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Left—Bureau of Reclamation officials on an inspection tour in Black Canyon. Right—The first blast which was fired just above Black Canyon on September 16, 1930. Insert—Secretary of the Interior Wilbur driving a spike of Nevada silver to mark the beginning of construction of the railroad to Boulder City.

Construction of the Hoover Dam

*Some General Facts Regarding the Undertaking and the Men Who are Directing It**

By C. H. VIVIAN

BIDS for the construction of the Hoover Dam, power plant, and appurtenant works were opened March 4, 1931, at the Denver office of the Bureau of Reclamation. Only three bids were submitted, although contractors from all sections of the country were present and many of them had expected to bid until the time set for the opening drew near. The lowest bid, submitted by Six Companies Incorporated, of San Francisco, and subsequently accepted, was \$48,890,995.50. The second bid of \$53,893,878.70 was submitted by the Arundel Corporation, of Baltimore, associated with Lynn H. Atkinson of Los Angeles. Woods Brothers Construction Company, of Lincoln, Neb., and A. Guthrie & Company, of Portland, Ore., were the third bidders with \$58,653,107.50.

The voluminous plans and specifications prepared by the Government engineers, and appraised as models of their kind, divided the complete work into 119 separate items for bidding. On most of these items the three bids were fairly uniform. The only outstanding difference between the two lowest bids was on the item of placing 3,400,000 cubic yards of concrete in the dam, the respective figures being \$2.70 and \$4.15 per cubic yard. This variation accounted for \$4,930,000 of the \$5,002,883.20 difference between those bids. Both concerns bid \$8.50 per cubic yard

for the tunnel excavation. The three largest items in the successful bid were \$13,285,000 for the 1,563,000 cubic yards of tunnel excavating; \$9,180,000 for placing the concrete in the dam; and \$3,432,000 for lining the diversion tunnels with 312,000 cubic yards of concrete. No other single item was as much as \$1,000,000. From the foregoing facts it



U. S. Bureau of Reclamation
**Dr. Elwood Mead, Commissioner,
Bureau of Reclamation.**

can be seen that the construction of the dam and its associated works resolves itself into the performance of a few major tasks and a multitude of smaller but closely related ones. The successful bid was only \$24,000 more than the estimated cost as computed by the Government engineers. This was considered remarkably close figuring in view of the great size of the undertaking.

Upon the occasion of signing the authorization of the contract on March 11, Secretary Ray Lyman Wilbur of the Department of the Interior commented that it was the largest contract ever let by the Federal Government. He predicted that the consummation of the project would transform the desert region below the dam site into one capable of supporting 5,000,000 persons. "It is a satisfaction to see this great contract get underway", he said. "The Colorado River, instead of being a menace, will now be a great benefit".

Just how this project compares in size with previous ones of the same general character may be judged by the fact that the Bureau of Reclamation, during the 29 years of its existence prior to 1931, let contracts call for an aggregate use of 4,400,000 cubic yard of concrete, whereas 4,500,000 cubic yard will be required for this one job.

The terms of the contract, which departe



Some leading figures in the Hoover Dam project. From left to right—Ray Lyman Wilbur, Secretary of the Interior; Walker R. Young, resident construction engineer for the Bureau of Reclamation; F. T. Crowe, general superintendent for Six Companies Incorporated; Raymond F. Walter, chief engineer, Bureau of Reclamation.

omewhat from established practices, were considered very fair by bidders. They provide that the Government shall purchase practically all materials required, such as cement, steel, etc. This relieves the contractors from possible losses arising from fluctuations in the costs of materials. Accordingly, bidders were able to figure more closely the actual costs of doing the work. Another provision favorable to the contractors is that the Government will assume all damage which may result from floods experienced after the cofferdams and diversion tunnels are completed and accepted. This means that for more than two-thirds of the period of construction, the contractors will be relieved of loss from high water.

The entire work to be carried on under the Hoover Dam contract consists of five major divisions:

1. River diversion works, consisting of upstream and downstream cofferdams and four tunnels through rock, each 16 feet in diameter before lining with concrete and approximately 4,000 feet long.

2. A concrete arch gravity type dam 1,180 feet long on the west and 727 feet high, with a radius of curvature of 500 feet.

