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NAVAJO BRIDGE
SPANNING THE COLORADO RIVER AT U.S. HIGHWAY 89 ALTERNATE
PAGE VICINITY
COCONINO COUNTY
ARIZONA

HAER NO. AZ-28

PHOTOGRAPHS

HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
NATIONAL PARK SERVICE
WESTERN REGION
DEPARTMENT OF THE INTERIOR
SAN FRANCISCO, CALIFORNIA 94107

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N A V A J O

Historic American Engineering Record Documentation of the Navajo Bridge ▼ HAER No. AZ-28

Location: Spanning the Colorado River on U.S. Highway 89 Alternate, Milepost 537.88; 12.9 miles southwest of Page; Southeast ¼ of Section 34, Township 40 North, Range 7 East; Coconino County, Arizona; UTM: 12.443710.4074660

USGS Quadrangle: Lees Ferry, Arizona (15 Minute Series, 1954)

Construction Date: June 1927 - January 1929

Designer: Ralph A. Hoffman, Bridge Engineer, Arizona Highway Department

Fabricator/Builder: Kansas City Structural Steel Company, Kansas City MO

Present Owner: Arizona Department of Transportation

Present Use: Two-lane highway bridge

Significance: As the only crossing of the Colorado River for some 600 miles, the Navajo Bridge has had a profound impact on the commerce and transportation of a rugged, remote and isolated part of Arizona. Its construction opened the state from the north, providing a valuable tourist route to Grand Canyon National Park and the rest of the state. The Navajo Bridge marked an important milestone of engineering design, logistical planning and construction supervision. It was the first steel deck arch built in Arizona and a nationally prominent example of this uncommon structural type. An extraordinarily dramatic span high over the Grand Canyon, the Navajo Bridge is Arizona's most aesthetically and functionally successful example of civil engineering.

Assembled by: Clayton B. Fraser
Fraserdesign
Loveland, Colorado

September 1993

The Historic American Engineering Record [HAER] documentation for the Navajo Bridge was conducted by Fraserdesign of Loveland, Colorado, under contract with the Arizona Department of Transportation. ADOT has proposed the construction of a parallel bridge to carry vehicular traffic, adaptively reusing the Navajo Bridge for a pedestrian overlook. This recordation is intended to mitigate, in part, the impact on the bridge by this action. Field recording of the Navajo Bridge was undertaken in July 1990. The research for this project has involved three primary archival sources: the Arizona Department of Transportation, the Phoenix Public Library and the Arizona State Library, all located in Phoenix.¹

Of all the obstacles to overland transportation in the West, none was more formidable than the Grand Canyon of the Colorado River. Explorers, pioneers, teamsters, engineers and others have sought a way to cross the yawning gorge ever since its tentative explorations by Spanish missionaries in the mid-18th century. When John Wesley Powell made his now-famous series of explorations along the river's length a century later, the Grand Canyon had been seen by only a handful of Anglos, and then only in small parts. "The Grand Canyon of the Colorado is a canyon composed of many canyons," Powell stated in his 1895 *Canyons of the Colorado*. "It is a composite of thousands, of tens of thousands, of gorges. In a like manner, each wall of the canyon is a composite structure, a wall composed of many walls, but never a repetition. Every one of these almost innumerable gorges is a world of beauty in itself. In the Grand Canyon there are thousands of gorges like that below Niagara Falls, and there are a thousand Yosemites. Yet all these canyons unite to form one grand canyon, the most sublime spectacle on the earth."²

It was the Mormon church, in its efforts to colonize the Great Basin region, that provided the early impetus to cross the Colorado River in the remote canyonlands of Utah and Arizona. Located at the border with Utah, the northernmost crossing of the river in Arizona was an isolated location called the Ute Crossing. The site was discovered during the 1776 exploration of the region by Catholic priests Atanasio Dominguez and Silvestre Valez de Escalante, who were the source for its more widely known name, *Vado de los Padres*, or "Crossing of the Fathers".³ The precipitous approaches to the Crossing of the Fathers could be negotiated on foot or on horseback with some difficulty. But they were far too rugged to accommodate wagon traffic. This prompted Mormon missionary Jacob Hamblin late in 1858 to explore the Colorado at the mouth of the Paria River, searching for a suitable wagon crossing for southbound colonists.⁴ Hamblin tried, but failed, to traverse the river at the Paria two years later. In 1864 he built a crude raft about a mile upriver and successfully navigated the Colorado for the first time.⁵

On August 4, 1869, the first of the Powell expeditions reached Hamblin's crossing, by then the site of a small Mormon settlement. A month later Hamblin again rafted the river here. Powell's crew reportedly built a rough scow in October 1870, which he and Hamblin used to reach Moqui villages in the region. When Mormon President Brigham Young visited the site in the fall of 1870, an armed garrison had reportedly been built to fortify the settlement.⁶

The Navajo called the site *Tsina'ee Dahsa'ash*, or "Where the boat sits", an apt description of the ferry operated by John Doyle Lee beginning in 1872.⁷ A polygamist Mormon and an instigator of the infamous Mountain Meadows massacre, Lee had fled to the remote region to escape from federal authorities. He built a log cabin near the mouth of the Paria and secured the rights to operate the ferry here from the Mormon church.⁸ Lee acquired one of Powell's boats, the *Nellie Powell*, in August 1873 to replace the makeshift raft that he had been using. This small boat was in turn replaced later that year with a flatbed barge built by John L. Blyth. Measuring 20 feet by 40 feet, the new ferryboat was capable of carrying two loaded wagons and teams. Lee used the barge to ferry Mormon pioneers between Utah and settlements in northern Arizona, typically exchanging river passage for provisions.⁹

As it increased in popularity, the crossing became widely known throughout the region as Lee's Ferry. The notoriety was to prove John Lee's undoing; he was captured by U.S. marshals while on a trip to southern Utah in the fall of 1874. One of Lee's wives, Emma, continued to run the ferry as the Little Colorado Station, so named because it was stationed on the main road between southern Utah and the Mormon settlements on the Little Colorado River. Emma Lee sold the ferry back to the Mormon church in 1877.¹⁰ She left the area soon after John Lee was executed standing in a pine coffin at the Mountain Meadows site. The Mormons operated Lee's Ferry for their own use for some 30 years,¹¹ making occasional repairs to the equipment and grounds.¹² Improbably, although John Lee himself operated the ferry for only two years, its name became inextricably tied with his, and the site has since been known as Lee's Ferry.

In August 1909 church trustee Joseph F. Smith quit-claimed the property to the Grand Canyon Cattle Company, a Los Angeles corporation doing business in northern Arizona. The cattle company in turn sold the ferry to the Coconino County Board of Supervisors in 1910 and then contracted with the county in the 1910s and 1920s to operate the boat. Coconino County repaired and improved the ferry as necessary. In 1911, for instance, a new steel cable and anchors were installed; in 1918, and again in 1923, new boats were built. But these renovations could not ameliorate the basic problems associated with a ferry crossing. The descent from the rim to the canyon floor was winding and precarious, the process of loading and unloading the ferryboat slow and cumbersome, and the crossing over one of the most unpredictable rivers in the West was often danger-

ous or impossible. For wagon traffic these difficulties represented a major inconvenience; for automobile traffic they were intolerable. By the 1920s it had become clear to officials in Arizona and Utah that a permanent bridge high above the canyon floor was needed to facilitate commerce in the region.

Arizona had changed considerably in the fifty-some years between 1872, when John Lee first established his ferry, and 1923, when planning began in earnest for the bridge to replace it. In addition to the Mormon road from the north, two other major wagon routes brought immigrants into the territory from the east and west. These were paralleled and augmented in the 1880s by transcontinental railroads. The region's population multiplied severalfold during the late 19th century, while mining towns sprang up in the central and southern mountains and an extended agricultural community flourished in the Salt River Valley. As towns such as Prescott, Yuma, Tucson, Flagstaff and Phoenix developed, a network of roads formed to link them, following the typical pattern of settlement and transportation.

The territorial government made only minimal impact on overland transportation in Arizona during the 19th century, instead passing the responsibility for road and bridge construction to toll companies and the individual counties. Eventually the territory assumed control of the major routes, but the process was slow and tentative. It was indicative of the relatively loose grasp that the Territorial Assembly had on local affairs that a regionally important facility such as Lee's Ferry was controlled, not by Arizona, but by an outside religious institution.

After the turn of the century, most major road projects were beyond the capability of the individual counties. Further, the counties were building roads on an individual basis, without regard to the roads in adjacent counties. This tended to create an uneven patchwork of dissimilar routes, making travel difficult for all but a few destinations. To take a more active role in the development of its highways, the Territorial Assembly created the office of the Territorial Engineer in 1909, the year that Lee's Ferry passed into public hands. Soon after taking office, Arizona's first and only Territorial Engineer, J.B. Girand, began building a network of territorial highways that would link the county seats and more populous towns.¹³

By the time Arizona was admitted to the Union in 1912, the territorial government had constructed some 243 miles of highway. Additionally, 1,812 lineal feet of bridges over 100 feet in length had been built. Girand estimated that an additional 740 miles of trails and county roads would soon be upgraded to form highways, "completing the great east and west and north and south roads."¹⁴

The east-west route entered the state at Duncan, extended westward through Clifton, Safford, Globe and Phoenix, and crossed the Colorado River at Yuma, on the western border. The north-south highway extended from Douglas, in the state's southeast corner, north through Tucson, Phoenix and Flagstaff and terminated at the south rim of the Grand Canyon. "The routes selected had become fixed to a certain extent by the construction of several units of their length," said Lamar Cobb, Arizona's first State Engineer. "And, though not meeting with entire approval, they had also become fixed in the public mind as the State Highways. It was, therefore, thought best not to make any changes in their location as it would undoubtedly lead to others by succeeding administrations, resulting in State Highways 'that would start nowhere and end nowhere,' thus defeating one object of the State Road appropriation - a State system of roads comprised of coordinating county units connecting every county seat in the State."¹⁵

Despite this progress, Arizona roads were in dismal condition, as Cobb reported to the state legislature in 1914:

I have been over a great many roads in every county in the state except two, and I have not found a foot of properly graded and protected mountain road or road in a rolling country that was not constructed under the direction of the [territorial] engineer department. There are a few miles of graveled road in Graham, about ½ mile in Yuma and several miles of caliche road in Maricopa. I know of no other improved roads in the state, outside of the cities, towns or special road districts, though I may have missed a half mile or so elsewhere. Every two years the personnel of the various boards of supervisors is almost completely changed. They go in imbued with the idea that their predecessors squandered the county road funds and go out with the public equally confident that they have. With both more or less correct in their opinions, but it has not been the fault of the supervisors. With county road funds of limited proportions to repair hundreds of miles of road, and with every man in the county clamoring for work in his locality, it has been next to impossible for them to set aside a sum, in any amount, for permanent work.¹⁶

The state was slow to embrace the automobile in the 1910s, due largely to the poor condition of its roads. Even the major routes were little more than wagon tracks in places, troubled by steep, rocky grades in the mountains and shifting sand in the deserts. In its appropriations for road and bridge construction, the state legislature was responding not only to requests from its Arizona constituency but to pressure from out of state as well, in the form of tourists. The Petrified Forest near Holbrook was designated a national monument in 1906. Grand Canyon National Park was established in 1919, rapidly becoming one of the country's premier scenic attractions. These and a profusion of other sites drew visitors from all directions. "In recent years the automobile industry has concentrated attention on so-called pleasure traffic and transportation by auto and trucks," said State Engineer B.M. Atwood in 1918. "The public demand, so far as the highways are concerned, has been most insistent for better roads especially constructed to meet

As more sightseers were taking to Western roads in cars or motor coaches in the 1920s, Arizona's need for better highways became more urgent.

Nowhere was this more apparent than on the roads through the rugged country north of Flagstaff. The Nogales-Grand Canyon Highway extended northwest of Flagstaff and terminated at Grand Canyon Village on the south rim (see Figure 1).¹⁸ An updated version of the territorial north-south highway, this route would remain forever blocked by the Grand Canyon, which was at least three miles wide at the road's northern terminus. Travelers attempting to reach Utah instead followed a county road north from Flagstaff through the sprawling Navajo Indian

Reservation. This route crossed the Little Colorado River at Cameron, over a suspension bridge that had been erected in 1911 by the Office of Indian Affairs. From Cameron the road extended 25 miles north to Tuba City. There it branched into two routes - one northeast to Kayenta and south-eastern Utah, the other northwest to Lee's Ferry and then to Kanab, Utah.

The Lee's Ferry road had neither the status nor the traffic that the Grand Canyon highway commanded, and its maintenance suffered accordingly. "The road from Flagstaff to Fredonia [on the Utah state line] is passable except during the most severe rainy season, but for the most part is little more than a desert trail," stated one observer. "Like all desert roads, however, fair traveling can be found over part of the way. This road is not now widely known or traveled by tourists, but is traveled by the traders and Indians, or those whose business necessarily takes them that way."¹⁹ As it had when John Lee operated the ferry, the road wound its way into the canyon to the ferry site and back up the other side on a path that was barely improved since the Mormons

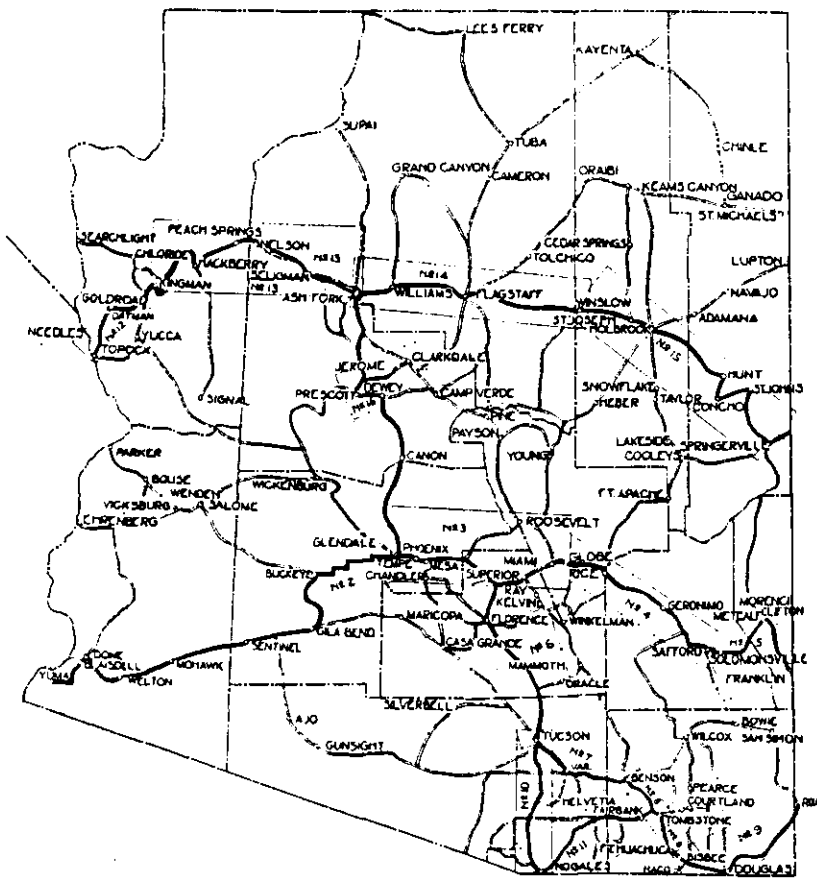


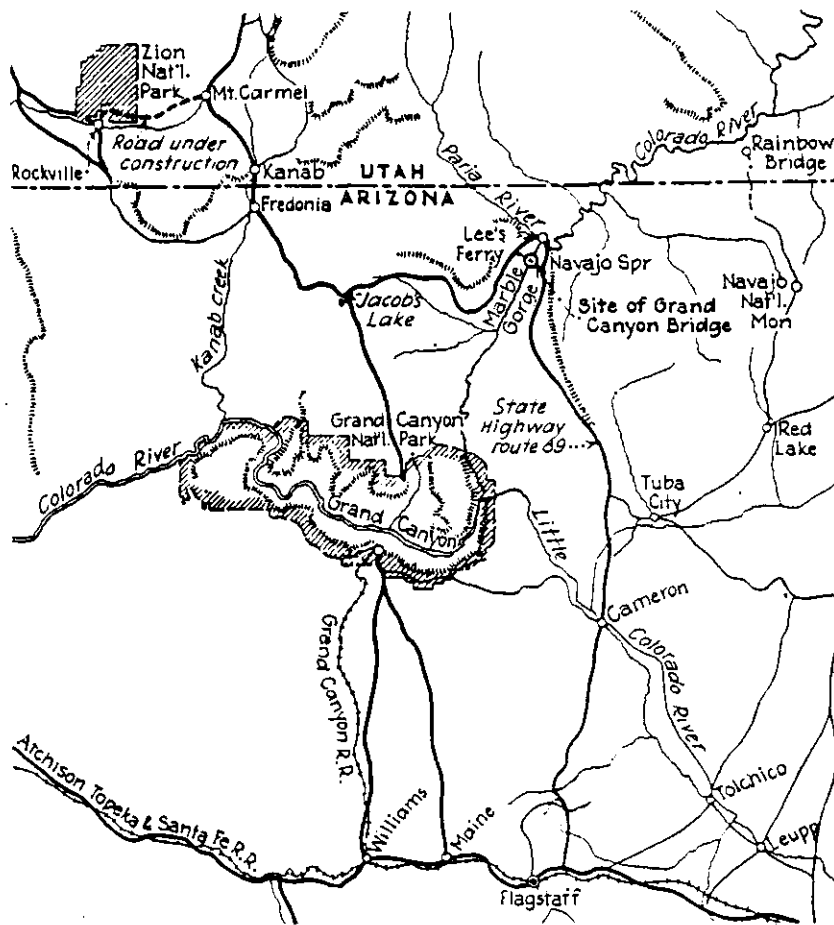
Figure 1. Map of Arizona, by Arizona Highway Department, 1920.

had built it in the 1870s. And the ferry itself, despite efforts to improve it, was still a dangerous means of crossing the river.²⁰ As a practical matter, automobile travel between Phoenix and Salt Lake City was virtually impossible without swinging eastward through New Mexico or west to Nevada and California.

