and L.E. Copeland, "The Chemistry of Concrete," *Scientific American* 210 (April 1964), pp. 81-91.

The author thanks Mr. Howard Newlon of Charlottesville, Virginia, for his help in explaining the chemical nature of concrete.

[32] Whitney, "Unsung Genius of the Drawing Board," p. 49. The following lists Eastwood's known dams with completion dates (compiled by the author): 1. Hume Lake Dam, California, 1908; 2. Big Bear Valley Dam, California, 1910-11; 3. Big Meadows Dam, California (only partially built and never completed), 1911-12; 4. Los Verjeles Dam, 1913-14; 5. Kennedy Dam, California, 1914; 6. Argonaut Dam, California, 1916; 7. Mountain Dell Dam, Utah, 1916-17; 8. Eagles Nest Dam, California, 1917; 9. Murray Dam, California, 1917; 10. San Dieguito Dam, California, 1917; 11. Malad Dam, Idaho, 1917; 12. Lake Hodges Dam, California, 1917-18; 13. Cave Creek Dam, Arizona, 1922-23; 14. Fish Creek Dam, Idaho, 1919-20; 15. Anyox Dam, British Columbia, 1922-23; 16. Weber Creek Dam, California, 1922-23; 17. Little Rock Dam, California, 1923-24.

[33] Cannon, "The Mountain Dell Dam."

Accompanying this 1917 article are prints of Eastwood's original drawings, which clearly show the vertical top sections.

[34] Other designers of multiple arch dams include Lars Jorgensen of San Francisco, Fred Noetzli of Los Angeles, R.P. McIntosh of San Francisco, and Gardner S. Williams of Ann Arbor, Michigan. The Bureau of Reclamation has built only two complete multiple arch dams in its history. These are the 24-foot-high, Three Mile Diversion Dam (1914) on the Umatilla River in Oregon, and the 287-foot-high Bartlett Dam (1939) in Arizona (United State Department of the Interior, *Reclamation Project Data* (Washington, D.C., 1961)).

[35] In the *Engineering News-Record* 93 (October 20, 1924), p. 563, it was reported that Fred Noetzli had recommended to the Salt Lake City Engineer's Office that completion of the Mountain Dell Dam to a 145-foot height was safe.

[36] MAD, JSE papers, WRCA.

[37] J.S. Eastwood to S.Q. Cannon, November 7, 1915, MDD, JSE papers, WRCA.

[38] Wegmann, *Design and Construction*, p. 470; Schuyler, *Reservoirs*, pp. 386-387; Norman Smith, *A History of Dams* Secaucus, New Jersey, 1972), pp. 189-192. The concept of a multiple arch dam dates at least to the 16th century as described by J.A. Garcia-Diego in "The Chapter on Weirs in the Codex of Juanelo Turriano," *Technology and Culture* 17 (April 1976), pp. 229-230. There is evidence in the Multiple Arch Dam Folder, JSE papers, WRCA, that Eastwood prepared a draft patent for his multiple arch dam design ca. 1914-15, but there is no record of his ever filing an actual patent application. It has been stated that Henry Goldmark's dam was constructed (Carl Condit, *American Building Art*, 2 Vols. (New York, 1:264); however, as stated in Wegmann (p. 240), it never was.

[39] William W. Jacobus and Lilli Rathi, *Manic 5: The Building of the Daniel Johnson Dam* (Garden City, New York, 1971), p. 11.

[40] Wegmann, pp. 500-504.

[41] The author thanks Professor Thomas Hughes of the University of Pennsylvania for pointing out that this is a case of factor endowment.

[42] Enke, "Investigation."

Following a thorough examination of the Mountain Dell Dam in 1972, both physically and theoretically, Enke determined that the design was remarkably safe. His recommendations were that the upstream face of the dam be resurfaced with 1/32 inch nylon-reinforced butyl rubber and that all concrete showing signs of deterioration be throughly cleaned and then coated with a moisture barrier type of sealant. He also recommended that a permanent set of benchmarks and alignment discs be installed in the walkway across the top of the dam at each buttress, and at each abutment, to allow a periodic survey check capable of detecting any differential foundation rotation or settlement. With such measures taken, Enke declared the dam to be a safe and adequate structure with many years of service ahead of it.

Addendum to:
MOUNTAIN DELL DAM
Interstate Highway 80
Salt Lake City
Salt Lake County
Utah

HAER No. UT-16

HAER
UTAH,
18-SALC!,
22-

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
Department of the Interior
Washington, DC 20013-7127

HISTORIC AMERICAN ENGINEERING RECORD

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Addendum to:
MOUNTAIN DELL DAM
Interstate Highway 80
Salt Lake City
Salt Lake County
Utah

HAER No. UT-16

Data pages 1 through 26 were previously transmitted to the Library of Congress. This is data page 27.

INVENTORY OF PHOTOGRAMMETRIC IMAGES

The glass photogrammetric plates listed below are not reproducible except with special permission. However, reference prints and film copy negatives have been made from the plates indicated by an asterisk (*) and are included in the Library of Congress collection of formal HABS/HAER photographs.

2 5" x 7" glass plate negatives (one stereopair) produced by Perry E. Borchers of the Ohio State University in 1971.

One survey control contact print from each plate; survey control information for each pair.

LC-HAER-GS05-B-1971-1101L *	VIEW FROM WEST BELOW THE DAM--LEVEL
LC-HAER-GS05-B-1971-1101R	VIEW FROM WEST BELOW THE DAM--LEVEL
	Left and right overlap: 75%

PROJECT INFORMATION STATEMENT

Photogrammetric images were incorporated into the HABS/HAER collections in the summers of 1985 and 1986. Inventories of the images were compiled and filed as data pages for each structure recorded. Since the glass photogrammetric plates are not reproducible except with special permission, a reference print and film copy negative were made from one plate of each stereopair and from the most informative plates in sequential sets. The reference prints and copy negatives were then incorporated into the formal HABS/HAER photograph collections.

The Photogrammetric Images Project was a cooperative endeavor between the HABS/HAER Division of the National Park Service and the Prints and Photographs Division of the Library of Congress. The reference prints and film copy negatives of the original plates were made by the Library of Congress Photoduplication Service with funds provided by the Library of Congress Flat Film Preservation Fund. Additional reproductions were made by HABS/HAER. The project was supervised by HABS/HAER Architect John A. Burns, AIA, and completed by HABS Historians Jeanne C. Lawrence (University of London) in 1985 and Caroline R. Alderson (Columbia University) in 1986.

ADDENDUM TO: HAER UT-16
MOUNTAIN DELL DAM *HAER UTAH,18-SALCI,22-*
Parley's Canyon, Northwest side of I-80, West of State Route 39
Salt Lake City
Salt Lake County
Utah

COLOR TRANSPARENCIES

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
1849 C Street NW
Washington, DC 20240-0001