3. Two spillways, one on each side of the river, each consisting of a 50x50-foot stoney ate, a concrete ogee overflow rest 700 feet long, and a concrete-lined open channel.

4. Twin outlet works of similar design and capacity, each consisting of two separate

systems regulated by cylinder gates in the bottom of intake towers.

5. A U-shaped power house of concrete and structural steel immediately below the dam.

The Government will furnish all materials and equipment that become a permanent part of the completed structure, delivering it to the contractors at Boulder City, the construction town. The hydraulic and electrical machinery, equipment, and wiring for the power house will be installed by the Government, and the contractors will place concrete around such machinery as it is installed. The Government will also furnish and Six Companies Incorporated will install an inclined freight-car elevator alongside the canyon wall immediately below the power-house site on the Nevada side of the river. This will

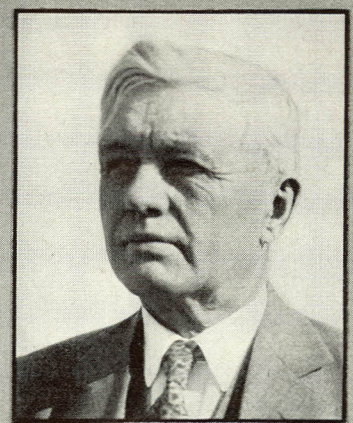
connect at its upper end with a highway from Boulder City, and will be available for transporting machinery and supplies for the power house to the canyon bottom, a vertical distance of approximately 600 feet. Sand, gravel, and stone for concrete will be taken by the contractors from a Government owned property known as the Arizona gravel pits located eight miles up the river from the dam site.

From an engineering standpoint, one of the most interesting clauses in the contract is that providing for induced cooling of the concrete in the dam as it is poured. The chemical reaction which takes place during the setting of concrete is accompanied by the generation of considerable heat. If large blocks are poured at a time, subsequent cooling may result in the development of contraction cracks. To promote cooling, it is customary to build large concrete dams in a series of columns of rectangular section and to leave spaces between these columns to provide for the greatest possible exposure of the faces to the air. Columns are built up in stages, the amount of concrete poured at a time being limited sufficiently to permit ample cooling before more material is placed on top of it. The spaces between the original columns are later filled with other columns, which are likewise built up progressively. Subsequent grouting helps to consolidate them into a solid or monolithic structure.

Because of the great mass of



Installing a 7,000-cubic-foot-per-minute compressor plant at lower end of the work on the Nevada side of the river.



Three officials of Six Companies Incorporated who are closely identified with the momentous work in hand. From left to right—Henry J. Kaiser, chairman of the executive committee; Charles A. Shea, director in charge of construction activities; and Director H. J. Lawler.

concrete—3,400,000 cubic yards—that will go into the Hoover Dam, however, the time required for its cooling by natural means would be unduly long. To expedite matters, it was decided to follow the columnar method of construction and to hasten cooling by circulating cold water through the concrete by means of built-in pipes. For this purpose, there will be 800,000 linear feet of 2-inch pipe or boiler tubing embedded in the concrete. This piping will remain a permanent part of the structure, and will be filled with grout under pressure.

Cold water for circulating through the concrete will be supplied by a refrigerating plant maintained by the contractors. With a thought for this latter phase of the work, Six Companies Incorporated bought air compressors for the initial or drilling phases of the operations that can readily be transformed into ammonia compressors on the ground. The compressors are Ingersoll-Rand 2-stage units driven by synchronous motors. Some are of the large Class PRE design; others are the intermediate size designated as Type XRE.

Most of the work during the first three years will consist of excavating and tunneling and making ready for subsequent operations. Placing of concrete in the dam proper is not scheduled to begin until December 1, 1934. The time allowance for completion of the contract is 2,565 days, or approximately seven years. The contractors are subject to a penalty of

\$3,000 for every day of overtime required to complete each of the five divisions of the work.

Six Companies Incorporated is a combination of six prominent contracting concerns operating in the West. It was incorporated in February, 1931, for the express purpose of pooling resources, experience, and personnel in so far as the Hoover Dam is concerned. For all other purposes, the several member firms have retained their individual identities and are carrying on their separate activities as before.

