Bridging the Grand Canyon with a 600-Ft. Steel Arch

Highway Structure on Route North from Flagstaff, Arizona, Will Eliminate Difficult and Dangerous Lee's Ferry Crossing

THE GRAND CANYON of the Colorado River is being bridged by the Arizona Highway Department with a three-hinged steel-arch structure 618 ft. center to center of end pins. This bridge was recently described in *Arizona Highways,* the monthly bulletin of the Arizona Highway Department, by Ralph A. Hoffman, bridge engineer of the department. The bridge is located about 130 miles due north of Flagstaff, Ariz., the nearest railroad point, and will eliminate the present river crossing known as Lee's Ferry, about six miles by road upstream from the site. It will also eliminate the narrow and dangerous piece of mountain road leading down the face of the bluff to the ferry from the Flagstaff side. Lee's Ferry was established in 1871. During a large part of its early existence it was owned by the Mormon Church, but later it was acquired by Coconino County, Arizona, and is now operated under toll by the county. The present road is not now widely known or traveled by tourists, but mostly accommodates traders and others whose business necessarily takes them that way. The bridge will open to automobile traffic a scenic part of the Southwest and provide a new route of north and south travel to points in Arizona and Utah.

A bridge was proposed at the present site many years ago by the Denver & Rio Grande R.R. A highway bridge was first surveyed in 1923, following which Congress passed a bill providing for an appropriation of $100,000 to be matched with state funds for the construction of a bridge. In the history of the project designs have been made both by the Bureau of Public Roads and by the Arizona state highway department, the design of the latter being the one that is now under construction.

The total length of the bridge will be 833 ft. The main span is to be a three-hinged arch of 618 ft. span and 90 ft. rise, c. to c. The trusses have 22 panels at 28 ft., are set on a batter, and are designed for cantilever erection. The

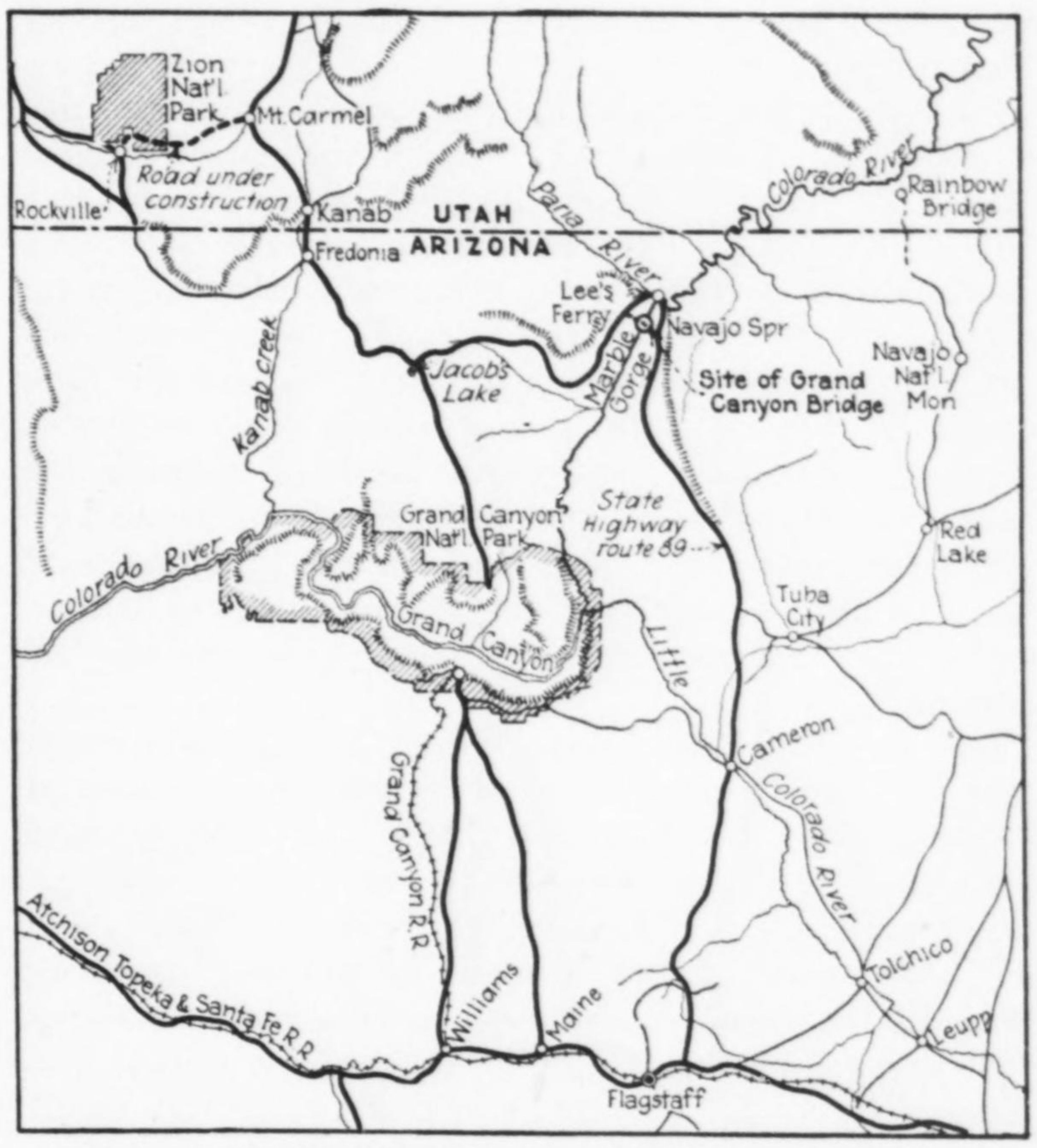


FIG. 1—LOCATION OF 600 FT. STEEL ARCH HIGHWAY BRIDGE ACROSS THE GRAND CANYON

bridge was proportioned for a loading of 60 lb. per sq.ft. on the reinforced concrete roadway, which has a clear width between curbs of 18 ft. The loading of the floor system was taken as one 15-ton truck or two $12\frac{1}{2}$-ton trucks side by side on the roadway. In this floor system, in order to utilize the excess material required in the top chord during erection, the floor load is carried on steel cross-beams at 4 ft. 8 in. spacing directly on the top chord. To reduce the dead load the curb was built of steel angle plates, this built-up member also acting as a stringer carrying part of the floor load.

The bottom chord is a box member built up of eight angles and three plates, the maximum section at the abutment being about 32 in. square, 36 ft. long and weighing about 12 tons. The bottom side of the bottom chord is laced with 6-in. channels. The top chord is also a built-up