The motivation to improve the Lee's Ferry road in the 1920s came once again from Utah, although this time it was the Utah State Road Commission [USRC], not the Mormon church, that provided the catalyst. After the formation of Bryce Canyon National Monument in 1923, USRC designated the road south from Bryce to Kanab as part of its Seven Percent System, making it available for federal funding. Utah's motivation was apparently to boost tourism in the region by linking

the north rim of the Grand Canyon with Bryce and Zion National Park, through what was called the "Park-to-Park Highway".²¹ The route on Arizona's side of the border was still only a rutted county road, but Utah's move prompted the Arizona Highway Department [AHD] for the first time to begin considering its improvement. "While it is not possible to extend the Seven Per Cent System from Flagstaff north via Lees Ferry to Fredonia, due to insufficient mileage," AHD stated in 1924, "this connection however, is worthy of consideration as a part of the State Highway System."²²

The overriding obstacle to development of the route was, as always, the Colorado River, which cut through the road like a giant slash in the desert fabric. The ferry would always constitute the route's weak link, regardless of how well the rest of the road was built and maintained. For the route to attain true highway status, a permanent bridge was needed over the Grand Canyon (see Figure 2).



■ Figure 2. Map of Grand Canyon Region, from *Engineering News-Record*, 5 January 1928.

The technology to bridge the Grand Canyon had existed for decades, as exemplified by three early Arizona spans. The oldest of these, the Red Rock Bridge, had been built in 1890 to carry the Santa Fe Railroad over the Colorado River. Designed by J.A.L. Waddell, it featured a 660-foot, cantilevered through truss.²³ In 1916 a 592-foot, cantilevered through-arch structure was erected just downriver from the Red Rock Bridge to carry the Old Trails Highway.²⁴ And The Cameron Bridge over the Little Colorado River featured a 660-foot suspension span with steel wire cables and a pin-connected stiffening truss.²⁵ All three of these long-span bridges could have cleared the gorge at its narrowest stretches, and two of them were later used as models for the Grand Canyon Bridge itself.

Despite its corner-to-corner course through Arizona, the Colorado River could be bridged at only a few places. Ultimately, the engineers eliminated all but one of these sites - over Marble Canyon east of Grand Canyon National Park. Here the distance between canyon walls was only 585 feet, the narrowest spot along the river's entire length in Arizona. State Engineer W.C. Lefebvre explained:

Nowhere in North America and in very few localities in the world are there any such barriers to road building as the Grand Canyon of the Colorado. Practically cutting the State from east to west, the canyon offers only two or three crossings feasible from a financial standpoint. Two of these possible crossings are in the vicinity of the numerous proposed dam sites on the Colorado River and until this very involved situation is cleared, these sites cannot be considered; furthermore, they are too far west to be any value to the State as a whole. Eliminating these for the reasons stated above, it leaves but one feasible crossing of the Colorado River for a north and south highway. This site is located about six miles down the river from Lee's Ferry; the canyon is comparatively narrow at this point and can be crossed by a span of 600 feet.²⁶

The Denver and Rio Grande Railroad had surveyed this site earlier for a proposed line through the region. Coconino County Engineer J.B. Wright selected a location a thousand feet from the railroad site when in 1923 he conducted his own preliminary investigation for a highway bridge.²⁷ Wright patterned his suspension bridge design after the Cameron Bridge (see *Figure 3*). Like its predecessor, Wright's 800-foot structure featured a single span stiffened by a timber-decked through truss.²⁸

The U.S. Indian Service [USIS] used Wright's design when it requested an appropriation from Congress to fund construction of the bridge. Like the State of Utah, USIS viewed the highway and bridge as a means to promote commerce on the sparsely populated Navajo and Hopi reservations. USIS could not commit Navajo money for a state highway, but it could fund construction of a bridge, through Congressional action. In December 1923 Congress allotted \$100,000 of Navajo tribal funds for the Grand Canyon bridge, to be matched by the State

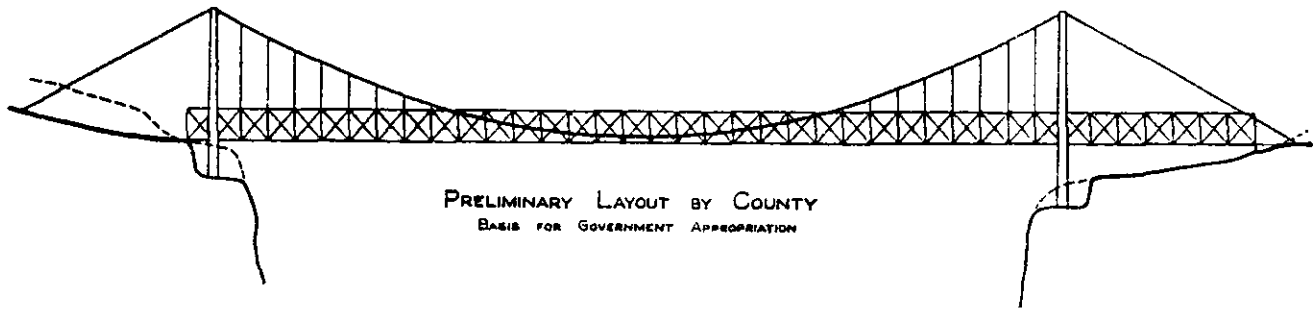


Figure 3. Profile of preliminary design for the Grand Canyon Bridge, by J.B. Wright, Coconino County Engineer. 1923.

of Arizona.²⁹ This would be the only bridge over the Colorado River in the 600-mile stretch between Green River, Utah, and Topock, Arizona. With Utah already building the northern link and half the cost of the bridge obligated by the federal government, the Arizona Highway Department finally recognized the value of a highway to join the two states. Lefebvre belatedly acknowledged:

it is probable that an improved highway built over this route would bring to the State more new traffic than any other improvement that can be made. The traffic between the north and south rims of the canyon would, in the summer at least, be a considerable item and it is natural to suppose that it would be as important a route of travel as our other main highways. At least alternate routes either east or west for a distance of 500 miles will not divert the traffic from this road as there are none and the prospects are good that there will be none for many years to come.³⁰

Located partly on the Navajo Reservation, the proposed Grand Canyon bridge fell under the jurisdiction of the Department of the Interior. Interior officials turned the responsibility for its planning and design over to the U.S. Bureau of Public Roads [BPR]. In 1924 engineers from the bureau's Washington office made additional surveys of the site and soon concluded that the bridge could not be built for \$200,000. They produced a series of estimates, ranging from \$230,000 for a lightweight suspension structure with a wooden deck to \$341,000 for a "first class steel structure with a concrete deck and a 20 foot roadway."³¹ For the latter structure, BPR engineers delineated a steel through arch patterned after the Old Trails Bridge at Topock (see Figure 4). The bureau's figures were used by the Arizona State Legislature, when a \$130,000 appropriation - the lowest amount possible - was made toward the bridge's construction. This sum was increased to \$185,000 by the legislature in March 1927.³²

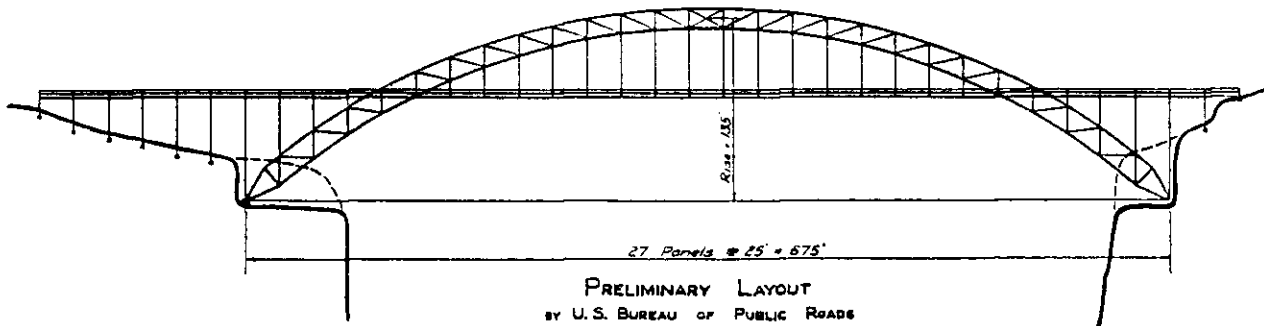
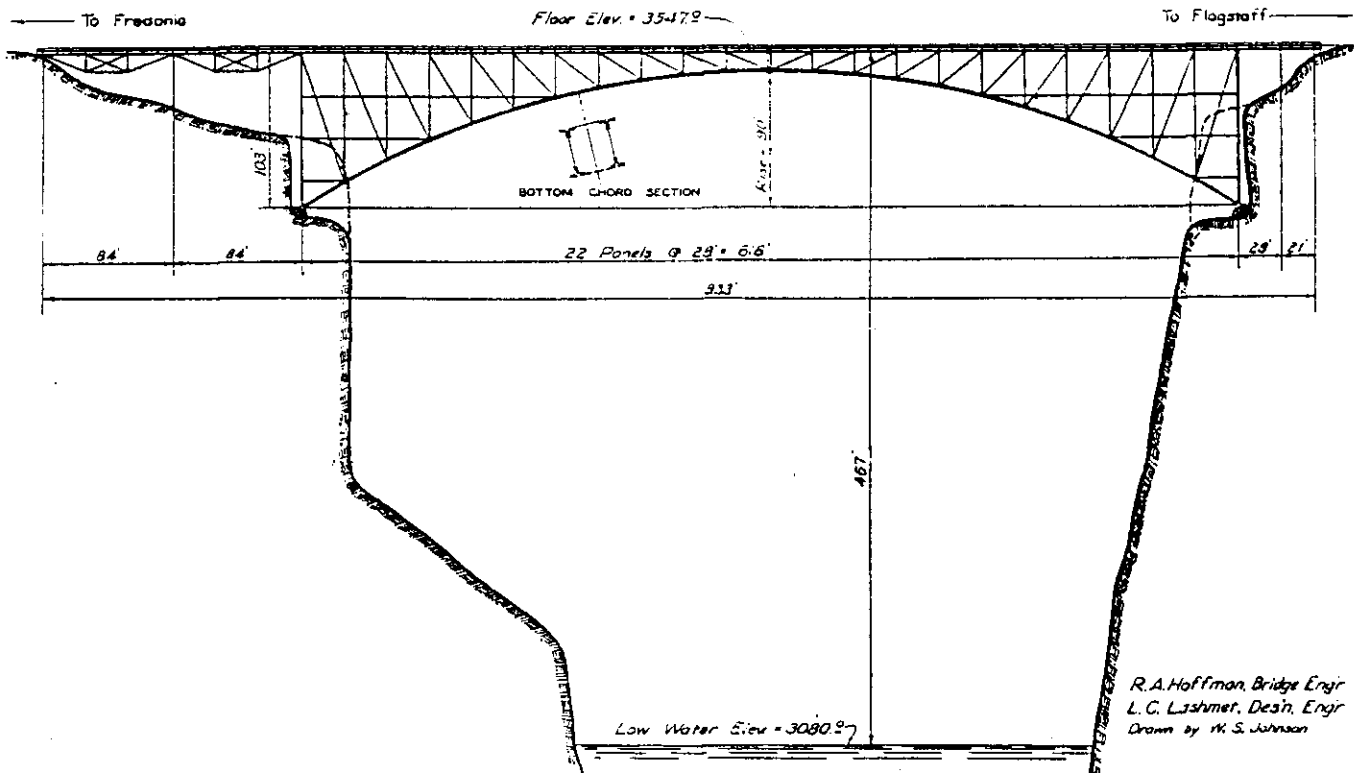


Figure 4. Profile of preliminary design for the Grand Canyon Bridge, by Bureau of Public Roads, 1924.

Arizona Highway Department Bridge Engineer Ralph A. Hoffman had designed his own alternative to J.B. Wright's suspension bridge in 1923. But his deck-arch configuration had been used for neither the federal nor state appropriations. When the final design of the Grand Canyon bridge was turned over to the highway department in March 1927, it fell into Hoffman's lap. He wasted little time in discarding the earlier designs in favor of his own. "The Bridge Department, after a thorough study of all data available and the local conditions to be met," Hoffman stated, "arrived at the conclusion that the unit prices used in previous estimates were too low on account of the remoteness of the site, and the 130 mile haul of structural materials, and this department prepared estimates based on an entirely different type of design. This had previously been suggested by the Department as the most fitted to the location from all standpoints, using at the same time higher unit prices on structural materials."³³

Hoffman dismissed the suspension design as too costly and, with a ten-ton load limit, too flimsy. Construction of a through arch, he maintained, would have necessitated the use of heavy overhead cableways to hoist the span halves into place. With the expense of returning the cables and tower materials prohibitively high, these would be abandoned at the site, adding considerably to the cost. "The site appeared to be ideal for the use of a deck arch and a few computations showed that this type had many advantages in erection," Hoffman concluded. "Practically all the erection material could be used in the approach spans. These spans were needed on account of maintaining a high grade line on the structure in order to get a satisfactory grade line out of the canyon on either side."³⁴

The Grand Canyon Bridge was designed by Hoffman and AHD Designing Engineer L.C. Lashmet. Their plan featured a three-hinged deck arch that cantilevered from the canyon walls on both sides (see Figure 5). The spandrel-braced arch was comprised of a 22 equal panels; it featured a span length of 600 feet, a roadway width of 18 feet, an arch rise of 90 feet and an overall height of 115 feet from bearing shoe to guardrail. Including two 84-foot deck trusses on the north approach and a 49-foot approach on the south, the bridge extended a total of 833 feet. The most impressive dimension of the Grand Canyon Bridge, however, was its distance above the river level: some 467 feet from deck to water, making it the highest bridge in the world at the time of completion.³⁵



LAYOUT PROPOSED AND ADOPTED
 BY THE ARIZONA HIGHWAY DEPARTMENT

■ Figure 5. Profile of preliminary design for the Grand Canyon Bridge, by Arizona Highway Department, 1927.

With the federal appropriation about to lapse, Hoffman and Lashmet were forced to push the design in April and May, 1927. "The Department was handicapped in making extensive studies of approaches and erection schemes," Hoffman said, "as only about six weeks remained between the time of receiving orders to prepare plans and the time of the expiration of the government funds." The engineering was well under way when test excavations at the site revealed fissures in the Kaibab sandstone of the canyon's north wall. This necessitated excavating to solid rock and extending the arch's span. The bridge was completely redesigned, this time with a 616-foot span.

The structure was engineered for a uniform live load of 60 pounds per square foot on the deck, or 15,000 pounds per 28-foot panel. The loading of the floor system was calculated for one 15-ton truck or two 12½-ton trucks side-by-side on the roadway, with a 30 percent allowance made for impact loading. The wind load was taken as 60 pounds per square foot on the exposed arch webs and 30 pounds per square foot on the floor and guardrails. This was partially offset by a batter of the spandrels of one eighth inch to a foot. Hoffman described some of the features of the structure:

The bottom chord is a box member built up of eight angles and three plates, the maximum section at the abutment is about 32 inches square - having a sectional area of 140 square inches - 36 feet long and weighs about 12 tons. The bottom of the box member is laced with six inch channels. The top chord of the truss is also a built up member of angles and plates top and bottom.