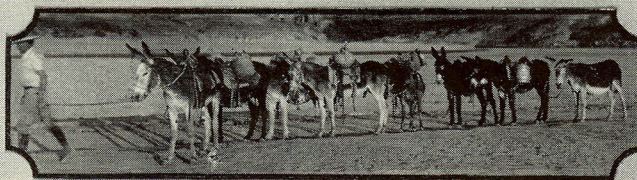
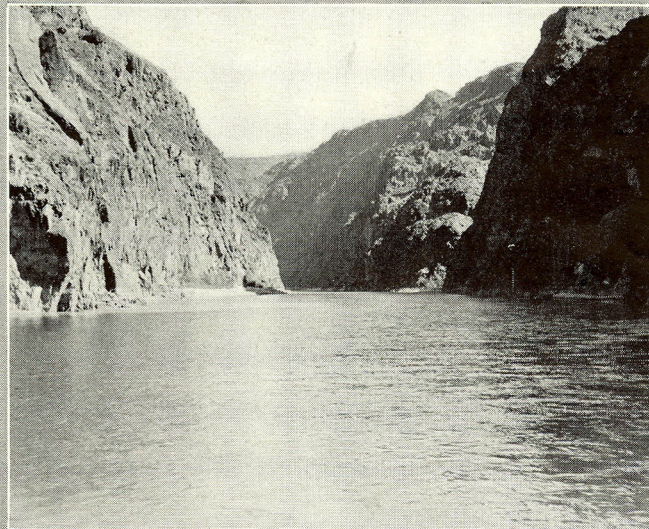
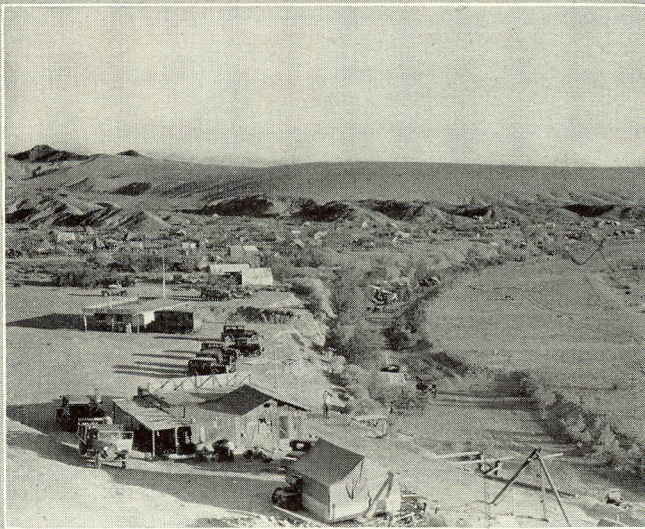
The firms making up Six Companies Incorporated, with the percentages of their participation in the profits or losses that may accrue from this contract, are: W. A. Bechtel, San Francisco, and Henry J. Kaiser, Oakland, Calif., 30 per cent; Utah Construction Com-

pany, Ogden, Utah, 20 per cent; MacDonald & Kahn Company, Los Angeles, 20 per cent; Morrison-Knudsen Company, Boise, Idaho, 10 per cent; J. F. Shea Company, Portland, Ore., 10 per cent; and Pacific Bridge Company, Portland, Ore., 10 per cent. These companies had, collectively, completed \$409,000,000 in contracts up to March, 1931, and had underway other work totaling more than \$30,000,000. All told, they had carried out 3,024 individual contracts, of which 178 were for Government work, and had 69 additional contracts in hand at the time they were awarded the Hoover Dam undertaking.

Of these member companies, the Utah Construction Company is perhaps the best known, as it has fulfilled contracts in virtually every state in the western third of the country. Since its formation, in 1900, it has done approximately \$200,000,000 worth of contract work—chiefly railroad construction, but including also considerable irrigation and reclamation work. The Pacific Bridge Company was organized in 1869 and has specialized in bridge building, particularly in underwater foundation work. W. A. Bechtel Company has been operating for seventeen years, during which period it has completed approximately \$30,000,000 worth of railroad, dam, and general construction contracts. Kaiser Paving Company, Ltd., dates its corporate existence back to 1913, and has specialized in paving contracts. MacDonald & Kahn Company, made



River camp of Six Companies Incorporated, at Cape Horn, above Black Canyon, where some 400 workmen make their homes.