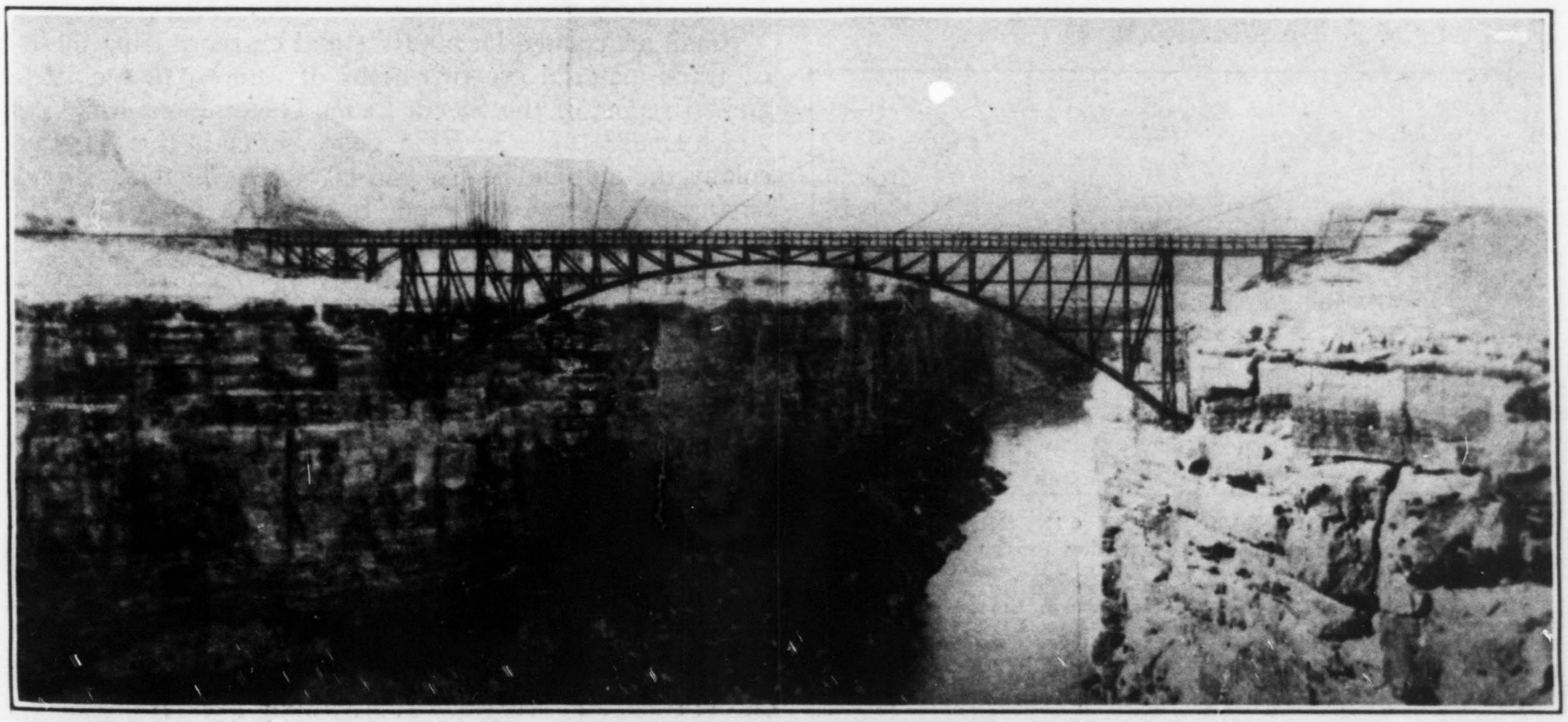


FIG. 2—STEEL ARCH HIGHWAY BRIDGE SPANNING GRAND CANYON
Arch is 600 ft. long and crown is 467 ft. above the Colorado River.

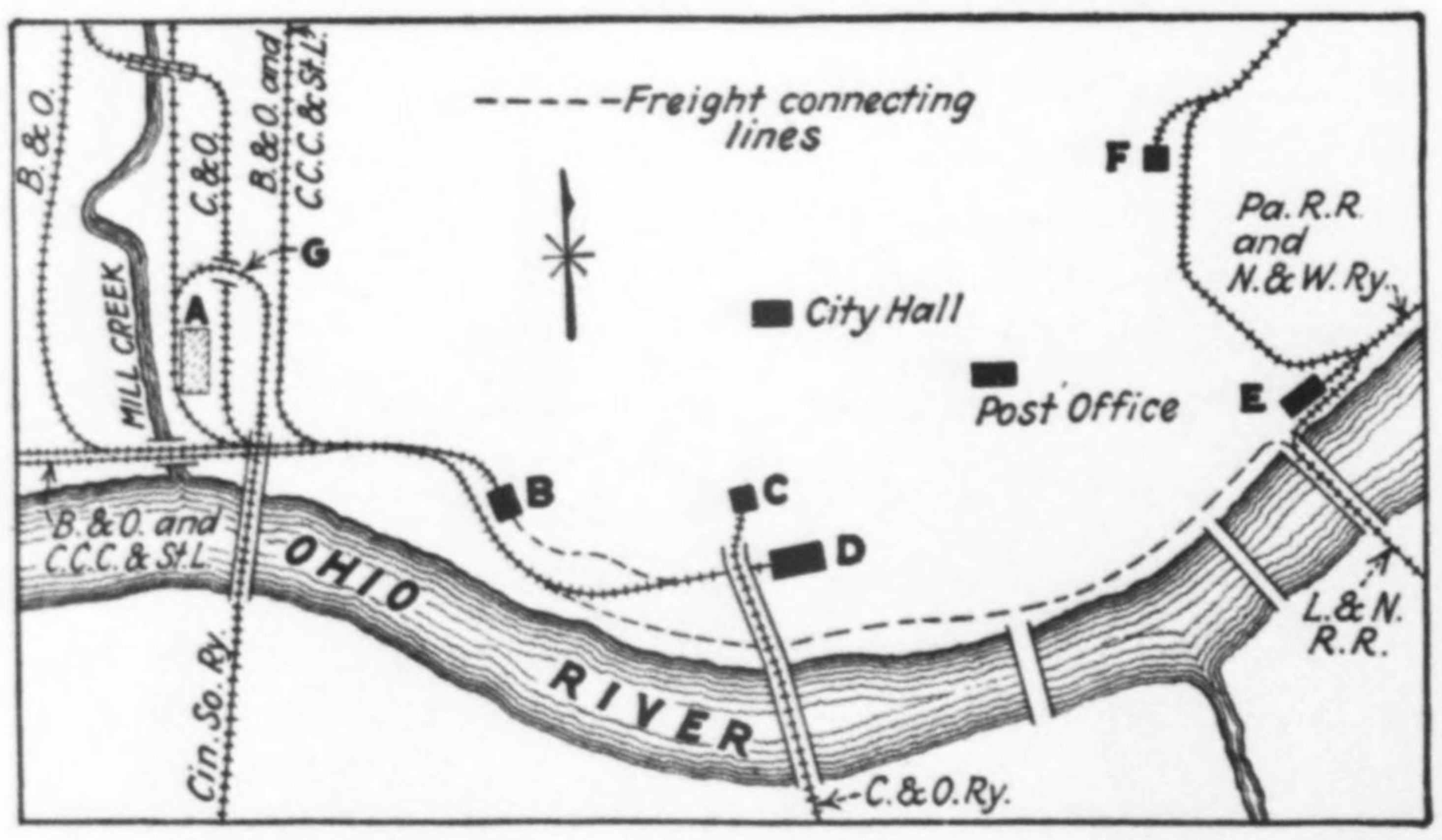
member of angles and plates with batten plates top and bottom.

For the approach spans the top chord is similar to that of the arch. Through this member the entire erection stress, amounting to about 750,000 lb. tension at each truss, is carried back to the erection anchorages. These chords also carry the floor system, on floorbeams similar to those of the main arch. After the erection stress is taken off, the box member is sufficient to carry this floor load in bending, in addition to its direct stress as the top chord of the truss. The bottom chords of the approach trusses and also the diagonals are made from the anchorage eyebars which had been made in exact lengths to fit the truss and used with packing rings in the eyes to compensate for the smaller pins required in the finished structure.

The contract price plus engineering expense totals $341,000. It was based on the following quantities of materials, all of which must be hauled 130 miles by road to the site of the structure: 500 cu.yd. concrete in foundations and deck, 83,000 lb. of reinforcing steel and about 1,875,000 lb. of structural steel; in addition, the price covered 9,000 cu.yd. of excavation. The contractors are the Kansas City Structural Steel Co. The design was prepared by L. C. Lashmet, designing engineer, under the supervision of Ralph A. Hoffman, bridge engineer, Arizona Highway Department. The contract calls for the completion of the structure Sept. 1, 1928.