In the first design the floor system was carried by longitudinal stringers and floor beams at the panel points and to reduce the dead load the curb was built up of steel angles and plates instead of the usual concrete, and this built up member also acted as a stringer carrying part of the floor load. Later, after the bids were taken, this floor system was redesigned to utilize the excess material required in the top chord during erection by carrying the floor load on steel cross beams at 4 feet, 8 inches centers directly on the top chord. This revision required some changes in the top chord members, but materially reduced the total steel in the job.³⁵

Given the high costs of materials and haulage, Hoffman and Lashmet designed the bridge so that erection materials would be used in the final structure. The approach spans, for instance, were designed to re-use the materials from the construction tie-backs. During erection, each cantilevered arch half was anchored to the ground by means of an adjustable tie-back [see *Figure 6*]. The toggle arms for these tie-backs were to be later recycled as the vertical posts for the approach trusses. In like manner, the trusses' eyebar diagonals and lower chords, as well as the floor beams, were to be used first for the anchorages during construction. (Packing rings would be inserted into the eyes to compensate for the smaller truss pins in the completed structure.) "As the bids were taken on a pound price for

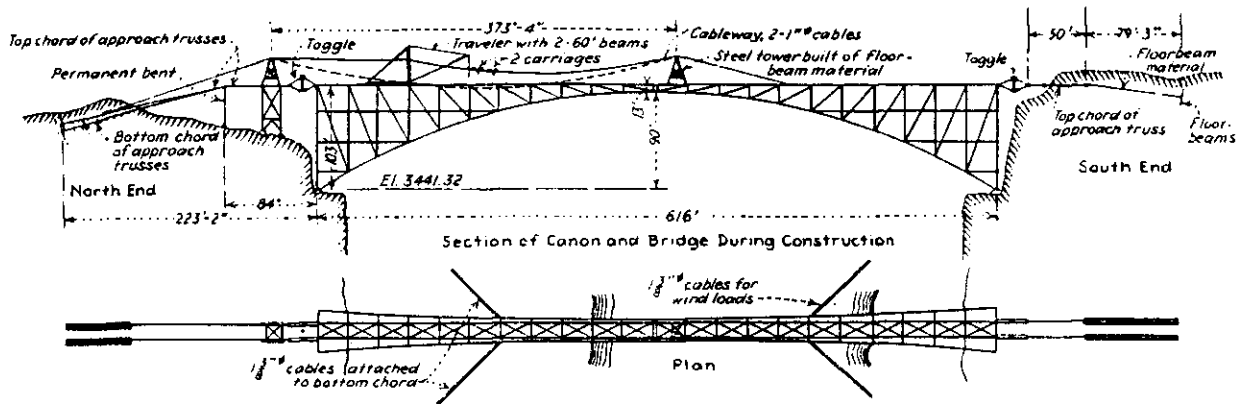
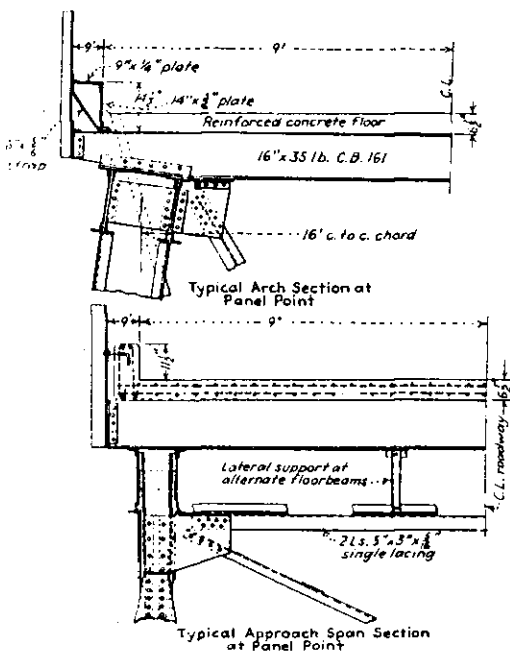


Figure 6. Plan and Construction Profile of Bridge, from *Engineering News-Record*, 5 January 1928.

steel," Hoffman said, "this system resulted in a lower general price on the structural steel, than would have been obtained if erection material had not been used in the finished structure."



Comprised of built-up members similar to those of the arch, the approach trusses' upper chords were first used as the arms that tied the arch halves to their anchorages. These members were required to withstand as much as 750,000 pounds of tensile stress from the outstretched arch halves during construction. They were thus over-designed for later use as approach truss chords. To help compensate for this, they carried the deck on floor beams similar to those of the main arch [see *Figure 7*].

Hoffman insisted on a concrete deck, even though it added considerably to the structure's weight and cost. A timber floor constituted an unacceptable fire hazard, he contended, given the isolated location of the bridge. Further, it would require more frequent maintenance. "Neighboring states had recently experienced the total loss of structures with timber floors in similar remote locations," he said. "It was thought advisable to prevent such a loss in this instance." Despite these attempts at structural efficiency, the Grand Canyon Bridge was immense, consuming over 2 million pounds of structural steel, 81,412 pounds of reinforcing steel and 503 cubic yards of concrete in the foundations and deck.³⁷

Figure 7. From *Engineering News-Record*, 5 January 1928.

Under Hoffman's supervision, Lashmet completed the construction drawings and specifications for the Grand Canyon Bridge in May 1927 [see *Figures 8 through 23 for construction drawings; see Appendix for construction specifications*]. The Arizona Highway Commission designated the bridge's construction Federal Aid Project 95-D and solicited competitive bids that month. Despite Hoffman's strongly stated preference for a concrete deck, he requested alternate bids for a "temporary" wood floor, as a hedge against high bids. On June 7th the solicitation was answered by four firms: the Anderson Brothers Construction Company of El Paso; the Ross Construction Company of Los Angeles, the McClintock-Marshall Company of Los Angeles; and the Kansas City Structural Steel Company of Kansas City. At \$323,290.00, the proposal of Kansas City was the lowest for the concrete-decked configuration. The bids of all four firms exceeded the federal and state appropriations, however.³⁸ Lacking sufficient funds to build the bridge, the highway commission tabled the issue, while the engineers considered ways to reduce costs.³⁹

Later that month a contract to build the Grand Canyon Bridge was awarded to the Kansas City Structural Steel Company [KCSS]. AHD had trimmed the contract cost by undertaking the foundation work with its own laborers. Further savings were achieved when Coconino County and the Tuba City Indian Agency agreed to take on some of the ancillary work themselves. Under the terms of the contract, KCSS was to complete its erection of the superstructure by September 1, 1928. The highway department would complete the approaches by the end of the year. The cost, including engineering, would total \$314,000.⁴⁰

By June 1927 the funding was in place, the design finalized and the construction contract let. The next step was construction of the bridge itself. The first major hurdle to be overcome - indeed, the single greatest hurdle of the project - was the transportation of some 3.2 million pounds of materials, supplies and equipment over the 130 miles from the railhead at Flagstaff to the bridge site. With little improvement since the 1910s, the road north of Flagstaff was still no more than a trail in many places. And with temperatures ranging from 110° to 16° below zero, the travel conditions varied wildly.

KCSS hired E.M. Moores and Son of Clarkdale, Arizona, to transport materiel from Flagstaff to the site, with the stipulation that 10 tons per day be delivered.⁴¹ To accomplish this, Moores used a 5-ton and a 12-ton truck. The loads varied greatly in size and weight, the largest steel components weighing 12 tons. This posed a serious problem at the Cameron Bridge. Rated at ten tons, the light-weight suspension bridge had to be strengthened by USIS before heavy hauling could begin. In addition to his role as teamster, Moores was responsible for road maintenance in the northernmost 80 miles of the route. When snow drifted onto the road, the trucks were scheduled so that they passed over the snow-packed stretches at night to take advantage of the freezing temperatures. Moores's driv-

ers negotiated steep grades, sandy washes and deeply rutted roadways, taking between 13 and 20 hours for the 130-mile trip. They were able to trade off with other drivers from a road camp set up about halfway along the route. In spite of the hardships, Moores managed to ship everything to the site within a four-month period in 1927-28.⁴²

Once delivered to the site, the material was stored on the south rim. Much of the steelwork was hoisted to the opposite side by means of an overhead cableway. Vehicles and some supplies, however, were forced to use the old ferry, until it overturned during a crossing in June 1928, killing three people.⁴³ The highway department then rigged a 16-foot rowboat with an outboard motor as a makeshift ferry to haul supplies. "This did not lessen but increased the danger of crossing the river," AHD engineer W.R. Hutchins said. "I have seen the boat loaded until it was invisible. This would not necessarily have been dangerous on a lake or in still water, but strange as it may seem, the Colorado at this point was at times nearly choked with large blocks of floating ice. During the summer and fall freshets the same was true of driftwood, sometimes large trees, partly submerged and incapable of being seen on the surface - a dangerous menace when one is depending on an outboard motor."⁴⁴

Work on the bridge began on June 23, 1927. After struggling for days to haul an air compressor and other equipment to the north rim, a highway department crew began excavations for the arch foundations on the north side. The early testing had revealed fissures in the rock. This necessitated digging or blasting some 9,000 cubic yards of material to place the foundations on solid footing. Men dangled over the gorge on ropes, operating pneumatic drills and placing loads for blasting in the sheer canyon walls. Once the excavations had been roughly shaped, rope ladders were used, which were only marginally safer. "Climbing a rope ladder is no joy-ride," Hutchins commented. In this way, niches, 70 feet deep and 30 feet square, were cut into both sides of the canyon. By November the excavations were complete and work on the concrete footings had begun. Highway department laborers set forms on the ledges, using only enough concrete to build up suitably shaped footings for the massive cast steel pedestals. By the following April the foundation work on both sides was complete.

Meanwhile, in the Kansas City plant of KCSS, the components for the bridge were being fabricated from steel rolled by the Illinois Steel Company. The first erection equipment left the plant on January 5, 1928, the first structural steel two weeks later.⁴⁵ In all, the fabricators shipped some fifty carloads of material by train to Flagstaff, where it was loaded onto Moores's two trucks. Limited by the size of the trucks and the capacity of the Cameron Bridge, the largest steel members were 53 feet long and weighed 12 tons.⁴⁶

In mid-March the contractor set up camp on the south side of the canyon and moved its laborers to the site. Hailing largely from Missouri, the men began work by excavating tunnels for the anchorage of the south arch half. The strategy was to complete the south arm first. When completed, it would be used as a platform from which to hoist the steel to the north side. Once the anchorage was set, the steelworkers began assembling the tie-backs, toggles and first panels of the south arm (see photos AZ-28-31 and AZ-28-32). They set the cast steel bearing shoes on the newly formed concrete pedestals in April and connected the lower chords using 15-inch pins. The workers then built the first two panels and adjusted the steelwork for line and elevation by packing grout on the bearing pedestals. An erection traveler was built to assist in handling the steel members. Made up of two pivoting 60-foot beams, this crane rolled on the upper chords of the arch. With the traveler in place to hoist and position the steelwork, erection on the arm progressed quickly (see photos AZ-28-33 through AZ-28-36).

The arch half extended further over the canyon with each panel completed, until in mid-June the last panel was riveted in place (see photo AZ-28-37). At that time the 800,000-pound arm literally hung over the gorge, suspended by only the temporary tie-backs. Once the south arm was completed, a derrick was built at its end and a cableway strung across to the north rim. As steel and steelworkers rode over the gorge on the cable, the process began on the north side.

Under such extreme living and working conditions, the job took on unusual dimensions. "The men had no regular hours," stated Hutchins, "The day's work was ended when they reached camp for the night. This may have been five o'clock - the usual end of a day - or it may have been two o'clock in the morning, depending upon how fortunate they were on that day."⁴⁷ Part of the lore of the Grand Canyon Bridge holds that the steelworkers refused to have safety nets slung beneath the outstretched arms of the arch. This was partly true. In fact, a hemp rope safety net had been woven. It was never installed in part because of the men's protests that it might make them careless. But a larger reason was that the net was too costly and too dangerous to install. The steelworkers moved unfettered over the structure, apparently oblivious to the dizzying height of the bridge. All others were required to wear safety harnesses. One steelworker, LaFayette McDonald of Kansas City, did slip from a beam and fall to his death.⁴⁸ His body was never recovered from the river.

Work on the north arm progressed steadily that summer (see photos AZ-28-38 through AZ-28-41). The bearing shoes were set on July 12th and grouted three weeks later with two panels of the arch in place. By the end of August the tenth panel had been assembled. The gap between the two arms was then measured for the last panel. In the KCSS shop, small adjustments in the panel members were made to compensate for erection discrepancies. The last superstructural steel was then shipped to Arizona on September 1st. On September 12, 1928, the crew was ready to lower the two arch halves and couple the center pins.

The men began early that morning by aligning the two arms and inserting six-inch-diameter compression screws in the toggles. After five hours, they began lowering the south arm by adjusting the toggles. The arm was dropped nine inches before the north arm was screwed down similarly. At 5:30, the last pin was inserted (see photos AZ-28-42 and AZ-28-43). By then the temperature had begun dropping precipitously. The men screwed all four of the toggle jacks almost continuously to counteract the movements of the cooling arms, as the weight was shifted gradually from the temporary supports to the arch itself. When one of the screws became lodged and could not be lowered quickly enough to keep up with the movements of the arm, it was freed entirely. By 9 o'clock that night the toggles had been loosened completely and the span completed.⁴⁹

The erection traveler was dismantled the next day and the tie-backs and anchorages converted to approach spans later that month. "The hazardous part was over but still much work to be done to complete the structure," Hoffman said.⁵⁰ Their job completed, the steelworkers moved out on October 20th. By then other laborers had begun building the forms for the roadway slab. The arch had been designed so that the slab would be poured in six equal sections, distributed to prevent excessive stress on the lateral bracing. To spread the load, the forms were set and reinforcing steel placed for the entire deck before any concrete was poured. Sawdust, shipped from sawmills in Flagstaff, was spread over the slab and wetted to cure the concrete, once poured. The water for this was hauled some four miles from Navajo Springs, "which may seem peculiar to some because the river carries a great volume of water at all times," Hoffman stated. "But then it is realized that the river water was not satisfactory for concrete, carrying too high a percentage of silt, and that the water for curing would have only been developed at a lift of 475 feet from the stream to the bridge floor."⁵¹

Completion of the deck on December 9th marked the last construction on the bridge itself. This left only the grading of the approaches to make the crossing accessible. The highway department had been drilling and grading in the rocky bluffs on the south side of the bridge since July. By the time the concrete had finished curing early the next year, the temporary road on this side was ready. The Grand Canyon Bridge was opened to traffic on January 12, 1929 (see photo AZ-28-44).⁵² Two days later a highway department power shovel crossed the bridge to begin work on the north approach.

The January opening was held unceremoniously, with only a few laborers and engineers present while a cold wind blew through the canyon. The gala opening would occur that summer, with the promise of better weather for the visiting dignitaries. The ceremonial dedication of the bridge took place on June 14th and 15th, as reported by the *Arizona Republican*:

Under a typical Arizona cloudless sky, the heat tempered by a gentle south breeze, the Grand Canyon Bridge across the chasm of the mighty Colorado river was formally dedicated by four governors of neighboring states this afternoon in the presence of a crowd of more than 5,000 persons, representatives of at least 20 states. As movie and other cameras clicked and with three other chief executives of as many states standing by, [Arizona] Governor John C. Phillips clipped the purple and yellow ribbons which represented the breaking of an age-old barrier between the lands to the north and south of the Colorado river. Miss Elizabeth Phillips, daughter of the governor, christened the bridge by breaking a bottle of Colorado river water over the railing. Governor Phillips, who was standing at her elbow, was well sprinkled by the water, as were dozens standing near.⁵³

Cars and trucks driven from Utah and Arizona clogged both sides of the bridge, as flags adorned its guardrails and an Indian band marched among the milling crowd (see *photo AZ-28-45*). "Today marked the dawn of the new epoch in the history of the Southwest," Phillips declared. "Man has achieved another triumph over grim nature. By his creative genius and daring, his engineering skill, he has bridged this barrier with ribs of steel and concrete and brought into closer touch the people of two great states and has opened an avenue whereby the traffic of the west may view our scenic wonders and our people."⁵⁴ The governors shook hands at mid-span for the cameras and returned to a promontory on the north side. There they listened to speeches and bands, watched in awe as an airplane flew beneath the bridge (see *photo AZ-28-46*), and held court over the symbolic "Marriage of the Southwest and Northeast". The ceremonies concluded that evening with a campfire program, in which the governors and highway officials passed around a peace pipe. Contemporary accounts do not record the reaction to this revelry of the Navajo and Hopi Indians encamped on the south rim.