Left—A section of "Ragtown", a riverside mushroom settlement above Black Canyon. Right—Black Canyon, viewed from above. Bottom—A pack train of one of the Government's early surveying expeditions along the Colorado.

up of Alan MacDonald and Felix Kahn, has a record of \$75,000,000 in contracts fulfilled, consisting chiefly of building construction on the Pacific Coast. The firm was formed in 1920. The Morrison-Knudsen Company, composed of H. W. Morrison and M. H. Knudsen, has been in business since 1912 and has completed \$30,000,000 worth of contracts covering the building of roads, railroads, dams, and other construction work. J. F. Shea Company has accounted for some \$40,000,000 in contracts since its organization in 1914. It has done a general contracting business, with special attention to tunnel work.

It can be seen from the foregoing brief resumé of their past activities that the component members of Six Companies Incorporated are admirably equipped to supervise and perform the many and diverse tasks that enter into the building of the Hoover Dam. Their combined experience covers every phase of the work now in hand. Some of the things to be done in Black Canyon are on a larger scale than ever before attempted, but among the personnel of the contractors are men who have had ample theoretical and practical acquaintance with the problems involved.

The officers of Six Companies Incorporated are: W. A. Bechtel of Bechtel & Kaiser, president; E. O. Wattis of the Utah Construction Company, first vice-president; H. W. Morrison of the Morrison-Knudsen Company, second vice-president; Felix Kahn of MacDonald & Kahn Company, treasurer; Charles A. Shea of J. F. Shea Company, secretary; K. K. Bechtel of Bechtel & Kaiser, assistant secretary and treasurer, W. H. Wattis, elected president of the company at

the time of its organization, died in September, 1931. He was for many years an officer of the Utah Construction Company, and was one of the leading construction men of the West. Directors of the company are: W. A. Bechtel, S. D. Bechtel, Philip Hart, Henry J. Kaiser, Felix Kahn, Alan MacDonald, H. W. Morrison, Charles A. Shea, E. O. Wattis, H. J. Lawler, and Guy LeR. Stevick.

While all the directors of Six Companies Incorporated visit the operations at regular intervals, the active management is in the hands of an executive committee composed of four members—Henry J. Kaiser, chairman; Charles A. Shea, director of construction; Felix Kahn, in charge of all activities of the subsidiary Boulder City Company which is charged with the feeding, housing, and transporting of the men; and S. D. Bechtel, in charge of purchasing, auditing, and warehouse activities. Mr. Shea spends most of his time on the job, and is as active as Francis T. Crowe, the general superintendent of Six Companies Incorporated, in supervising the manifold construction details involved. He acts as contact man between the board of directors and the operations personnel. In addition to the Boulder City Company, another subsidiary, the Hoover Dam Transportation Company, was formed.

The man upon whose shoulders rests the chief responsibility for carrying through this record-breaking contract is the general superintendent. Mr. Crowe is thoroughly schooled in the work he is directing, both from the standpoint of the contractors and of the Government bureau for which the work is being done. He is 49 years old, and was

graduated from the University of Maine. He entered the service of the Bureau of Reclamation in 1904 as engineering aid, and was advanced until he was general superintendent of construction attached to the Denver office when he resigned in 1925. While with the Bureau he was in charge of construction of the Jackson Lake Dam in Wyoming and of the Tieton Dam on the Yakima Project in Washington, the latter an earth-and-rock fill structure 222 feet high. He served for a time as assistant to the construction engineer on the 349-foot Arrowrock Dam in Idaho. He also was project manager of the Flathead (Indian) Project in Montana. In 1925 Mr. Crowe went with the Utah Construction Company and the Morrison-Knudsen Company, jointly, as superintendent of construction. In that capacity he had charge of the building of the Gibson and Deadwood dams, both Bureau of Reclamation enterprises.