Railway Terminal Improvements for Cincinnati, Ohio

A NEW union passenger station for the city of Cincinnati, Ohio, is assured by an agreement entered into between the Cincinnati Railroad Terminal Development Co. and the seven trunk line railroads entering the city. This agreement provides for the new passenger terminal, with coach yards and an engine terminal. It does not include freight terminals, but improvements in freight facilities are already planned or under way by some of the individual railroads. The cost of passenger terminal facilities is estimated at about $35,000,000, while the several freight terminal improvements of the individual roads are expected to bring the grand total to nearly $75,000,000.



PASSENGER STATIONS AT CINCINNATI
A. Approximate location for new Union Station. B. Baymiller St. Station: Baltimore & Ohio R.R. and Erie R.R. C. Fourth St. Station: Chesapeake & Ohio Ry. and Louisville & Nashville R.R. D. Central Union Station: Baltimore & Ohio R.R.; Chesapeake & Ohio Ry.; Cincinnati Northern R.R.; Cincinnati Southern Ry.; Cleveland, Cincinnati, Chicago & St. Louis Ry.; Erie R.R.; Louisville & Nashville R.R. E. East End Station: Louisville & Nashville R.R.; Norfolk & Western Ry.; Pennsylvania R.R. F. Court St. Station: Norfolk & Western Ry.; Pennsylvania R.R. G. Loop Approach to Cincinnati Southern Ry. Bridge.

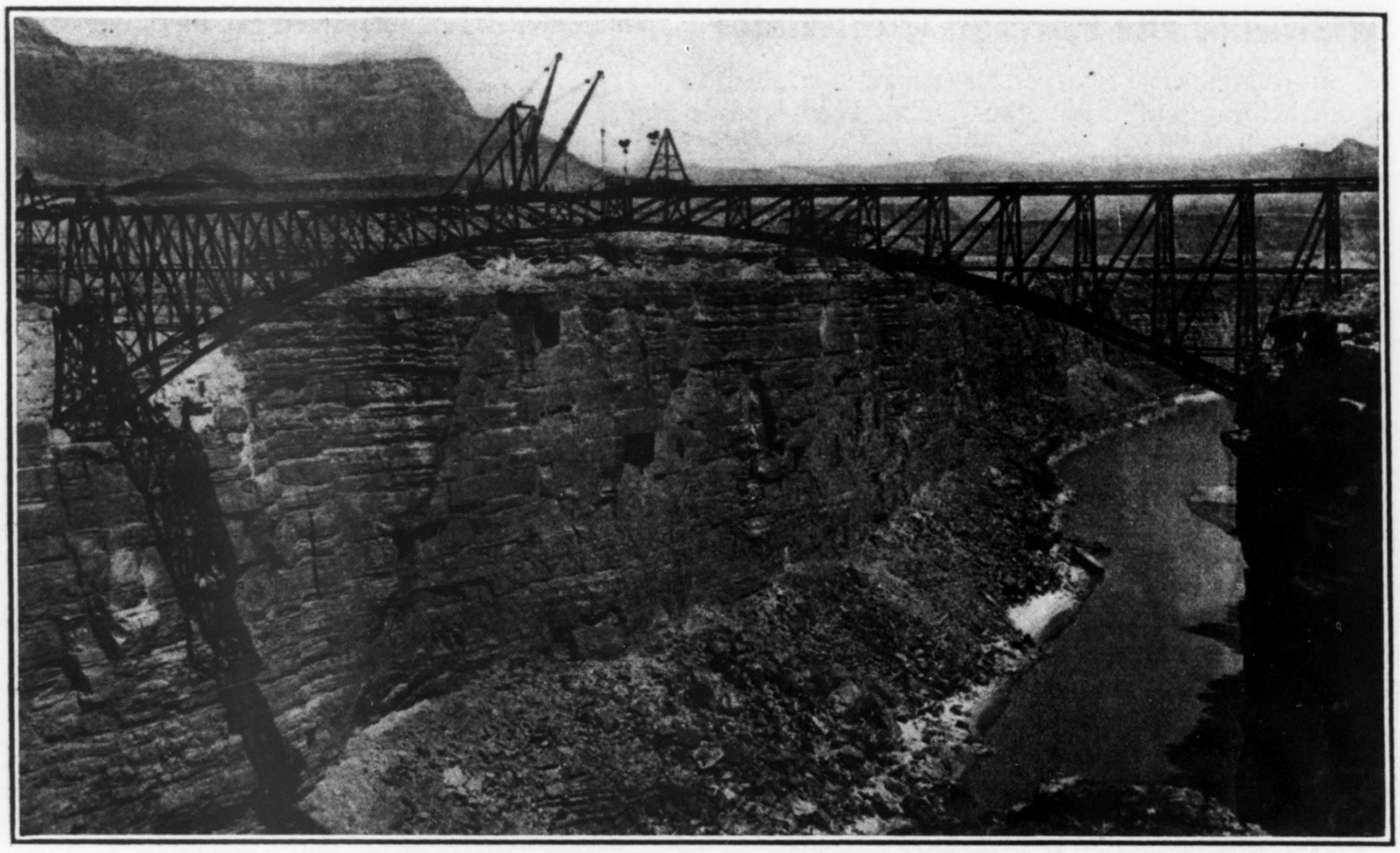
The terminal development company was organized in 1923 by a group of leading citizens, with George D. Crabbs as president, for the purpose of aiding the railways to secure adequate facilities, which were much needed and had been under discussion for several years. The present central station and its approaches are badly congested, while the original freight terminals have become outgrown by modern traffic conditions. Following this agreement with the railways, the Cincinnati Union Terminal Co. was organized in November by representatives of the terminal development company and the seven railroads. Its president is H. A. Worcester, vice-president of the Cleveland, Cincinnati, Chicago & St. Louis Ry. The new company has appointed as its chief engineer, Henry M. Waite, a former city engineer and widely known as the city manager of Dayton, Ohio, for several years; C. A. Wilson, consulting engineer of the terminal development company, is also consulting engineer for the new union station company. An architect will be appointed soon for the design of the station building.

A site has been proposed in the Mill Creek valley, on the west side of the city, outside of but adjacent to the business section. As the Pennsylvania R.R. uses two stations at the east side and does not enter the present union station, some special arrangements were necessary to enable it to reach the new union station. This has been effected by an agreement between the Baltimore & Ohio R.R. and the Pennsylvania R.R., by which the former grants running rights over part of its line and will build additional tracks for the use of the Pennsylvania R.R.

Improvements in freight terminal facilities and engine terminals are under way by some of the individual railroads, including the Baltimore & Ohio R.R. and the Cleveland, Cincinnati, Chicago & St. Louis Ry. (New York Central System.) The Chesapeake & Ohio Ry. is already at work on its new Ohio River bridge and approach lines, estimated to cost $12,000,000, while the Southern Ry. will undertake considerable work as a result of the recent extension of its lease of the Cincinnati Southern Ry.

The Sierra Leone Railway, Africa

Small articulated locomotives and extraordinary thefts of track material are two items of interest in the 1926 annual report of the Sierra Leone Government Railway, which has 338 miles of 30-in. gage. Even in this African colony the automobile has caused trouble to the railway, having so reduced passenger traffic on a line to a residential district (near Freetown, the capital) that abandonment of the line has been proposed. Steel ties are largely used, to which the rails are secured by steel keys or wedges, and during the year some 20,000 of these were stolen, or approximately 84,000 in four years. Other track material disappears in the same way. With ruling grades of 2 per cent, curves of about 400-ft. radius and an axle-load limit of 5 tons, the 23-ton 4:8:0 locomotives could handle only trains of 110 tons and the 20-ton 2:6:2 tank engines only 80 tons. New articulated locomotives of the Garrat type, weighing 45 tons, with 2:6:2—2:6:2 wheel arrangement and the same axle-load limit, can haul loads of 190 tons, with a saving in coal consumption, while the engines are easier on the track and bridges. T. A. Young is chief engineer, and R. Malthus, chief mechanical engineer.