Caught up in the euphoria of the moment, the highway department congratulated itself in its house publication, *Arizona Highways*:

For two years the engineers of the Arizona Highway Department endured heat and cold, disappointment, discomfort, danger and responsibility almost too heavy for human shoulders; and day by day, through that time, the great bridge over the Colorado River grew under their charge. In January of this year the engineers looked upon their completed work and saw that it was good, - permanent - to endure when all memory of the builders perished.⁵⁵

In truth, construction of the Grand Canyon Bridge did mark a major event in Arizona history. After the highway linking it with Flagstaff was completed two years later, it played a pivotal role in the development of a vast region that covered two

states. As the only crossing of the Colorado River for some 600 miles, the bridge has had a profound impact on the commerce and transportation of a rugged and remote part of the West. Its construction opened the state from the north, providing a valuable tourist route to Grand Canyon National Park and the rest of the state. Although the Navajo Nation did not realize a long-promised economic vitalization as a result of the bridge, its role in financing the project was recognized six years later, when in January 1934 the structure's name was officially changed to Navajo Bridge.

As Ralph Hoffman himself allowed, the design of the Navajo Bridge contained little in the way of engineering innovation. Iron and steel deck arches had been part the repertoire of civil engineers since the erection in 1779 of the first all-iron bridge, the 100-foot arch over the River Severn at Coalbrookdale, England. Despite this, the Navajo Bridge did mark an important milestone of engineering design, logistical planning and construction supervision. It was the first steel deck arch built in Arizona and a nationally prominent example of this uncommon structural type. What makes this bridge technologically noteworthy is its immense scale, its inspired logistical planning and its breathtaking span over one of the most spectacular bridge sites in America. Although Hoffman was concerned primarily with the functional aspects of the Navajo Bridge and not its appearance, this handsomely proportioned structure ranks among the country's most dramatic bridges. Flying high over the Grand Canyon, the Navajo Bridge is Arizona's most aesthetically and functionally successful example of civil engineering.

Endnotes

¹This HAER documentation draws upon the statewide inventory of highway bridges for background information. For more on bridge construction in Arizona, see Clayton B. Fraser, "Arizona Bridge Inventory," prepared for the Arizona Department of Transportation, October 1987.

²John Wesley Powell, *Canyons of the Colorado*, 1895, as quoted in Tony Hillerman, *The Best of the West* (New York: Harper Collins, 1991), pages 21-22.

³Marshall Trimble, *Arizona: A Ponoromic History of o Frontier Stote* (Garden City, New York: Doubleday, 1977), pages 81-82.

⁴James H. McClintock, "Crossing the Mighty Colorado," *Arizona Highways*, October 1928, page 9.

⁵Will C. Barnes, *Arizona Ploce Nomes* (Tucson, Arizona: University of Arizona Press, 1985), page 75; Ralph A. Hoffman, "Bridging the Grand Canyon of Arizona: The Highest Highway Bridge in the World," *Arizona Highways*, No-

vember 1927, pages 5-7; "Highest Highway Bridge in the World to Connect Utah and Arizona," *Solt Lake Telegram*, 1 July 1928.

⁶James McClintock, "Crossing the Mighty Colorado," page 9.

⁷Byrd Howell Granger, *X Marks the Ploce: Historical Names of Places in Arizona* (Tucson, Arizona: Falconer Publishing Company, 1983), page 357.

⁸Lee chose this ranch site in large part because of its extreme isolation. Historian Byrd Howell Granger described Lee's need for secrecy:

In 1857 a group of men reportedly disguised as Indians attacked a train of Arkansas and Missouri emigrants at Mountain Meadows (Utah) and killed one hundred and fifteen. Lee was accused of leading the attackers. He spent many years trying to escape the law. He felt his loneliness apparently, for his name for this place was Lonely Dell, although it could not have been too lonely, for he was a polygamist.

Byrd Howell Granger, *X Marks the Ploce: Historical Nomes of Ploces in Arizona*, page 357.

⁹Frank M. Gold, "Lonely Dell Was the Original Name Given to Lees Ferry by Its Founder, John Doyle Lee," *Official Program of the Dedication of Grand Canyon Bridge, Arizona, 14-15 June 1929*; James H. McClintock, "Crossing the Mighty Colorado," page 10.

¹⁰The transaction of the ferry operation was brokered by Mormon church agent Warren M. Johnson. In May 1879 Emma Lee conveyed the property to the church through a warranty deed, which stated:

KNOW ALL MEN BY THESE PRESENT,

That I, Emma Batcheler Lee, owner of and residing at a place known as Lees Ferry on the Grand Colorado River, supposed to be in Yavapai County, Territory of Arizona, for and in consideration of the sum of \$3,000.00 to be paid by John Taylor of Salt Lake City, Salt Lake County, Utah Territory, certain real property therein described, together with all Ferry privileges, rights of landing on both sides of the river, boats, chains, ropes, lumber, dugways on both sides of the river, crossings, fences, houses, cellars, water rights and privileges.

As quoted in Frank Gold, "Lonely Dell' Was the Original Name..." Johnson's payment was 100 cows, which had been tithed to the church by brethren in southern Utah and northern Arizona.

¹¹During this time the first dry crossing of the lower Colorado River occurred at the ferry site, when in January 1878 the river's surface froze, permitting wagons to cross over it. As reported in the *Los Angeles Times* fifty years later:

The boatless crossing was afforded by Nature, which in January, 1878, sent a cold wave that froze the stream from bank to bank. Above and below the still water at the ferry the river was open and running rapidly. At that time came along a large caravan of Mormon emigrants, headed by John W. Young, bound for settlement on new lands in the Little Colorado River Valley. One of the members was Anthony W. Mins, now a member of the first presidency of the church. He has told that the ice was strong enough to bear up a wagon, even though loaded with a ton of freight, but that one ox was drowned by breaking through. Then the wagons were hauled across by hand and the horses taken singly. For further assurance of safety on the yielding ice, the remaining cattle were thrown and tied and each ox or cow hauled across by the tail. This could be done by a single man. Mr. Mins tells that he crossed thirty-two times in the several days required for the passage of the train.

"Colorado's First Span Was of Ice," *Los Angeles Times*, 14 October 1928. The ferry also played a part in the Brown-Stanton Survey for a railway through the Grand Canyon. After the initial excursion through the canyon ended disastrously in 1889, the surveyors returned the following year to Lee's Ferry to resume the work. Stanton reportedly had Christmas dinner at the ferry before setting out on the re-survey. He returned shortly thereafter to bring out his photographer, who had broken his leg in a fall. Lewis R. Freeman, "Bridging the Grand Canyon of Arizona," *Travel*, October 1929, pages 28-32, 45.

¹²One of the improvements made to the property by the church was the excavation of dugways for the roads winding down the canyon. According to Jeremiah Johnson, who lived at the ferry in 1928, the church contracted with "an outfit from Utah" in 1898 to build the dugways for \$3,000.00. Frank Gold, "'Lonely Dell' Was the Original Name..."

¹³Arizona State Highway Department, "History of the Arizona State Highway Department," unpublished manuscript, 1939, located at the Arizona State Library, Phoenix, Arizona.

¹⁴*Report of the State Engineer of the State of Arizona: July 1, 1909, to June 30, 1914* (Phoenix: Arizona State Press, 1914), page 5.

¹⁵*Report of the State Engineer of the State of Arizona*, page 5.

¹⁶*Ibid.*, pages 73-74.

¹⁷*Third Biennial Report of the State Engineer to the Governor and the Commission of State Institutions* (Phoenix: Arizona State Press, 1918), page 35.

¹⁸Called a highway, the Nogales-Grand Canyon route was in fact only a county road north of Flagstaff until the late 1920s.

¹⁹Ralph Hoffman, "Bridging the Grand Canyon of Arizona," page 5.

²⁰W.R. Hutchins, an engineer working on construction of the Grand Canyon bridge, graphically described the ferry and its eventual destruction:

From the south side, to find a place where the water edge could be reached at the site of the old ferry, one had to travel up the Colorado River for about six miles, the last two miles of which was over what is called the 'dugway', a road barely wide enough for the two wheels of the car or truck, cut in the bare sandstone bluffs and hanging in places four or five hundred feet above the river.

With few exceptions there was no room to pass other cars and only six inches to a foot between one and a vertical drop of several hundred feet to the river below. The grades or hills on the dugway were as steep as twenty-five percent, and it seemed at times as though one was climbing straight up the sides of a house. Parts of the dugway were held in place by a dry stone wall on the lower side, and in wet weather no one was authorized to travel the road. At times, however, when necessity demanded, the road was traveled when wet.

The old ferryboat at Lee Ferry consisted of a flat-bottomed boat of ancient vintage, propelled by the force of the current, but necessitating considerable pushing and pulling to effect a landing. This ferryboat in all probability would have lived its allotted three score years and ten and now be reposing peacefully in some museum instead of on the bottom of the river. If the construction of the new bridge had not thrown extra burdens upon the already decrepit ship.

The boys used the ferry to transport cars and supplies across the river, realizing the danger, up to within three hours of the time it actually sank, drowning three men. The body of one of these was found six weeks after the sinking of the boat; the others were not found.

W.R. Hutchins, "Hardships Encountered in Bridging the Grand Canyon," *Arizona Highways*, May 1929, page 15.

²¹*Eighth Biennial Report of the [Utah] State Road Commission: 1923-24* (Salt Lake City: Arrow Press, 1924), page 24.

²²*Sixth Biennial Report of the State Engineer to the Governor of the State of Arizona* (Phoenix: Manufacturing Stationers, Inc., 1924), page 125.

²³The Red Rock Bridge was, at the time of its completion, the longest-span bridge in America. "But more significant was the fact that it was the first important bridge of its type built in the Western states," according to David Plowden. David Plowden, *Bridges: The Spans of North America* (New York: W.W. Norton and Company, 1974), page 166.

²⁴The Topock Bridge was designed in 1915 by San Bernadino (California) engineer S.A. Sourwine, who evidently patterned it after the Bellows Falls Bridge in Vermont. Called "exceptionally daring and successful for a work of such magnitude," the structure was built by assembling the two arch halves on their sides on either side of the river, hoisting them into place and joining them using a unique ball-and-socket center hinge. The Topock Bridge, like the Navajo Bridge, was fabricated and erected by the Kansas City Structural Steel Company. For more information on it, see "Novel Method of Erection Adopted in Raising Longest Highway Arch Span," *Engineering Record*, 11 September 1916, pages 580-81.

²⁵For more on the Cameron Bridge, see Don Abbe, Roger Brevoort and Doug Kupel, "Cameron Suspension Bridge: National Register of Historic Places Registration Form," June 1980, on file at the Arizona State Historic Preservation Office, Phoenix, Arizona.

²⁶*Seventh Biennial Report of the State Engineer to the Governor of the State of Arizona* (Phoenix: Kelly Print, 1926), pages 62-63.

²⁷Ralph A. Hoffman, "Grand Canyon Bridge Opens New Route Across Greatest of All Natural Barriers," *Arizona Highways*, May 1929, page 13.

²⁸L.C. Lashmet, "Designing the Grand Canyon Bridge," *Arizona Highways*, December 1927, page 6.

²⁹Walter Runke (Superintendent of the Navajo Indian Reservation (1914-1920) and State Senator from Coconino County (1924-1928)), "Financing the Lees Ferry Bridge," *Official Program of the Dedication of Grand Canyon Bridge, Arizona, June 14, 15, 1929*; Ralph Hoffman, "Grand Canyon Bridge Opens New Route across Greatest of All Natural Barriers," page 13; Ralph A. Hoffman, "Bridging the Grand Canyon of Arizona," *Arizona Highways*, November 1927, pages 5-7.

³⁰*Seventh Biennial Report of the State Engineer*, pages 62-63.

³¹Ralph Hoffman, "Bridging the Grand Canyon of Arizona," page 7.

³²L.C. Lashmet, "Designing the Grand Canyon Bridge," pages 6-8.

³³Ralph Hoffman, "Bridging the Grand Canyon of Arizona," pages 5-7; "Steel Arch Highway Bridge Across Colorado River," *Engineering News-Record*, 1 November 1928, page 646; L.C. Lashmet, "Designing the Grand Canyon Bridge," page 6.

³⁴Ralph Hoffman, "Bridging the Grand Canyon of Arizona," pages 5-7.

³⁵The description of the bridge in subsequent paragraphs is abstracted from several sources: R.A. Hoffman, "Closing the Arch of the Grand Canyon Bridge," *Arizona Highways*, October 1928, pages 7-8, 15; "A.S. Taylor, "Bridging the Colorado Across the Marble Gorge," *Compressed Air Magazine*, October 1928, pages 2547-48; L.C. Lashmet, "Designing the Grand Canyon Bridge," page 6; "Bridging the Grand Canyon with a 600-Foot Steel Arch," *Engineering News-Record*, 5 January 1928, pages 17-18; "Steel Arch Highway Bridge Across Colorado River," pages 646-49; "New Bridge To Link Arizona and Utah in Upper Grand Canyon," [Salt Lake City] *Deseret News*, 3 November 1928; and Ralph Hoffman, "Bridging the Grand Canyon of Arizona," pages 5-8. The quotes from Hoffman come from this last article.

³⁶Ibid.

³⁷Ralph Hoffman, "Grand Canyon Bridge Opens New Route Across Greatest of All Natural Barriers," page 57.

³⁸"Bids Submitted On Lee's Ferry Bridge Exceed Appropriations," [Phoenix] *Arizona Republican*, 8 June 1927.

³⁹"Defer Action on New Bridge at Lees Ferry," *Arizona Republican*, 11 June 1927.

⁴⁰Ralph Hoffman, "Bridging the Grand Canyon of Arizona," page 8.

⁴¹Moore was paid \$35.00 per ton for materials delivered to the site. At the end of the project, the haulage contract totalled \$58,000. Ralph Hoffman, "Grand Canyon Bridge Opens New Route Across Greatest of All Natural Barriers," pages 13-14; "New Traffic Link Spans the Grand Canyon," *Construction Methods*, January 1929.

⁴²"Steel Arch Highway Bridge Across Colorado River," pages 646-47; Ralph A. Hoffman, "Grand Canyon Bridge Opens New Route Across Greatest of All Natural Barriers," *Official Program of the Dedication of Grand Canyon Bridge, Arizona, June 14, 15, 1929*.

⁴³Rupert L. Larson, "Bridge Opens Way to Land of Beauty," *Los Angeles Examiner*, 16 September 1928.

⁴⁴W.R. Hutchins, "Hardships Encountered in Bridging the Grand Canyon," *Arizona Highways*, May 1929, page 15.

⁴⁵Ralph Hoffman, "Grand Canyon Bridge Opens New Route Across Greatest of All Barriers," page 14.

⁴⁶"Lofty Bridge Into Form," *Kansas City Star*, 15 February 1928.

⁴⁷W.R. Hutchins, "Hardships Encounters in Bridging the Grand Canyon," page 15.

⁴⁸R.L. Duffus, "A Bridge Rises High over the Mighty Colorado," *New York Times Magazine*, 15 July 1928; Ellsworth Bennett, "The Colorado Spanned at Last," *Popular Science Monthly*, October 1928, page 19. A local newspaper recorded the incident:

The eleventh panel completing the Flagstaff side of the main arch was in place and riveted by June 15 [1928]. It was during this week that one of the steel workers lost his life - falling from the top chord of the bridge to the water 460 feet below. True to tradition the other four workers of the crew quit after the death of their comrade and a new crew had to be secured. The other crews remained on the job and went to work again the next day.

"Closing the Arch of the Lee's Ferry Bridge," [Flagstaff] *Coconino Sun*, 2 November 1928.

⁴⁹"Closing the Arch of the Lee's Ferry Bridge," *Coconino Sun*; Ralph Hoffman, "Closing the Span of the New Grand Canyon Bridge," *Badger Highways*, December 1928, page 8; "New Traffic Link Spans the Grand Canyon."

⁵⁰Ralph A. Hoffman, "Grand Canyon Bridge Opens New Route Across Greatest of All Natural Barriers," page 14.

⁵¹Hoffman, "Grand Canyon Bridge Opens New Route...," page 57.

⁵²The aggregate cost of the completed bridge and approaches was as follows:

Paid to contractor:	\$256,229.09
Cost of state forces:	\$ 73,304.79
Cost of approach grading:	\$ 73,466.12

Total cost	\$403,000.00

⁵³"Grand Canyon Bridge Dedicated in Ceremony Led by Governors," [Phoenix] *Arizona Republic*, 14 June 1929.

⁵⁴Ibid.

⁵⁵"The Bridge Builders," *Arizona Highways*, May 1929, page 30.