Mr. Crowe will "live on the job" both literally and figuratively until the Hoover Dam is completed. He established his residence at Boulder City soon after the bids were opened, and has since been there almost continually. It is not unusual to find him down in the canyon at 12 o'clock at night and again at 5 o'clock the following morning. He has surrounded himself with a group of efficient assistants for directing the tasks in hand. Most of his immediate staff were taken from the various member firms of Six Companies Incorporated. Virtually all of them have had years of experience in construction work similar to that now facing them. To Mr. Crowe and his assistants the building of the Hoover Dam is just another job—a job that

differs from previous accomplishments only in point of size and time requirement.

Something has been said in previous articles of this series about the extensive investigations, by Government engineers, which led to the selection of the Black Canyon site. Any account of the building of the Hoover Dam would be unfair and incomplete if it did not pay tribute, at the outset, to the Bureau of Reclamation for its part in paving the way for the contractors. Once the dam site was chosen, an almost incomprehensible amount of detail work had to be done in the field in order that adequate plans and specifications might be prepared. As these data were obtained, their translation into printed forms necessitated an enormous amount of office engineering work.

Unfortunately, there is not available a written record of the activities of the field force. It goes without saying that many hardships were endured. Whereas the men who build the dam will live in a modern, sanitary, city, the engineers who pioneered this great undertaking had only a cluster of tents that they could call home. Deprived of all but the most primitive necessities, they traversed a country without roads and almost without shade, risked their lives on precipitous rock walls, and carried on in blistering summer heat. Dr. Elwood Mead, Commissioner of Reclamation, gives a hint of what confronted them in the following words:

"The survey of the dam site and reservoir was of unprecedented magnitude and difficulty. It involved coping with a river which, in the highest floods, rushed through the canyon with the speed of a railway train; of taking topography in more than 100 miles of canyon where precipitous cliffs 1,000 feet high and of indescribable ruggedness had to be scaled. Three lives were lost in this hazardous undertaking. Every phase of the work involved great danger, but the dimensions of the possible dam and reservoir had to be known. Then there had to be a topographic map.

"Anyone who views the canyon either from the top of the rim or from the river at the bottom has a sense of the peril and hardship involved in fixing locations and making measurements on its cliffs. To have done this work by the old methods would have delayed beginning construction six months to a year. Resort was had to aerial surveys. This involved great hardship because of the intense summer heat and in making observations at great differences in elevation".

While the Bureau has discharged with credit its great task of preparing the engineering preliminaries for this mammoth undertaking, it is still faced with the responsibility of supervising and checking every phase of the construction activities to see that the plans and specifications are faithfully followed. Space permits mention of only a few names of individuals who have been and will continue to be prominent in the Government's part in the building of the Hoover Dam.

As the Bureau of Reclamation is a division of the Department of the Interior, Secretary Wilbur is the nominal head of its activities.

Having served as president of Stanford University and lived in the West for many years, he carried with him to his present office a thorough understanding of the Colorado River problem and a realization of the benefits that would result from its solution. It was through him and his assistants that the agreements and contracts were carried through which made possible the start of actual construction operations.

Doctor Mead, directing head of the Bureau of Reclamation, is declared by many to be the world's leading authority on land reclamation. A long list of completed projects in the western part of the United States bears testimony to his efforts; and he has served as consultant and director on similar work in Australia and Palestine. Like Secretary Wilbur, he is a western man, having started his engineering career as state engineer of Wyoming.

As chief engineer of the Bureau and head of its Denver office, Raymond F. Walter had active charge of the engineering staff which planned and designed the Hoover Dam and its appurtenant works. He is a specialist on problems connected with irrigation and with power development. John L. Savage served as chief designing engineer for the dam.

Walker R. Young is resident construction engineer. He designed the Arrowrock Dam, until recently the highest in the world. He was in charge of the Kittitas division of the Yakima Project, which involved a unique and very difficult task of canal construction, and directed the field work in connection with the investigations of dam sites on the Colorado River. The Bureau of Reclamation has maintained an office at Las Vegas, Nev., 30 miles from the dam site, since construction began, and will this month move into the Government administration building in Boulder City. John C. Page is office engineer there.



Looking upstream in Black Canyon toward the site of the Hoover Dam. The lower portals of three of the four diversion tunnels are shown. In the lower right-hand corner is the settling basin where river water is clarified before being pumped six miles to Boulder City. The dam will be built at about the point where the river disappears behind the cliff at the right. From a photograph made about December 1, 1931.