Marble Canyon Arch Bridge Near Lee's Ferry, Arizona

Steel Arch Highway Bridge Across Colorado River

Truck Haul of 130 Miles Affects Design of Three-Hinged Arch With 616-Ft. Span—Floor 467 Ft. Above Low Water

A THREE-HINGED steel arch recently completed across Marble Canyon on the Colorado River 6 miles below Lee's Ferry, Ariz., will be the first bridge for wheeled vehicles in all the 600-mile length of this stream between Topock, Calif., and the junction of the Green and the Grand rivers in Utah, where the Colorado really begins. This bridge was urgently needed in order that a north and south highway between Arizona and Utah could be made safe and dependable by the elimination of a ferry and an extremely dangerous stretch of road within the canyon itself. The bridge is located 130 miles almost due north of Flagstaff, Ariz., which is the nearest railroad point. Because of this long truck haul, much of it over what was little more than a desert trail, more than ordinary consideration was given to the various types of bridges that might be selected and the weight of materials involved.

A suspension bridge was found to be too costly; a half through-arch would have required a heavy overhead cable system to carry the dead load of the entire span during erection and the entire cost of this overhead system would have been charged to the job because the cost of the 130-mile return haul would exceed its salvage value.

The final choice, therefore, was for a three-hinged deck arch, half of which could be erected from each canyon rim as a cantilever structure, making final closure in the center. This type afforded the advantage that members could be designed to withstand cantilever stresses during erection without any considerable increase of cost and most of the extra steel used temporarily in tie-backs, etc., later could be incorporated in the approach spans. These members intended for a dual function were designed so there would be as little field work as possible in converting them to the latter use. Eye-bars used in the tie-backs became the bottom chords or diagonals of the approach span trusses, in which the posts consisted of the bars used first in the erection toggles. These approach trusses were designed to use members of the exact length suitable for the tie-backs, packing rings being fitted into the eyes to compensate for the smaller pins required in the approach truss.

Some of the members of the approach trusses have a heavier section than would be required if it had not been necessary to use them as construction material. However, as the bids were taken on the basis of a pound price for steel, this plan resulted in a lower general price on structural steel than would have been obtained if erection material had not been used in the finished structure. Throughout the job there were the strictest economies in weight and the tonnage to be hauled in to the site was kept as low as possible.

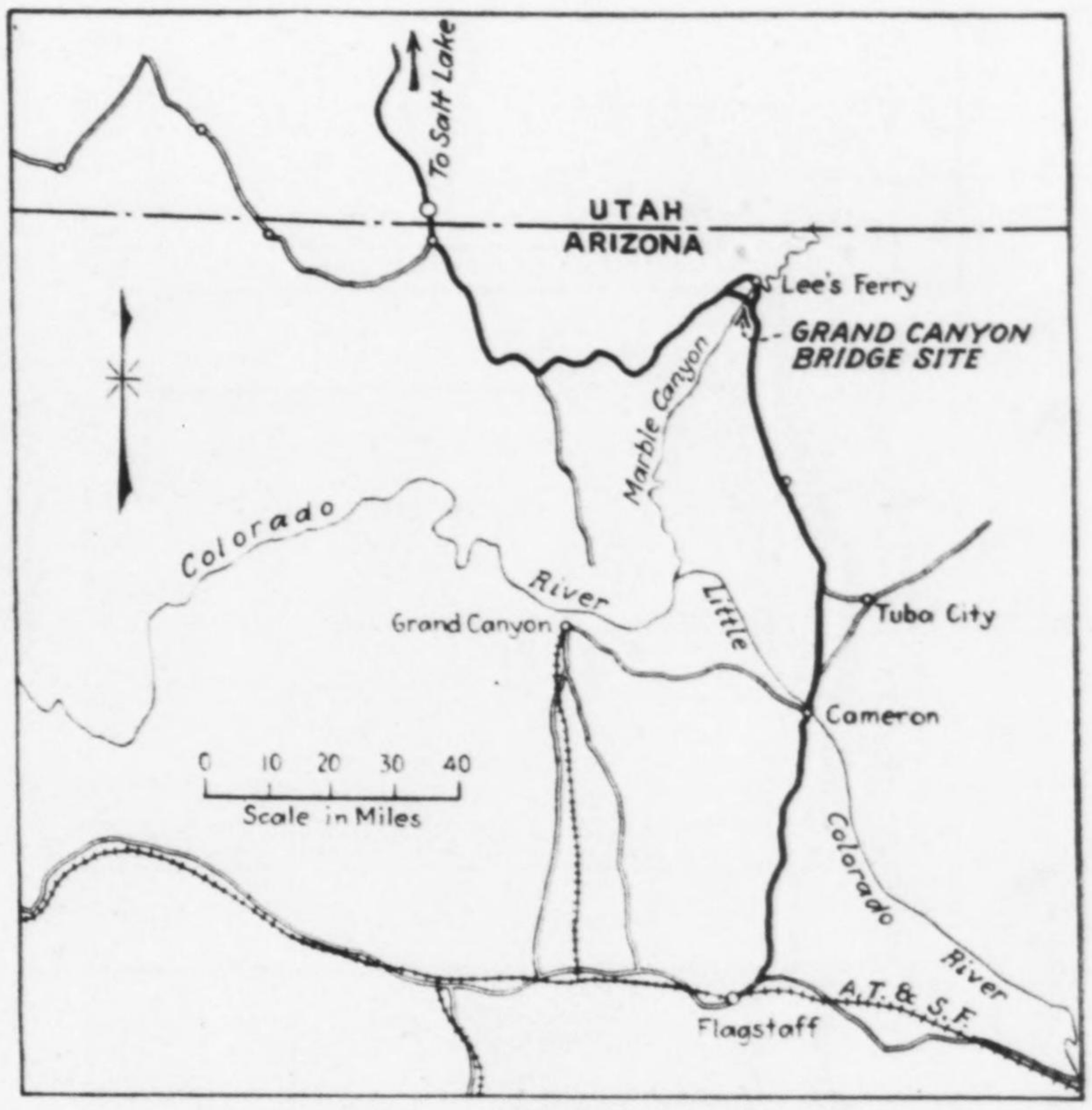
The total amount of freight for the job, including cement for the foundation as well as all erection equipment and materials (but not cement for the bridge floor), totaled about 1,500 tons, of which 1,200 tons was structural steel. The hauling contract stipulated that 10 tons per day should be delivered to the job continuously except when rainy weather made the roads impassable. The contractor employed two six-wheel trucks of 10- and 3½-ton capacities respectively, both equipped with 40x8-in. pneumatic tires. Some of the steel pieces were 53 ft. long and the maximum weight in a single piece was about 12 tons. These heavier loads required about thirteen to fourteen hours to make the trip.

The hauling contractor established a road camp about midway of the haul, and here the drivers changed shift. The extremes in temperature on this haul ranged from 110 deg. F. in the late summer to 16 deg. F. below zero in winter. Hauling through the snow would have been impossible were it not that the snow was confined to comparatively small areas at rather high elevations, and the hauling schedules were planned so as to cross these portions of the route at night, when the snow was frozen. The hauling contract was completed on schedule time and with the use of only the two trucks mentioned. Delivery of steel to the far side of the canyon was effected by a cableway slung across from the end of the first half of the arch on the south side.