STATE OF ARIZONA
MAY 1927

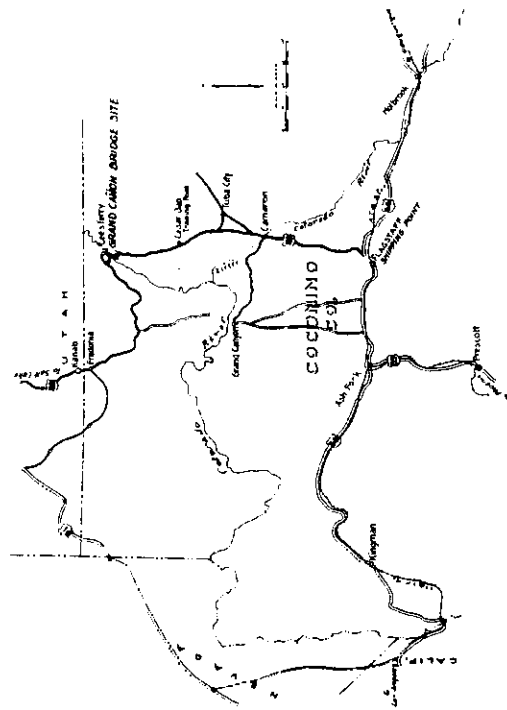
STATE HIGHWAY DEPARTMENT

PLAN OF PROPOSED
GRAND CANYON BRIDGE

OVER
COLORADO RIVER
NEAR LEE'S FERRY
U. S. ROUTE 89
COCONINO COUNTY

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COOPERATIVE PROJECT
STATE OF ARIZONA
UNITED STATES DEPT. OF INTERIOR

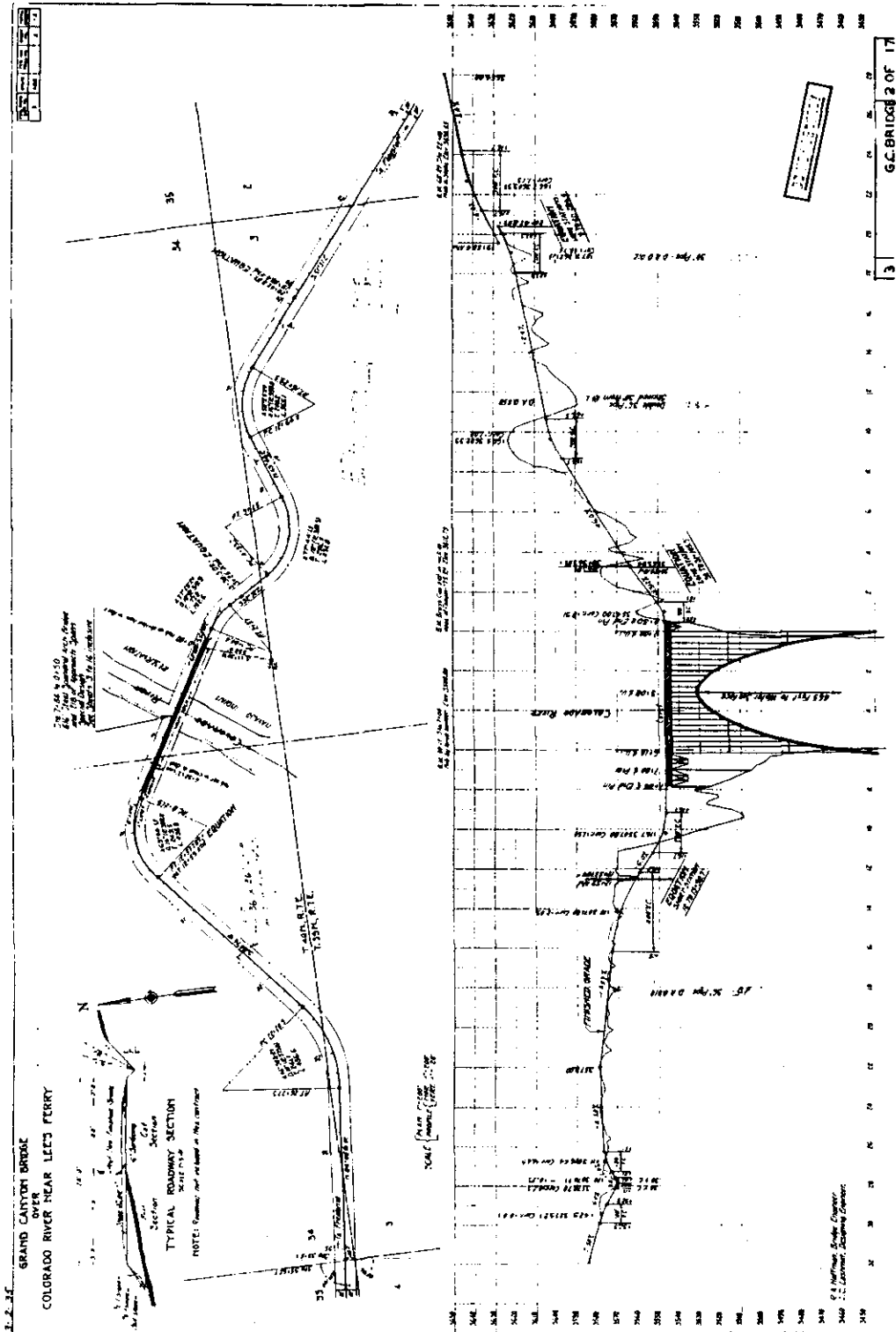
APPROVED FOR CONSTRUCTION
BY THE STATE ENGINEER
STATE OF ARIZONA
MAY 1927

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BY THE STATE ENGINEER
STATE OF ARIZONA
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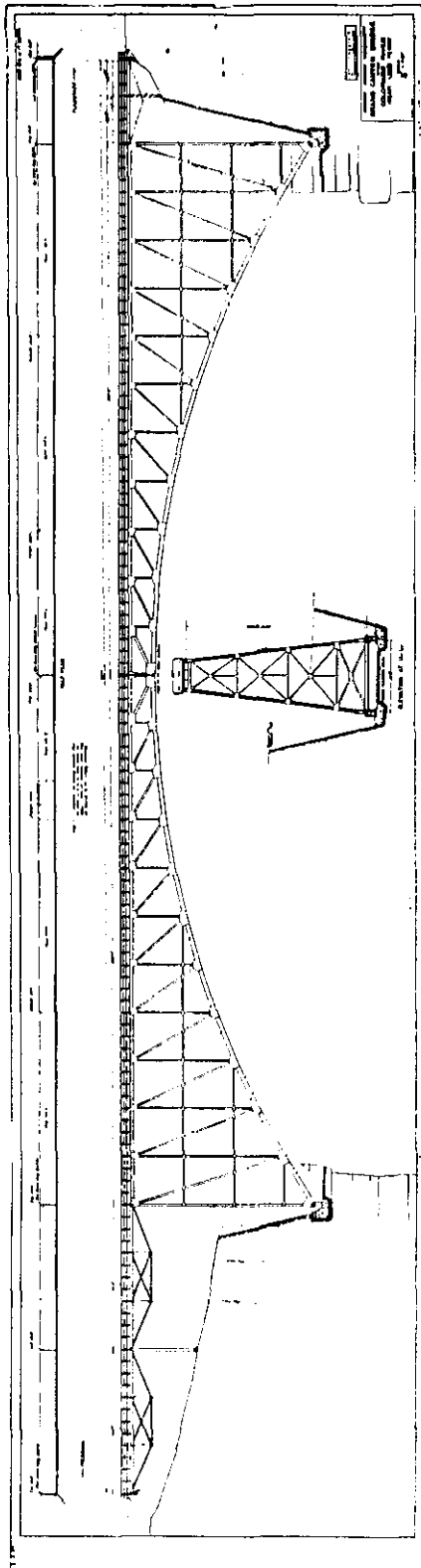
Navajo Bridge
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Figure 8. Title Page for Construction Drawings of Navajo Bridge, by Arizona Highway Department, May 1927.



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Figure 9. Plan and Profile of Navajo Bridge, by Arizona Highway Department, May 1927.



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Figure 10. General Layout of Navajo Bridge, by Arizona Highway Department, May 1927.

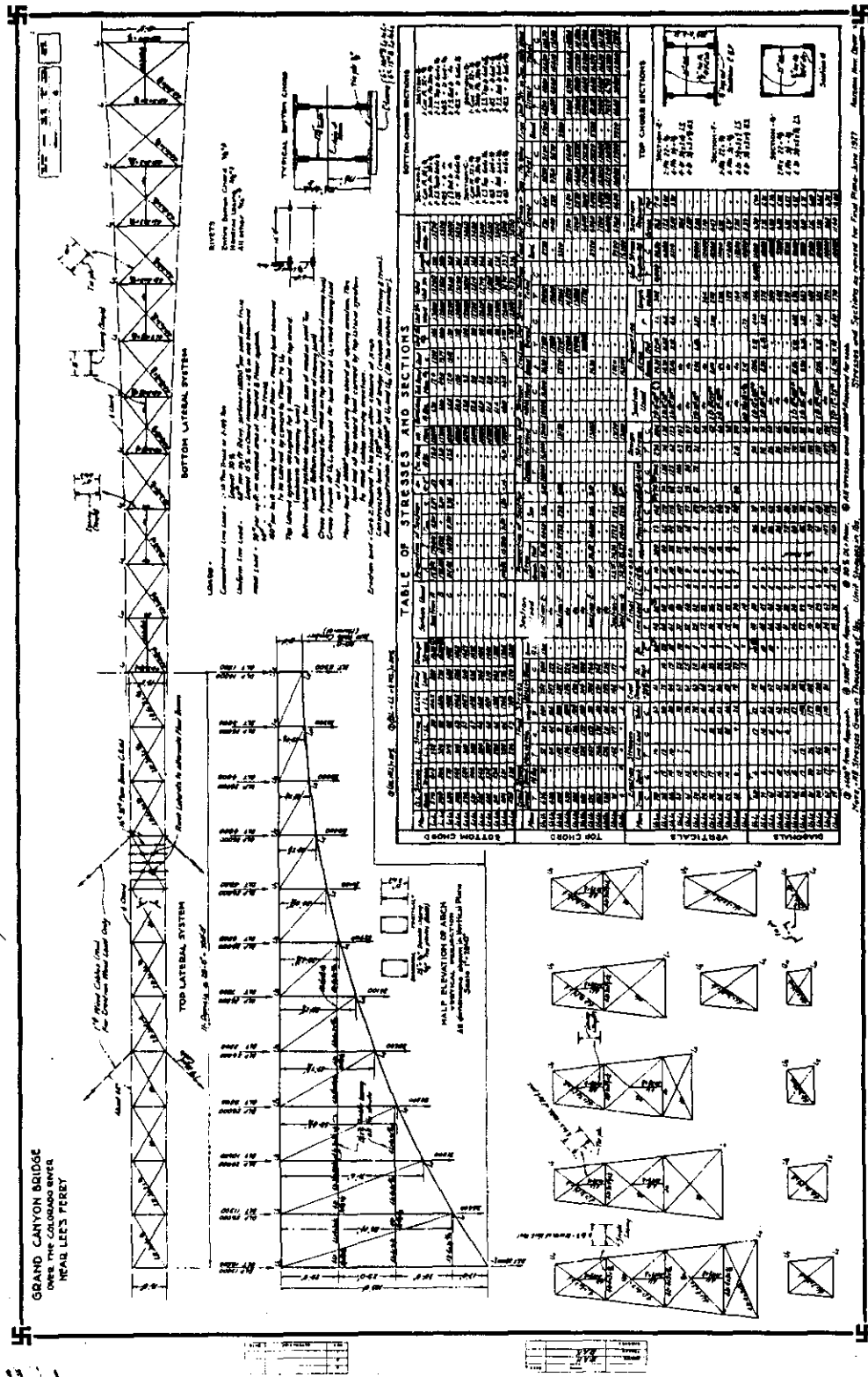


Figure 11. Stresses and Sections of Navajo Bridge, by Arizona Highway Department, May 1927.

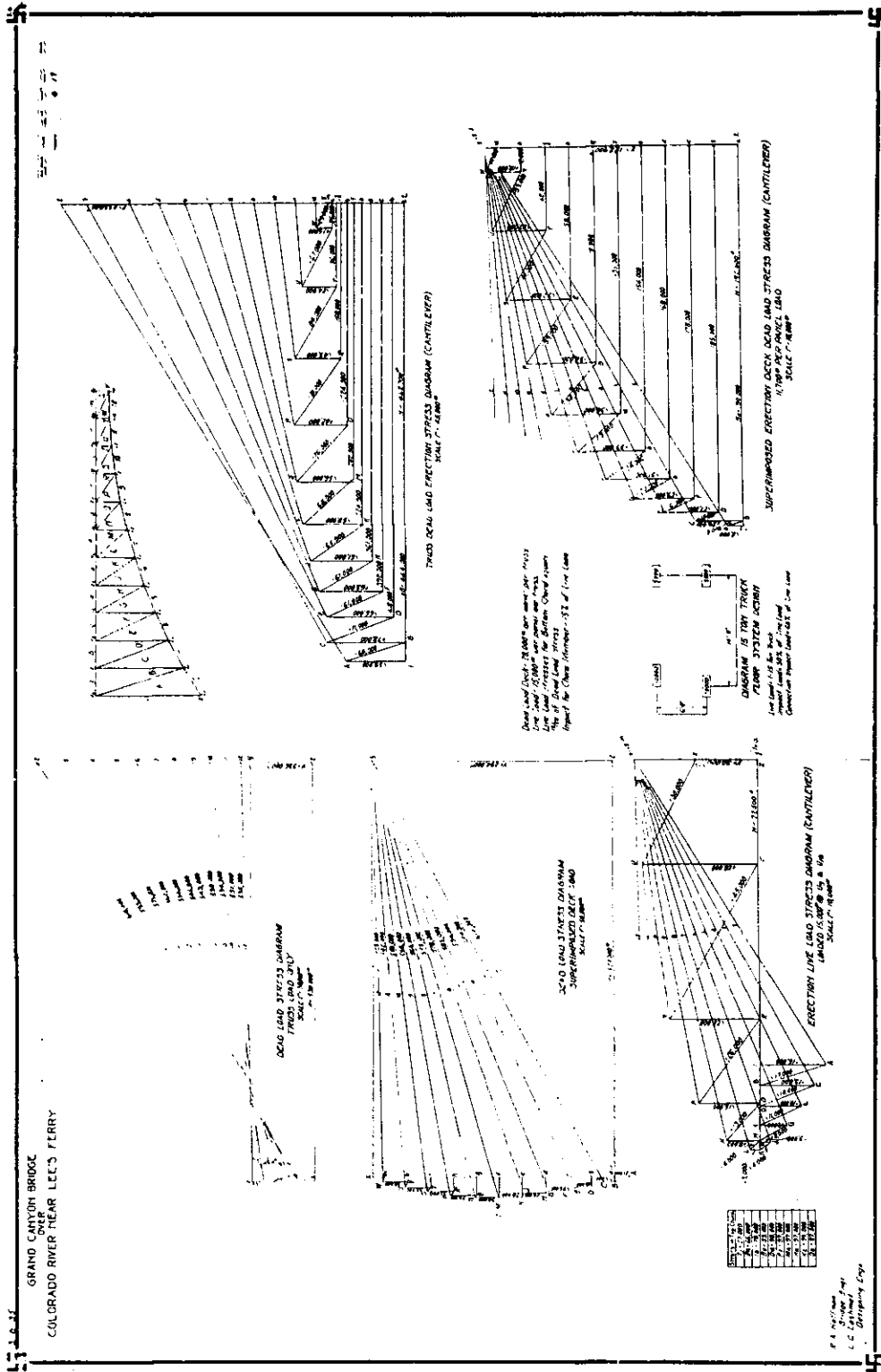


Figure 12. Stress Diagrams of Navajo Bridge, by Arizona Highway Department, May 1927.