In the canyon at the bridge site Kaibab limestone strata in horizontal layers afford ideal support as abutment footings. Niches were excavated on both sides of the canyon, care being taken to remove all loose or projecting rock to make sure that no slides or falling fragments would menace the completed structure. The estimate for this excavation was 9,000 cu.yd., but on the north rim a fissure was encountered entailing additional excavation and lengthening the arch span by 16 ft., and the total excavation was thus increased to 17,600 cu.yd. Only enough concrete was used to build up a footing of suitable shape under each truss, the total concrete for both ends of the bridge being not more than 100 cu.yd.

The main span, 616 ft. long, consists of 22 28-ft. panels. The roadway, 18 ft. wide between curbs, is 103 ft. above the bottom pins of the arch and 467 ft. above the river surface at low-water level. The total length is 834 ft., including two 84-ft. deck trusses on the north approach and two 25-ft. trusses at the south rim. The factors controlling the amount of rise in the arch were rock excavation and steel tonnage. An increase of the arch rise increased the rock excavation, and decreasing the rise increased the weight of steel required in the trusses. A 90-ft. rise from abutment pin to crown pin was found the most economical.

The main arch was designed for a uniform live load of 60 lb. per sq.ft. of roadway, or 15,000 lb. per panel point of each truss. The concentrated live load, and hence the basis for floor system design, was one 15-ton truck or

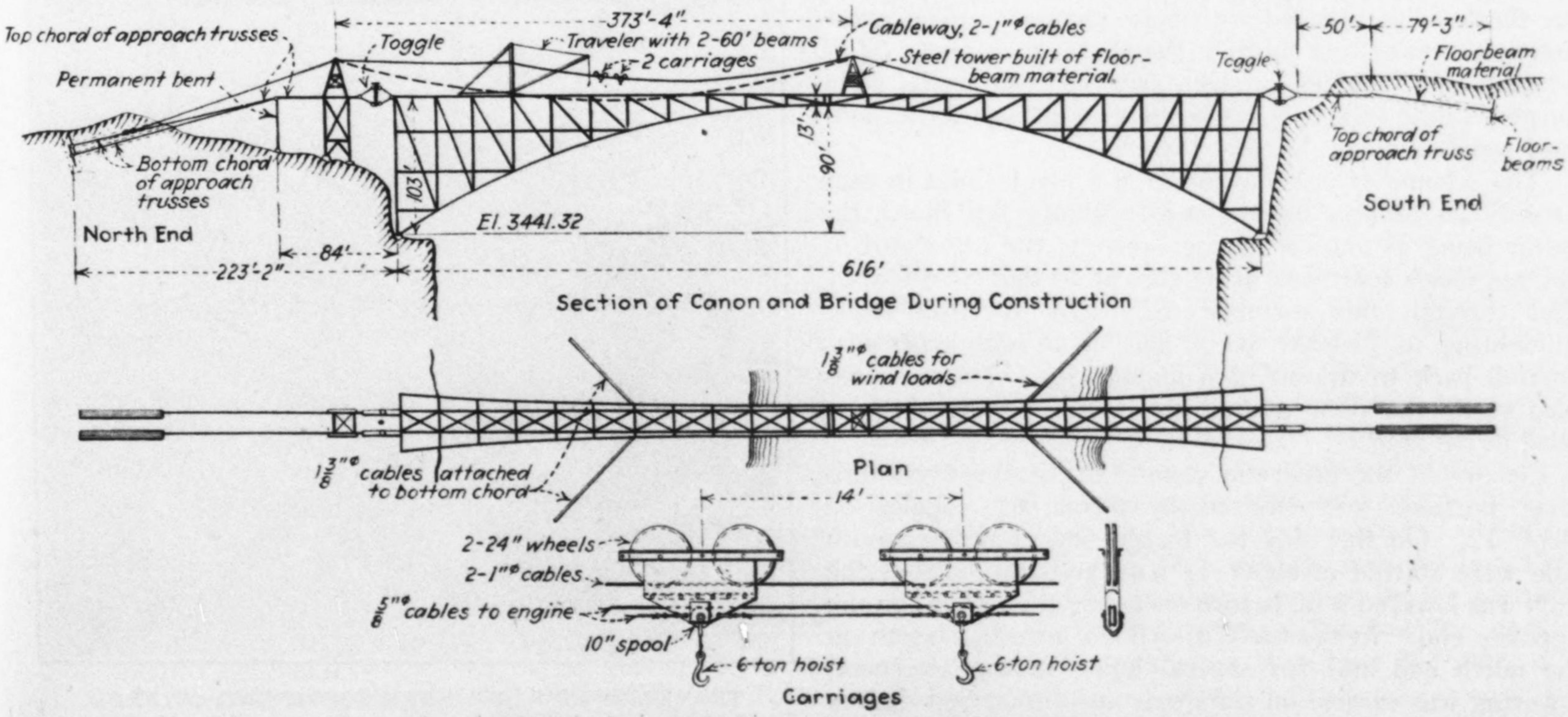


KEY MAP SHOWING LOCATION OF GRAND CANYON BRIDGE

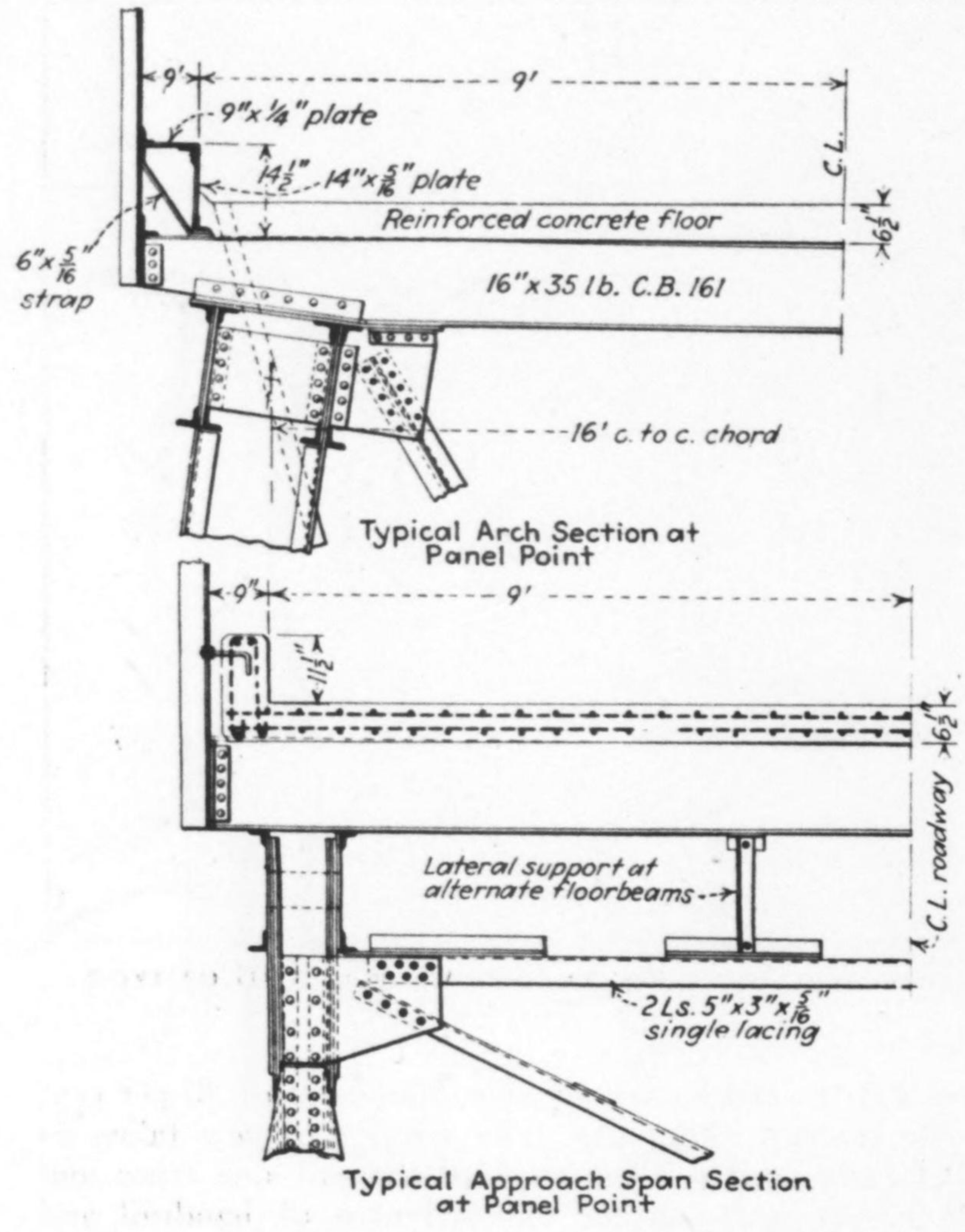
two $12\frac{1}{2}$-ton trucks side by side, allowance of 30 per cent being made for impact. The wind load was taken as 60 lb. per sq.ft. on the exposed area of one truss and 30 lb. per sq.ft. on the exposed area of handrail and floor system. To this was added 150 lb. per lin.ft. in the plane of the floor for moving load.

The erection load was worked out to allow for the use of a 30-ton erection traveler, with 15 tons on each truss, or a concentration of $7\frac{1}{2}$ tons on each of the two end panel points of each truss.

As first planned, the floor system was to be carried by longitudinal stringers over floor beams supported at the panel points. These plans were recast to utilize excess material required in the top chord during erection, the revised plans providing for a floor system supported on steel cross-beams spaced on $4\frac{2}{3}$-ft. centers and bearing directly on the top chords of the trusses. This materially reduced the total amount of steel in the structure.



PLAN AND ELEVATION OF THE STEEL ARCH



FLOOR SECTIONS ON ARCH AND APPROACH

A steel curb built of angles and plates was used, because the steel curb weighed about 30 lb. per lin.ft., as compared with 100 lb. for a corresponding concrete curb. This effected considerable saving because of the moment involved in the long span. The reinforced-concrete curb was cheaper, however, and was used on the approaches. The steel channels finally used in the curb were first employed during erection as rails for the track on which cars of material were moved out over the cantilever section.

The bottom chord of the arch truss is a box member built up of angles and plates, the bottom or open side of the box being laced with 6-in. channels. The maximum section of this chord at the abutment is about 32 in. square and includes a steel area of 140 sq.in. The largest single piece of this bottom chord was 36 ft. long and weighed about 12 tons.

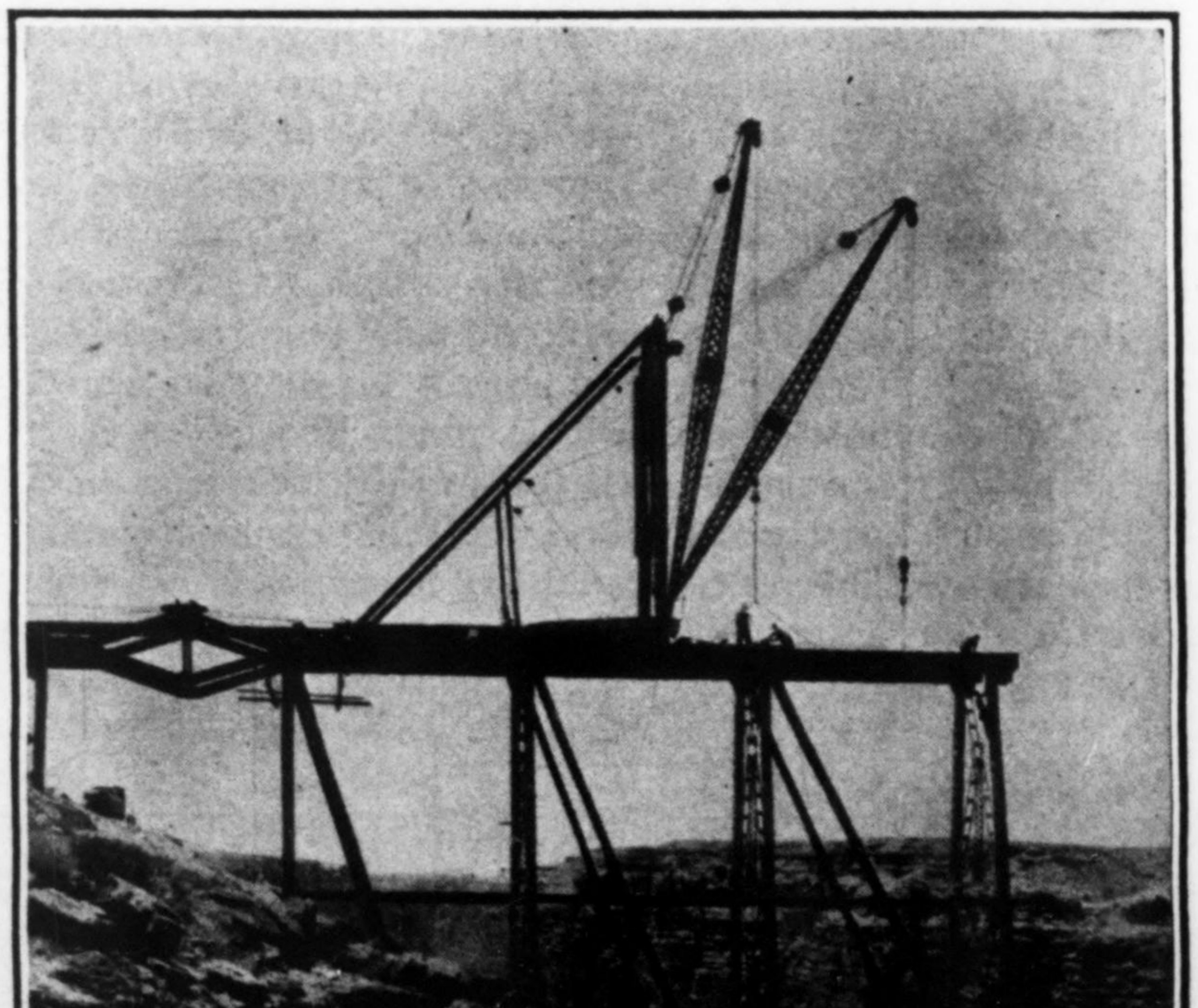
The scheme of erection involved a toggle joint in each truss. To connect the tie-backs with the top chord, the latter being in tension during erection, the top chord of the approach span was made similar to that of the arch, and through this member the entire erection stress amounting to 750,000 lb. in tension at each truss was carried back to the erection anchorages. These chords also carry the floor system on beams similar to those used in the arch.

Closure of the arch and connection of the two cantilever portions was effected by screw-jack toggles on Sept. 12. On that day the toggle screws on the south side were started at about 11 a.m. and this half of the arch was lowered 9 in. before operating the toggles on the opposite end. In the early afternoon lowering began on the north end and for several hours in the afternoon lowering was carried on simultaneously upon both halves in order to keep the pin sockets from binding on the pins which were secured in place in the steelwork of the south side. Final closure with both halves bearing on the pins was accomplished at about 5:30 p.m.