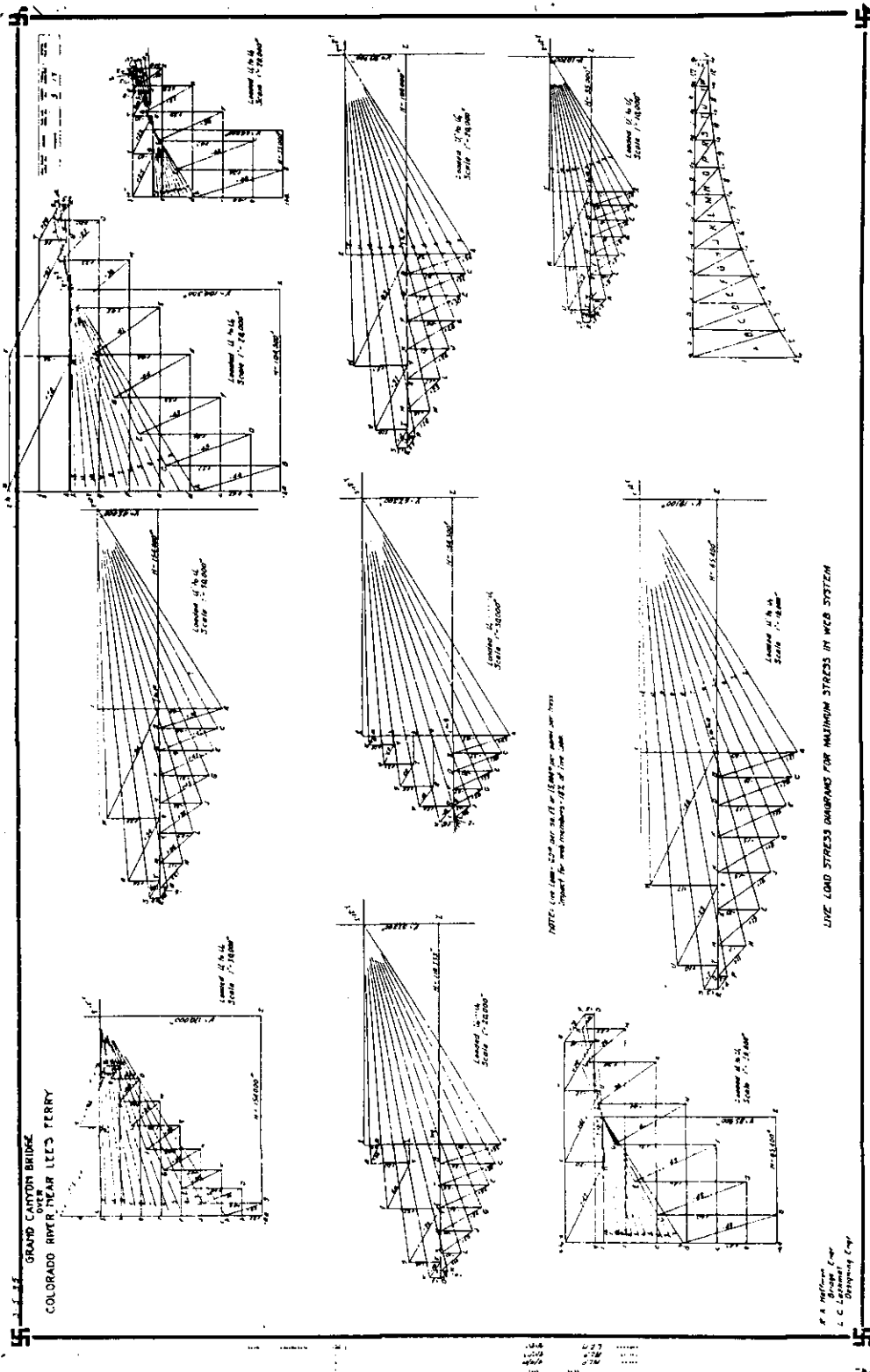


Figure 13. Stress Diagrams of Navajo Bridge, by Arizona Highway Department, May 1927.

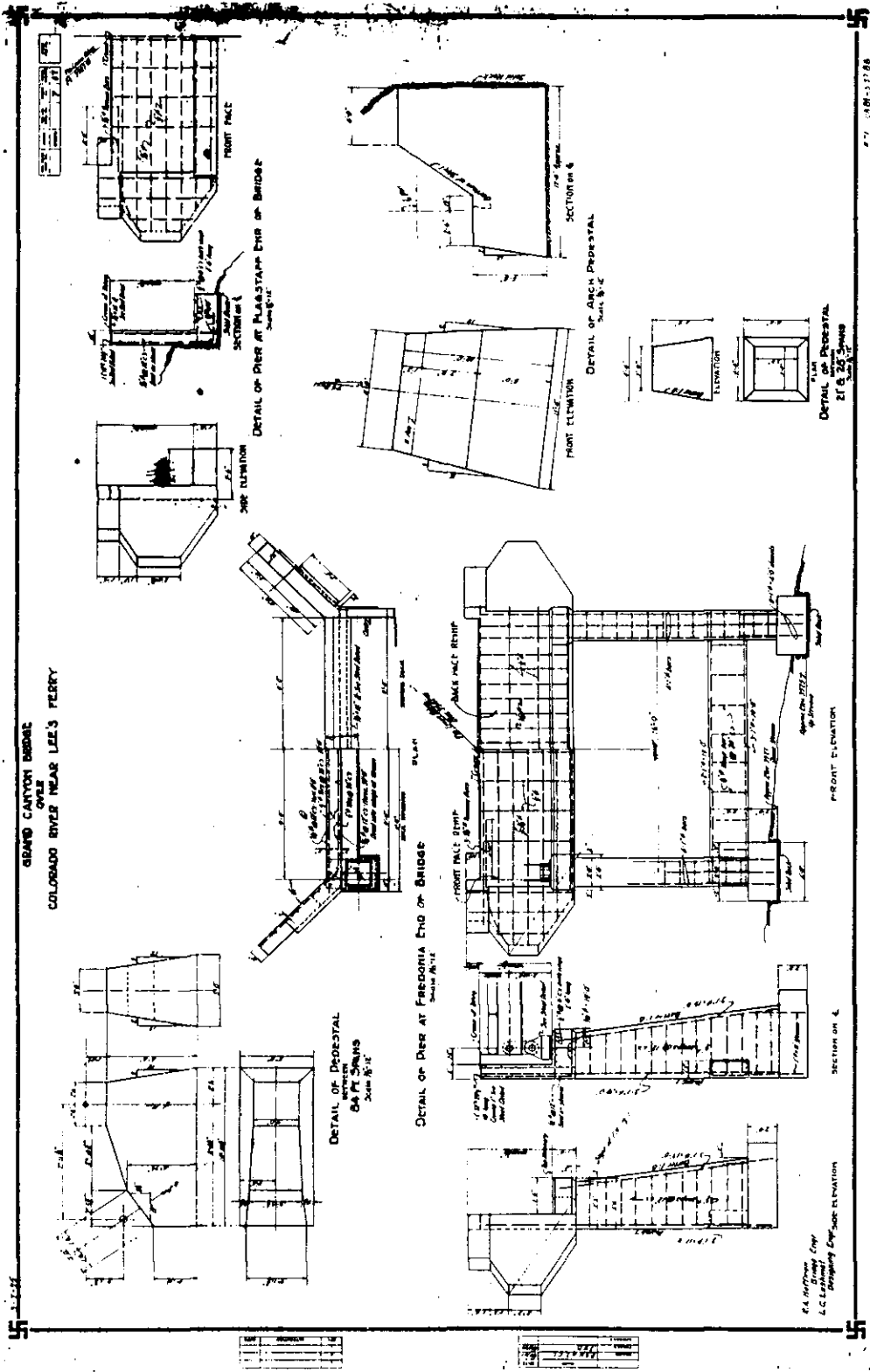


Figure 14. Foundations of Navajo Bridge, by Arizona Highway Department, May 1927.

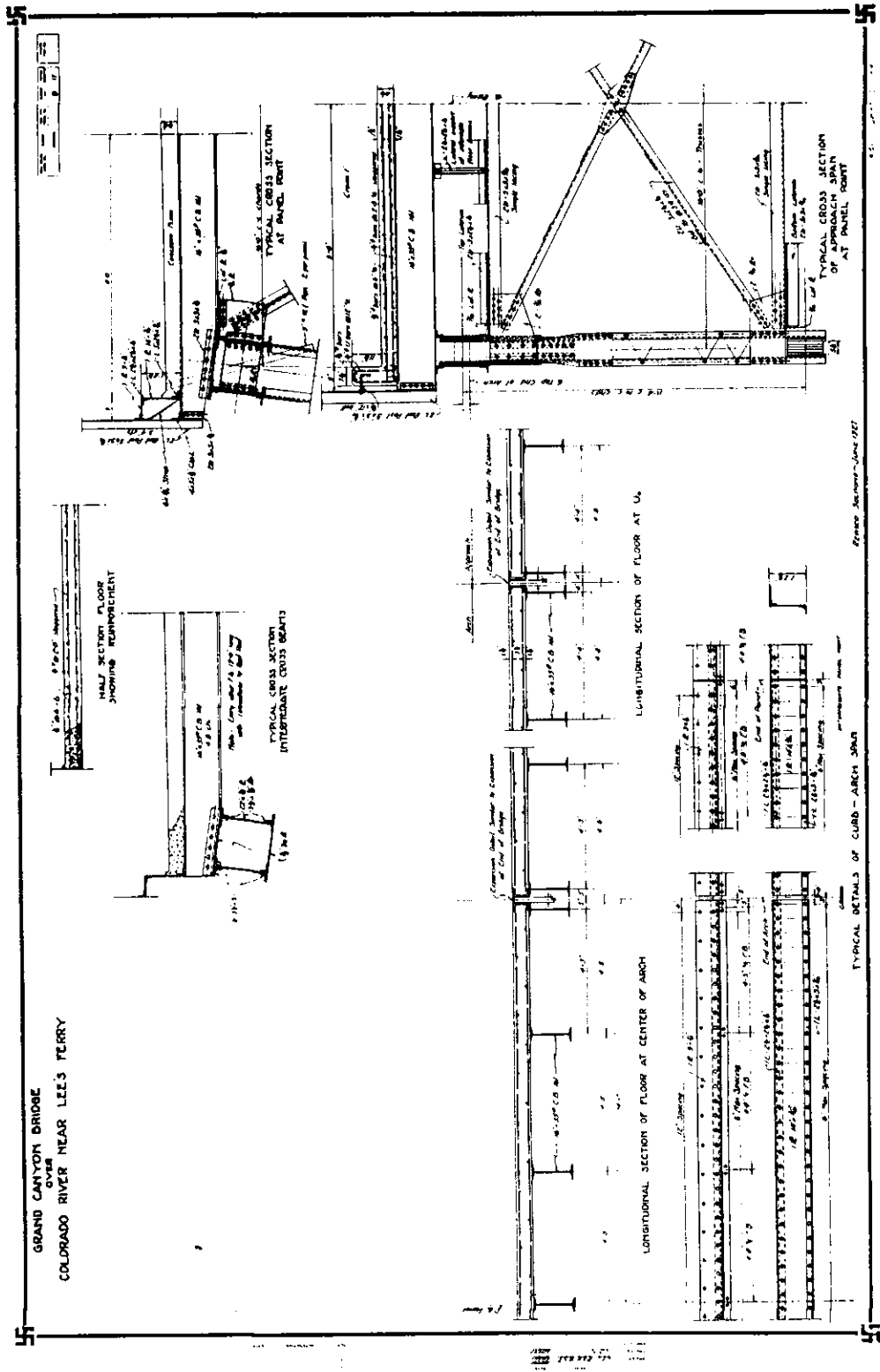
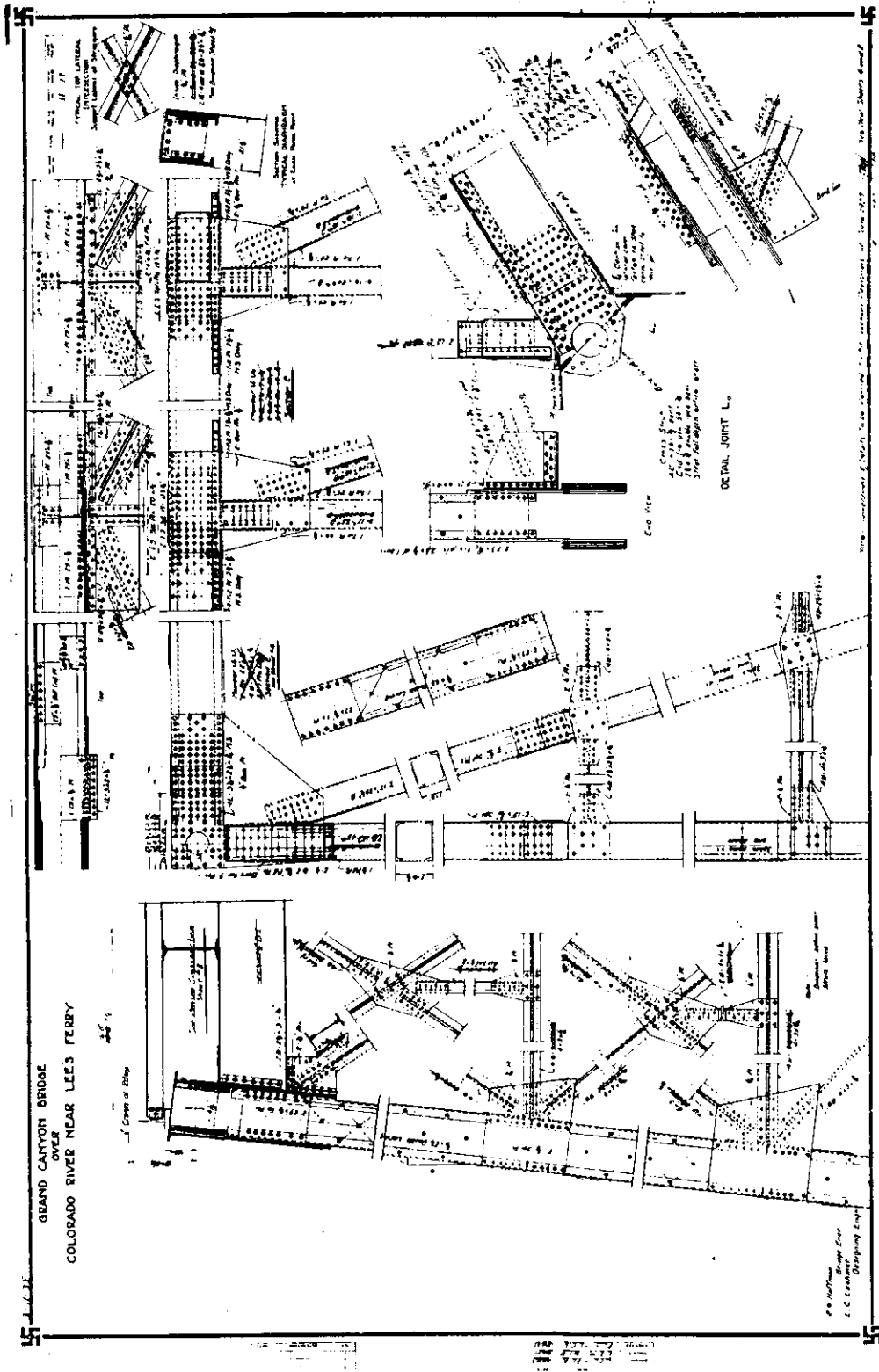


Figure 15. Floor System of Navajo Bridge, by Arizona Highway Department, May 1927.



■ Figure 18. Arch Detail, U₀ - U₂ of Navajo Bridge, by Arizona Highway Department, May 1927.