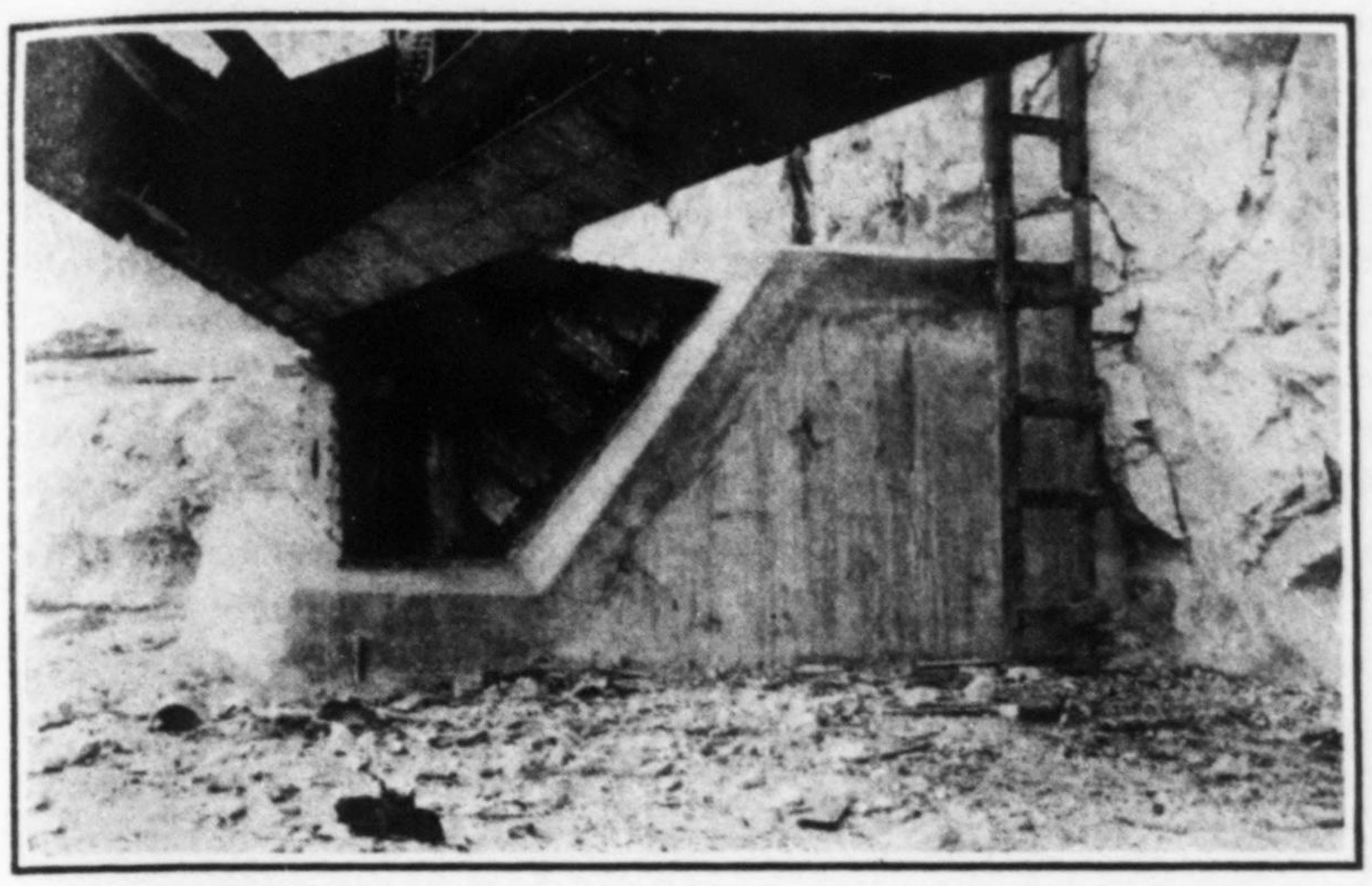
A notable point in this closure was the quick lowering of temperature after sundown, which caused the steel to contract so rapidly that it was necessary to continue the operation of the toggle screws until about 9 p.m. in order to prevent the toggles from again taking the stress of the center pin. According to calculations made at the time of design, temperature variations of 40 to 50 deg. F. would cause the span length to change nearly 2 in. After sundown on the day of the closure the toggle screws were operated as fast as possible to keep pace with the shortening. One of the screws on the north end was stiff and slow in operation and when it became apparent that it could not maintain the necessary speed, the screw was cut in two with the oxy-acetylene torch.

Due to the additional excavation that delayed work on the north half of the arch, it was known early in the construction period that the south half would be completed first. Hence final boring of the pin-bearing plates to go on the river end on the north half of the arch was not done in the fabricating shops when the other members were being finished. Instead, direct measurement was taken across the uncompleted portion of the span when the north half had approached to within three panel lengths of closure. This afforded a check on calculations and still allowed time to complete the shop work and get the final pieces on the job when they were needed.

First plans called for a timber floor because of the



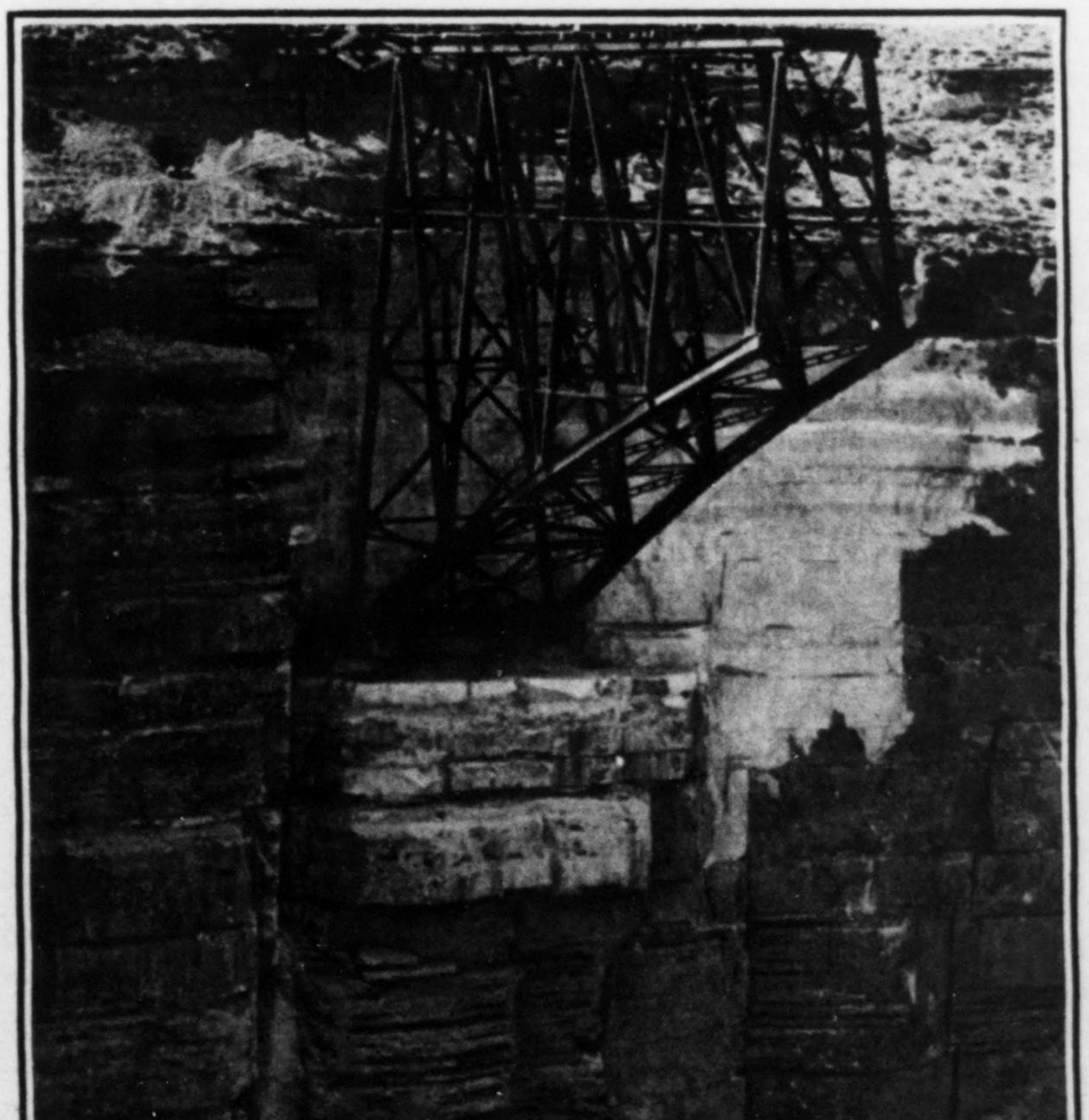
TRAVELER AT WORK NEAR SOUTH END OF ARCH
Note toggle in top chord and arrangement of double boom traveler. This view looks downstream.



SHOE AND THRUST FOOTING AT NORTH ABUTMENT

lighter weight and lower cost. However, the danger of fire in this remote location and the possibility that a floor system fire might endanger the entire structure made it desirable to use a concrete roadway. This was laid out as a 6½-in. heavily reinforced-concrete slab weighing 81 lb. per sq.ft. and spanning across the spaces between beams, which are 4 ft. 8 in. apart. The handrail will be of steel with posts resting on alternate floor beams—that is, 9 ft. 4 in. on centers. The latticed railing with steel posts will weigh about 45 lb. per lin.ft. The camber in the bridge is 15 in. at normal temperature.

For safeguarding the steel workers a hemp rope safety net was built designed to be slung under the cantilever span during erection. This was never used, however, partly because of the danger attending its erection and partly because of the frequent necessity for moving it as the work progressed. One steel worker fell from the bridge during erection. He was doubtless killed by the impact of the long fall and his body was never recovered,

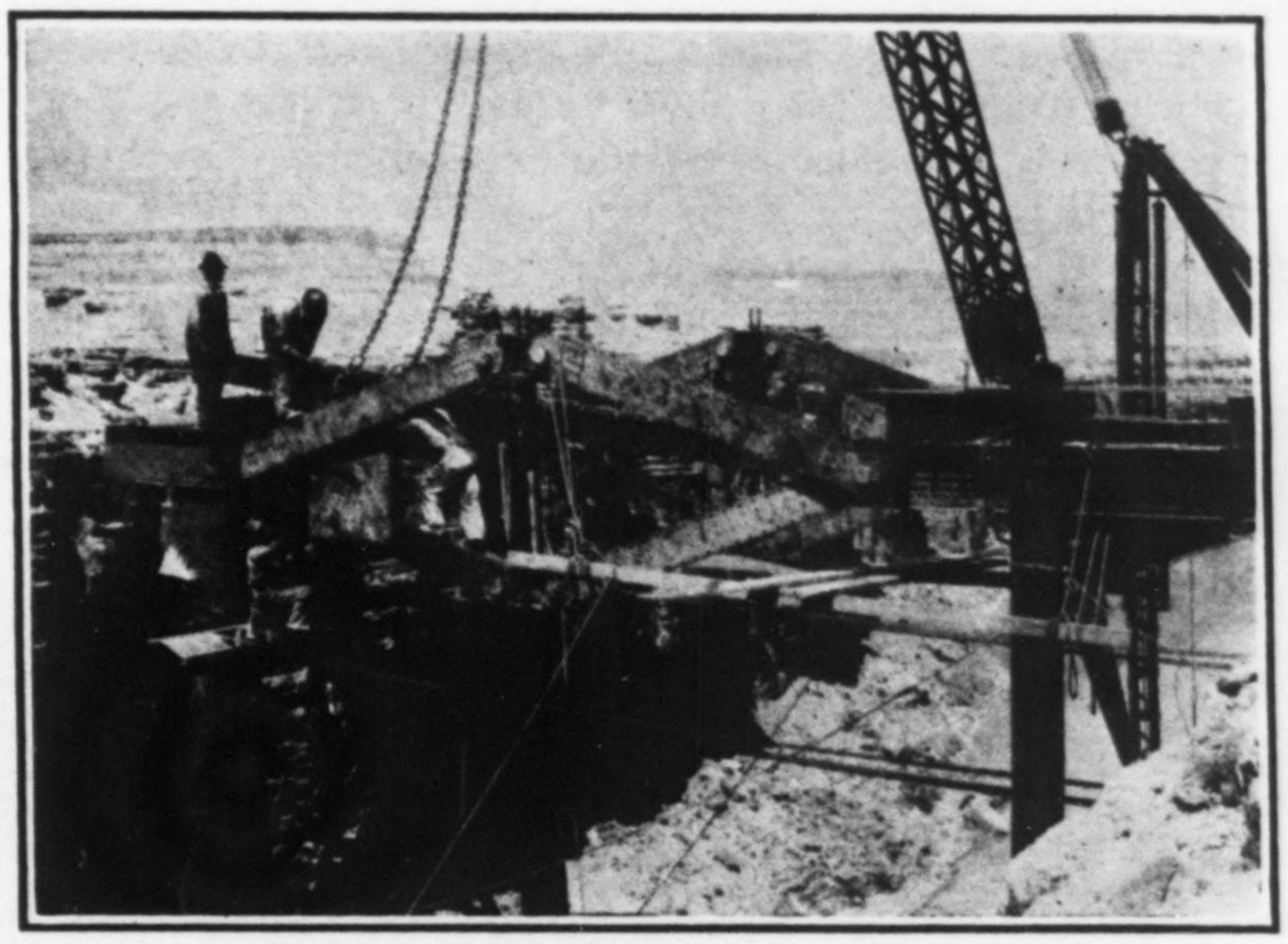


LOOKING ACROSS MARBLE CANYON TO NORTH ABUTMENT
All rock segments that might fall on the steel work were blasted out.

the river having considerable velocity in the canyon. The use of safety belts was required for all workmen on the structure other than the professional steel erectors, whose work required more freedom than the belt permitted.

The first money for the bridge was an appropriation of $100,000 authorized by the United States Congress in December, 1923, made contingent upon raising an equal amount by the State of Arizona. Ultimately, however, it was found necessary for the state to raise a total of $185,000, bringing the total available for completing the work to about $285,000. This would still have been insufficient, however, if the state highway department had not been able to finance the excavation and concrete footings independently.

Plans for the structure were developed by the officers of the Arizona State Highway Commission, W. C. Lefebvre, state highway engineer, W. W. Lane, chief engi-



SETTING UP TOGGLE AT SOUTH RIM

neer. Design and details were made under the direction of R. A. Hoffman, bridge engineer. The U. S. Bureau of Public Roads co-operated on the design and made frequent supervisory inspection during construction. R. C. Perkins was resident engineer in charge of construction for the State Highway Commission until July, 1928, when he was made district engineer in charge of construction and was succeeded by R. C. Bond as resident engineer. Contract was awarded to the Kansas City Structural Steel Company on July 29, 1927, with date of completion set for Sept. 1, 1928. R. A. Kizer, designing engineer, Kansas City Structural Steel Company, was resident in charge for the contractor.

Extending Automatic Train Control

The railroads of the country have equipped 11,213.3 miles of road or 19,703.5 miles of main track with train-stop or train-control devices to Aug. 31, 1928, according to a report by the Interstate Commerce Commission. This includes 2,821.2 miles of road or 4,557.4 miles of track equipped voluntarily by the railroads in addition to the mileage ordered to be automatically equipped by the commission. Locomotives with automatic control number 8,496, of which 7,451 were so equipped under orders of the commission. The railroads voluntarily added 844 locomotives to the number requested by the commission, and in addition 201 foreign locomotives have been equipped for automatic operation over 545 miles of joint operated track.