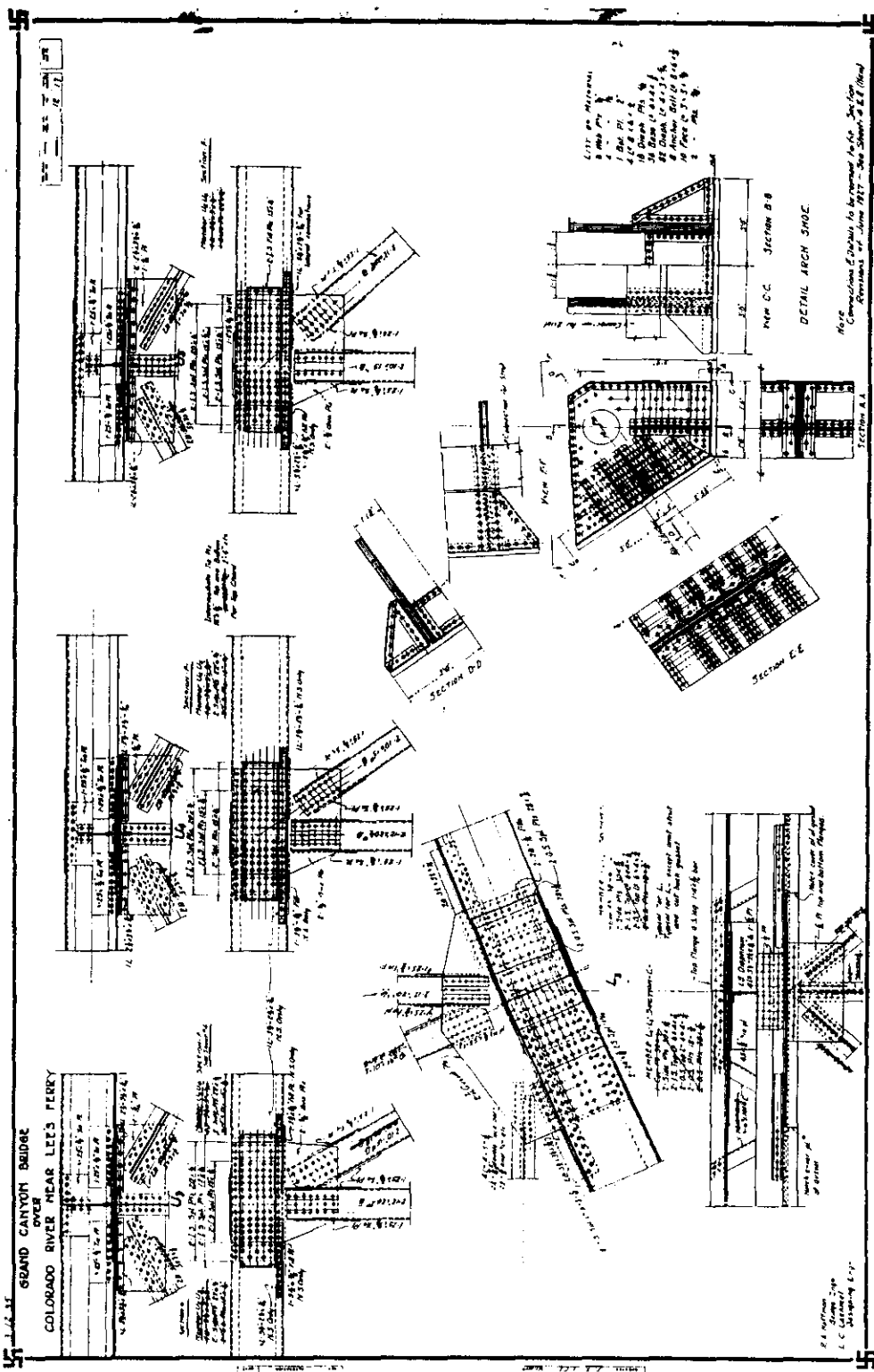
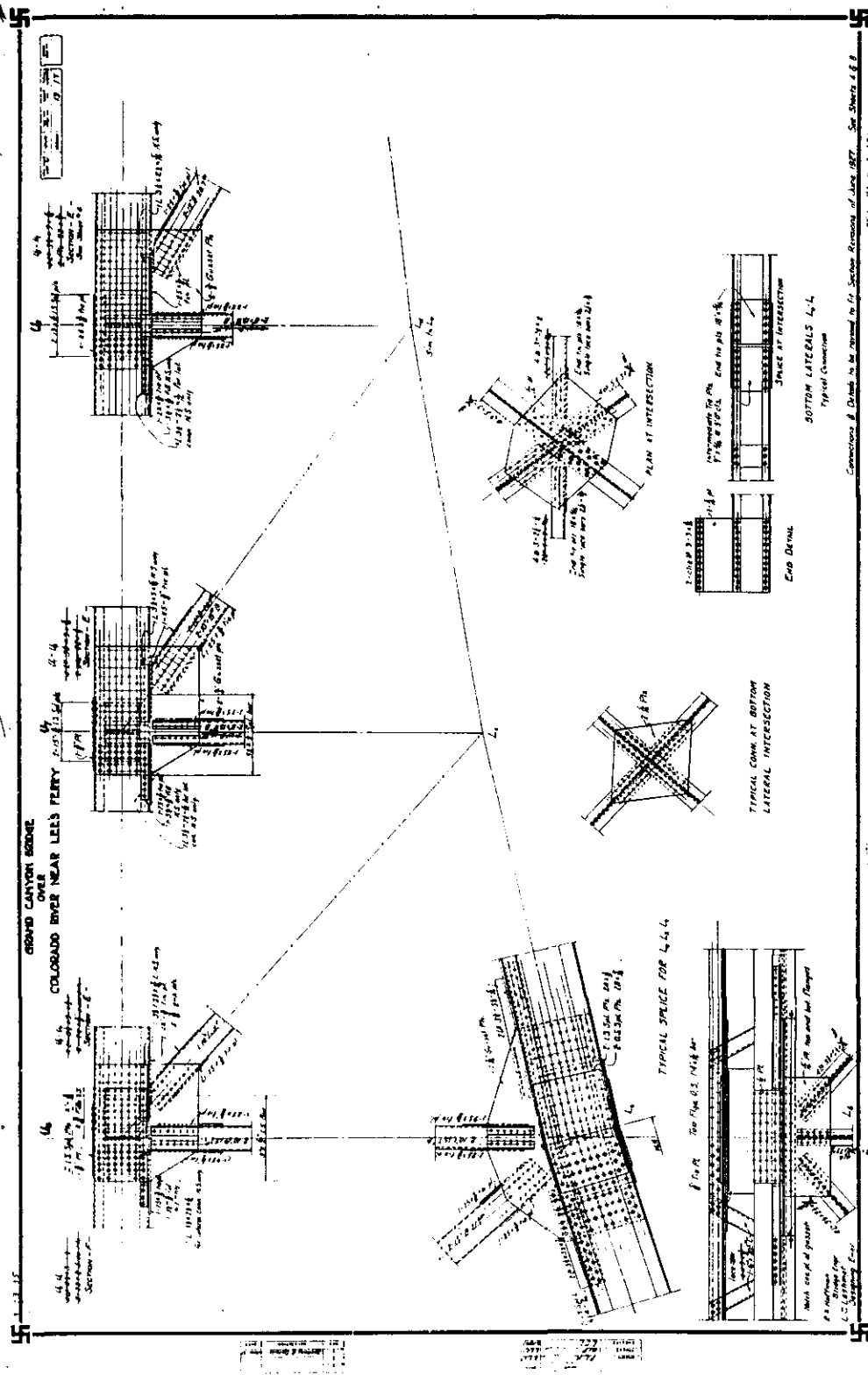


Figure 19. Arch Detail, U₃ - U₅ of Navajo Bridge, by Arizona Highway Department, May 1927.



■ Figure 20. Arch Detail, U₆ - U₈ of Navajo Bridge, by Arizona Highway Department, May 1927.

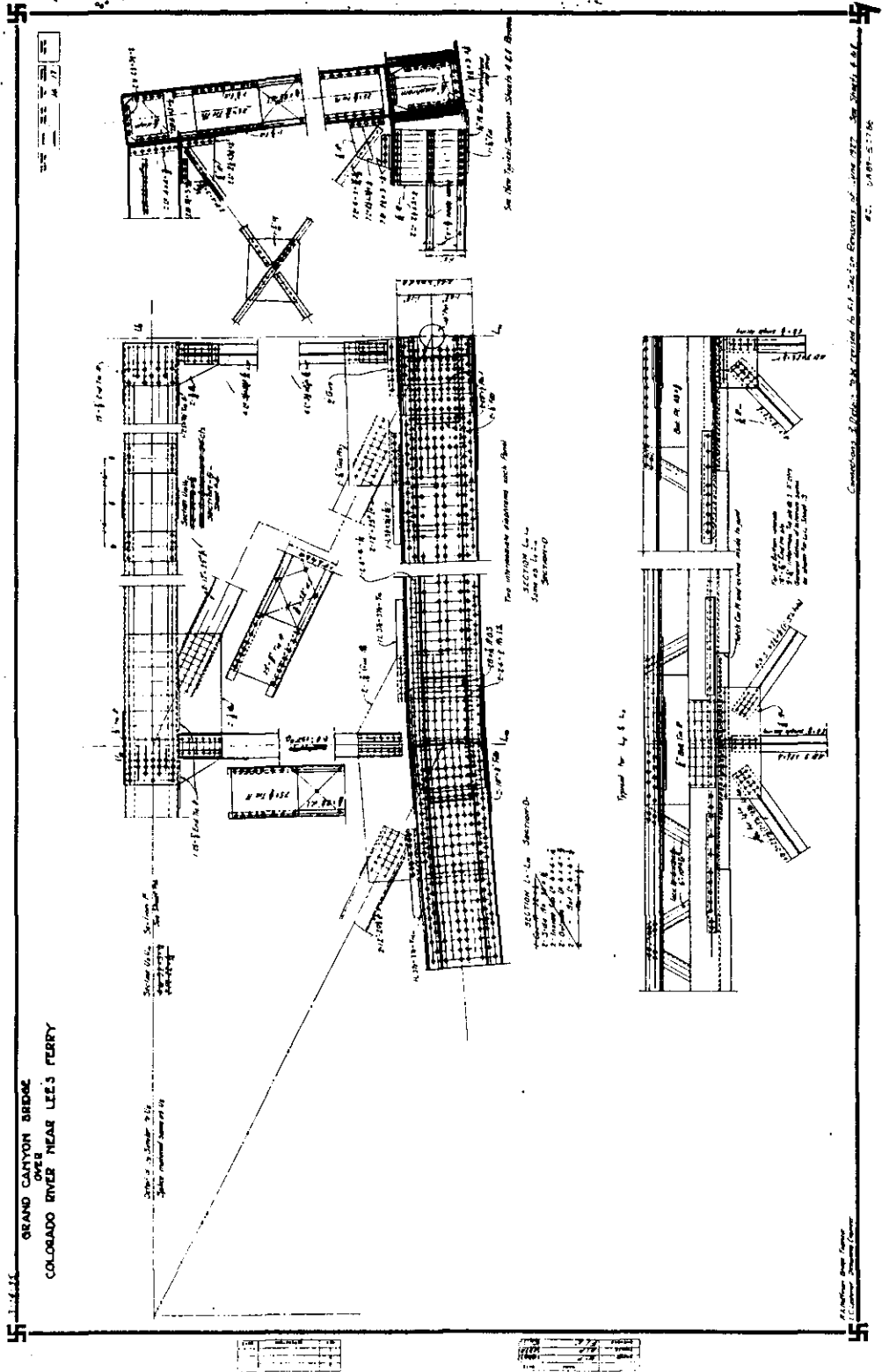


Figure 21. Arch Detail, U₉ - U₁₁ of Navajo Bridge, by Arizona Highway Department, May 1927.

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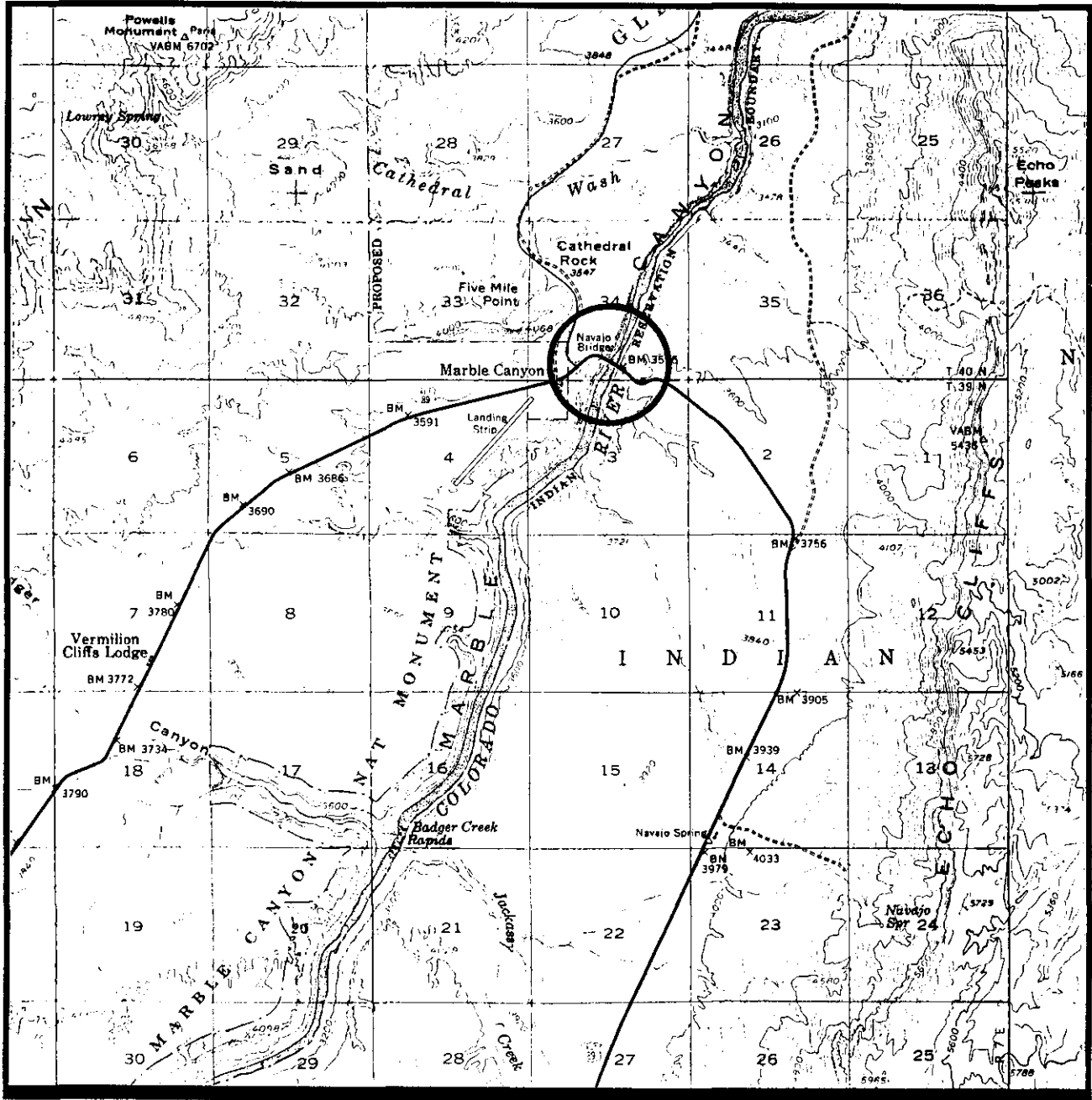
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■ Figure 24. Location Map of Bridge (Lees Ferry, Arizona, USGS Quadrangle Map: 15 Minute Series, 1954)

Appendix

SPECIFICATIONS FOR CONSTRUCTION OF THE GRAND CANYON BRIDGE Arizona Highway Department, 16 May 1927 (abridged)

EXCAVATION AND EMBANKMENTS

SECTION 1. DESCRIPTION

- (a) Excavation and embankment shall include the work of grading the roadway together with such surface ditches, channel changes, cut ditches, intersecting roadways, clearing and grubbing, excavation for structures, the backfilling of all structures and any incidental grading that may be found necessary to the proper completion of the work.

SECTION 2. CLEARING AND GRUBBING

- (a) Clearing shall include the clearing of the entire right-of-way or such part as the [State] Engineer may direct. Clearing shall be kept at least one thousand (1000) feet in advance of the grading. All trees, brush, etc. shall be cut as close to the ground as practical and in no case higher than the stump top diameter.
- (b) Grubbing shall be kept at least three hundred (300) feet in advance of grading. Grubbing will be required between the slope stakes of all excavations, and between the slope stakes of all embankments less than two and one-half ($2\frac{1}{2}$) feet in height. Cavities left by reason of powder being used to blow out stumps must be carefully and tightly back-filled. If ordered by the Engineer, these cavities are to be flooded.
- (c) No stump top will be permitted within two and one-half ($2\frac{1}{2}$) feet of the top of any embankment.
- (d) All stumps, brush, trees, etc. shall be burned, piled or otherwise disposed of as the Engineer may direct.
- (e) Unless otherwise provided in these specifications, the contract price for grading will cover clearing and grubbing.
- (f) Should the State Engineer have available special equipment for clearing and grubbing, he may direct that such work shall be done by the State forces, and shall be excluded from this contract; notice to this effect will be shown in a special provision.
- (g) Structures within the line of work and not necessary to the finished grade shall be removed as the Engineer may direct.

SECTION 3. ROADWAY EXCAVATION

- (a) Roadway excavation shall include all excavation mentioned under Sec. 1 of this specification.
- (b) All materials excavated shall be unclassified, or if classified, shall be classified as "Solid Rock", "Loose Rock", "Hard-Pan", or "Common Excavation", or as otherwise specified in Special Provisions.

"Solid Rock" shall comprise rock in solid beds or masses in its original position which may be best removed by blasting (excepting the material classified as hard-pan), and boulders or detached rock measuring one cubic yard or over.

"Loose Rock" shall comprise all detached masses of rock or stone of more than one cubic foot and less than one cubic yard, and all other rock that can be properly removed by pick and bars and without resorting to blasting; although steam shovel or blasting may be resorted to on favorable occasions in order to facilitate the work.

"Hard-pan" shall comprise all materials not loose or solid rock, which in the opinion of the Engineer, cannot be properly moved except by blasting on account of its own inherent hardness, but which after blasting has been resorted to, can be reasonably plowed by a six up plow, well handled and equipped.

"Common Excavation" shall comprise all materials that do not come from the classification of "Solid Rock", "Loose Rock", "Hard-Pan" or other classification of materials as may be established before the award of this contract.

SECTION 4. SLIDES AND OVERBREAKAGE

- (a) Excavation in excess of the authorized cross-section, as well as slides extending beyond the slope lines shall not be paid for unless due to causes beyond the control of the contractor or his agents.
- (b) In case that payment shall be made for materials in slides, etc. it shall be classified in accordance with its condition at the time of removal, regardless of prior condition.
- (c) Measurement of the material shall be the original space occupied.

SECTION 5. MATERIALS FOR SURFACING

- (a) Gravel or other suitable material encountered in excavation shall, when so directed, be reserved for surfacing of the roadway and other material may be borrowed to complete embankment. Payment for the material reserved will be made as materials excavated, payment for material borrowed to complete the work as material borrowed.
- (b) All muck, quick-sand or other unsuitable material shall be removed to such depth as the Engineer may direct and refilled with suitable material.

SECTION 6. EMBANKMENTS

- (a) Embankments shall be formed of suitable material and shall be carried to such height above subgrade and to such increased widths as may be deemed necessary provision for shrinkage, compression and washing.
- (b) As embankments become consolidated their sides shall be carefully trimmed to their proper slopes, and they must be maintained to their proper height, dimension and slope until the work is finally accepted.
- (c) When embankments are placed on sloping ground or existing fills are widened, the surface shall be deeply plowed or stepped as the Engineer may direct.
- (d) Material for embankments over and around structures shall be deposited in thin layers, and when directed by the Engineer, shall be carefully tamped. Care shall be exercised that no excessive strains be placed upon structures by unbalanced loading.
- (e) All embankments that are to have a paved surface shall be built in successive layers of not more than 12 inches in depth for the full width of the cross-section, each layer to be compacted thoroly [sic] with a power rolled weighing not less than ten tons. When the bottom of the fill is of insufficient width to permit the use of a roller, the material shall be tamped thoroly and satisfactorily. Materials containing sand in such proportions as to prevent it, when dry, from compacting readily when rolled, shall not be used except on written approval of the engineer.
- (f) The contractor shall be responsible for the stability of all constructed embankments and shall replace any portions which, in the opinion of the Engineer, have become displaced due to careless or negligently work on the part of the contractor.

SECTION 7. EXCAVATION FOR STRUCTURES

- (a) Excavation for structures, shall consist of the excavation of foundations according to the plans or as established by the Engineer. It shall include the removal of existing structures, the pumping or baling of water, bracing and sheeting.
- (b) Excavated material shall be disposed of as directed by the Engineer.
- (c) No payment shall be made for structural excavation which is more than one foot outside the area described by vertical planes passing thru the edges of the foundation bases.

SECTION 8. DISPOSAL OF SURPLUS EXCAVATION MATERIAL

- (a) When the quantity of excavation exceeds that required to make the embankments to standard cross-section, the surplus shall be used to widen the embankments uniformly, along one or both sides, or as the engineer may direct. The material, when possible, shall be deposited below grade and under no circumstances shall the waste bank have its nearest edge within ten (10) feet of the slope stakes of the cutting.

- (b) All wastebanks shall have a neat and finished appearance and if so directed by the Engineer shall be placed in such a manner as to divert storm water from the excavation.

SECTION 9. BORROW EXCAVATION

- (a) Land for borrow pits shall be provided by the State.
- (b) Borrow pits shall be connected with ditches and drained to the nearest water course, when required. Borrow pits shall not be excavated before they have been staked out.
- (c) Borrowing shall be done in regular shape in order to admit of ready and accurate measurements.
- (d) No classification or allowance shall be made for loose or solid rock or hard-pan in borrow pits unless specific written instructions are given to the contrary by the State Engineer, it being the intent and meaning of these specifications that all borrowed materials shall be classified and paid for as common excavation.

SECTION 10. BERME

- (a) A berme of not less than five (5) feet in width shall be left between slope stakes of embankments and the edge of the Borrow Pit. When conditions require, the width of the berme shall be increased as the Engineer may direct.

SECTION 11. OVERHAUL

- (a) No payment shall be made for hauling material when the length of haul does not exceed the limit of free haul, which shall be Five Hundred Feet (500').
- (b) The limits of free haul shall be determined by fixing on the profile two points - one on each side of the neutral grade point - one in excavation and the other in embankment such that the distance between them shall equal the specified free-haul limit and such that the included quantities of excavation and embankment shall balance. All haul of material beyond the free-haul limit shall be estimated and paid for on the basis of the following method of computation, viz:
- (c) All material within this limit of free-haul shall be eliminated from further consideration.
- (d) The distance between the center of gravity of the remaining mass of excavations and the center of gravity of the resulting embankment, less the limit of free haul as above described, shall be the overhaul distance.
- (e) Overhaul shall be computed in units of 1 cu. yd. moved 100 ft. or one station yard and compensation to be rendered therefor shall be computed on such units.

- (f) In case material is obtained from borrow pits along the embankment and runways constructed, the haul shall be determined by multiplying the number of cubic yards so hauled by one-half of the round distance made by them, less the free-haul distance. The runways shall be established by the engineer.

SECTION 12. SUBGRADE

- (a) The bottom of the excavation and the top of the fill, when completed shall be known as the subgrade and shall be true to line grades and cross-sections given.
- (b) Unless otherwise indicated the grade line shown on the profiles represents the finished surface.
- (c) After drains are laid and all structures backfilled the subgrade shall be brought to the correct shape. All loose rock shall be removed or broken off to a distance of six (6) inches below the surface of the subgrade and if holes are formed they shall be filled with suitable material.
- (d) All subgrade for paving shall be thoroughly rolled with a power roller of not less than ten tons weight for the full width of the paving and for a distance of one foot outside each edge of the same. When required by the engineer subgrade shall be wetted before being rolled.
- (e) Where grading material is not suitable for surfacing, the roadway shall be finished to subgrade elevation. Where excavated material is suitable for surfacing the roadway shall be constructed to finished grade. Roadway in all cuts and in fills when required by the engineer shall be plowed or scarified to a depth of six inches. All stones having a diameter of more than one and one-quarter inches shall be removed. The surface shall be brought to the proper cross-section. Payment for same is to be included in the cost of grading.

SECTION 13. PROTECTION OF SUBGRADE

- (a) The contractor shall complete all necessary ditches for the protection of the subgrade and will permit teams or other vehicles to use same only at his own risk. He will be held responsible for all damage so caused and shall repair or replace any damage to the satisfaction of the Engineer.
- (b) No foundations nor surfacing material shall be deposited on the sub-grade until it has been checked and approved.
- (c) Storage or material will not be permitted between the header boards except with the written approval of the State Engineer.

SECTION 14. SHOULDERS

- (a) Material for shoulders shall contain no vegetable matter, muck, quicksand or other material which may not be compacted to form a stable and enduring shoulder.

- (b) The shoulders for a gravel surfaced road shall be constructed to such additional height that when properly compacted and settled they shall be of the required cross-section and to the grade shown on the plans.
- (c) The shoulders for a paved road shall be rolled with a rolled weighing not less than ten tons and their finished grade shall be that as shown on the plans.

SECTION 15. MEASUREMENT OF QUANTITIES

- (a) Quantities will be measured in the units used in the contract. Grading work volumes will be computed by the method of average end areas; masonry volumes will be computed by the prismatic formula; other quantities will be computed by the customary engineering usage.
- (b) Where solid rock is excavated six inches below subgrade quantities will be computed to this depth but no payment will be made for refilling to subgrade.

SECTION 16. BASIS OF PAYMENT

- (a) The basis of payment of all material excavated will be the contract price per cubic yard with such additional payments as may be covered by extra work.
- (b) The basis of payment for earthwork overhaul shall be a unit of one cubic yard hauled 100 feet or one station yard.

CONCRETE CONSTRUCTION

SECTION 1. CLASSES OF CONCRETE

- (a) In general only three classes of concrete will be used. Special structures requiring other classes of concrete than those provided for below, or requiring modifications in the materials used will be provided for by means of detailed plans or detailed specifications covering each particular class of structure.
- (b) Class "A" Concrete shall consist of one cubic foot (94 pounds) of Portland Cement, two cubic feet of fine aggregate and four cubic feet of coarse aggregate, the several ingredients being measured separately before mixing. Fine and coarse aggregate shall be measured loose. Unless otherwise specified or shown on the plans, class "A" Concrete shall be used for all reinforced concrete and arch rings, and copings, and for all concrete deposited under water.
- (c) Class "B" Concrete shall consist of one cubic foot (94 pounds) of Portland Cement, three cubic feet of fine aggregate and five cubic feet of coarse aggregate, the several ingredients being measured separately before mixing. Fine and coarse aggregate shall be measured loose. Unless otherwise specified or shown on the plans, Class "B" Concrete shall be used for all plain concrete abutments, piers and other massive structures that do not come under Class "C".

- (d) Class "C" Concrete shall consist of one cubic foot (94 pounds) of Portland Cement, three cubic feet of fine aggregate and six cubic feet of coarse aggregate, the several ingredients being measured separately before mixing. Fine and coarse aggregate shall be measured loose. Unless otherwise specified or shown on the plans, Class "C" Concrete shall be used exclusively for footings.
- (e) The Portland Cement used in this work shall conform to the requirements of the U.S. Bureau of Standards Circular 33.

SECTION 2. WATER

- (a) Water used in mixing shall be subject to the approval of the State Engineer; it shall be measured at each mixer in containers adapted to ready adjustment and to accurate delivery of variable quantities. The quantity of water will be subject to regulation at all times by the Engineer, according to the requirements of the aggregate in use at that time.

SECTION 3. FINE AGGREGATE

- (a) Sand shall be well graded from coarse to fine and shall consist of clean, hard, durable, uncoated grains, free from lumps, soft or flaky particles, salt, alkali, organic matter, loam or other deleterious substance, and shall all pass a quarter-inch laboratory screen and not more than five per cent shall pass a 100-mesh "Standard Sieve." Not more than three per cent, by weight, shall be removed by the elutriation test.
- (b) Mortar composed of one part, by weight, of Portland Cement and three (3) parts, by weight, of sand, mixed and tested in accordance with methods referred to in the U.S. Bureau of Standards, Circular 33, shall have a tensile strength at the age of seven (7) and twenty-eight (28) days, of one hundred (100) per cent of that developed by mortar of the same proportions and consistency, made of the same cement and "Standard Ottawa Sand" except that sand giving a strength ratio at seven (7) days and twenty-eight (28) days of less than one hundred (100) but not less than eighty-five (85) per cent, will be accepted for use in concrete subject to their use of additional cement. The additional proportion of cement required will be determined by laboratory tests and shall be the percentage required to increase the tensile strength ration of the mortar to not less than one hundred (100) per cent at seven (7) and twenty-eight (28) days.

SECTION 4. COARSE AGGREGATE

- (a) Coarse aggregate shall consist of crushed stone or gravel, having particles larger than one-quarter inch in size and graded uniformly from the smallest to the largest particles. Crushed stone shall be obtained from clean, tough, durable rock having a French Coefficient of not less than 6. Gravel shall consist of clean, hard, durable and uncoated pebbles of high resistance to abrasion. Coarse aggregate shall be free from all deleterious matter, and shall not contain dust, nor soft, flat or elongated particles.

- (b) For plain concrete the maximum size shall not exceed two and one-half ($2\frac{1}{2}$) inches. For reinforced concrete the maximum screen opening shall not exceed the following:

$$S1 - (d \div \frac{1}{2} \text{ inch})$$

$$S2 - (\frac{1}{2}d \div \frac{1}{4} \text{ inch})$$

$$S3 - (d \div \frac{1}{4} \text{ inch})$$

$$S4 - (\frac{1}{2}d \div \frac{1}{4} \text{ inch}) \quad \text{Where } d = \text{diameter of bars}$$

S1 = Distance between center of bars

S2 = Distance from side form to center of nearest bar

S3 = Distance between centers of layers of bars

S4 = Distance from bottom of form to center of nearest bar

- (c) The use of unscreened gravel or crusher run stone shall not be permitted.
- (d) When so stated in the special provisions crushed slag fulfilling the following qualifications may be used as coarse aggregate in footings, abutments, and piers, but under no circumstances will the use of slag be permitted in slabs, girders or arch rings. The broken slag shall consist of clean, tough, durable pieces of iron furnace or other slag of equal quality reasonably uniform in density and quality, non-glassy and free from thin or elongated pieces. It shall be air-cooled and shall have been exposed to the weather for a period of at least six (6) months prior to use. It shall contain not more than 1.5 per cent of sulphur and the dried slag when shaken to refusal shall have a weight per cubic foot of not less than 75 pounds.

SECTION 5. FALSEWORK

- (a) False work shall be built on good firm foundation and be of sufficient strength to carry the loads without appreciable deformation. It shall be constructed with 1/20-inch camber for each foot of span and necessary wedges shall be kept driven as the weight of the concrete is added so that the bottom of the slab will not drop below the lines shown on the plans. If appreciable settlement occurs in the false work the Engineer shall stop the work and require a thorough remodeling to insure a first-class product.
- (b) When trussed centers or special means of support other than the ordinary falsework are to be used, detail drawings of same shall be substituted for approval.

SECTION 6. FORMS

- (a) Lumber: Douglas Fir, Southern Pine, or other suitable lumber may be used for forms; it shall be free from loose knots or other defects. For exposed surfaces, lumber shall be dressed at least on one side and both edges. Rough lumber may be used for unexposed surfaces.
- (b) The forms shall be durable and rigid and shall be so well braced that bulging or twisting cannot occur.
- (c) All form dimensions shall be checked, and if necessary corrected before concrete is placed therein.

- (d) Joints shall be sufficiently tight to prevent the leakage of the mortar.
- (e) The interior of forms shall be thoroughly wetted before concrete is placed and if necessary shall be soaked to close shrinkage cracks.
- (f) Forms for re-entrant angles shall be cambered and for corners shall be filleted. Before concrete is placed the interior of forms shall be thoroughly cleaned and all shavings, sawdust or other debris removed.
- (g) Form lumber used a second time shall be thoroughly cleaned and shall be in a condition acceptable to the Engineer.

SECTION 7. CONSISTENCY

- (a) Sufficient water shall be used, in mixing plain concrete to produce a mixture which will flatten and quake when deposited in which reinforcement is to be imbedded to produce a mixture which will flow sluggishly when worked and at the same time can be conveyed from the mixer to the forms without separation of the coarse aggregate from the mortar. In no case shall the quantity of water used be sufficient to cause the collection of a surplus in the forms.

SECTION 8. MIXING

- (a) A batch mixer of approved type shall be employed unless as otherwise permitted hand mixing may be employed.
- (b) The method and appliances used in measuring the aggregate before mixing shall be approved by the Engineer. When a batch mixer is employed it shall revolve at the speed for which it is designed, but not less than 14 revolutions per minute nor more than 20 revolutions per minute, for a period of at least one minute, and until a mixture of uniform color and consistency is obtained.
- (c) Hand mixing may be employed, by permission of the Engineer, on small isolated jobs that do not warrant the expense of moving a mixer thereto. Hand mixing shall be done on a water tight platform, in the following manner; the sand shall be spread to a uniform depth, the cement spread evenly over it and the two mixed dry until the mass is of uniform consistency and color. Over this mixture of sand and cement the stone or gravel shall be spread and water added as the mass is turned and mixed. The ingredients may be assembled and mixed in other order than above, but shall in all cases be turned at least six (6) times and until the mixture is of uniform color and consistency.
- (d) No hand mixed batch shall exceed one-half cubic yard in volume.
- (e) No concrete shall be mixed when the temperature is below 35 degrees f. and such precautions as may be desirable to the Engineer shall be used to protect the work during such time as the temperature is below the limit set by these specifications. No material containing ice or frost shall be used regardless of the temperature of the air at the time. Aggregate in such condition shall be heated until the material is in a satisfactory condition of use.

- (f) The entire contents of the drum shall be discharged before any materials are placed therein for the succeeding batch. No concrete will be placed in form after it has been mixed for more than thirty minutes.

SECTION 9. PLACING

- (a) No concrete shall be continuously and evenly deposited in forms. All shallow work, thin sections, and monolithic units, such as girders, slabs and curbs, shall be poured in one continuous operation. No construction joints shall be allowed except as shown on the plans, or approved by the State Engineer in writing previous to construction.
- (b) Bulkheads may be placed where their use is unavoidable. The location and the method of placing same shall be determined by the Engineer.
- (c) Arch rings shall not be concreted until the fill around the abutments has been carried up to the skewback. Arch rings shall preferably be cast in a single continuous operation, but where this is impracticable [sic], they may be divided by vertical bulkheads, into longitudinal sections or by radial bulkheads into transverse sections, of such size that each section can be cast in a continuous operation. Transverse sections shall be so arranged that the initial stress will not be created in the reinforcement. In either method, work shall be carried on symmetrically about the crown of the arch and the sections shall be keyed or doweled together as the Engineer directs. The spandrel walls shall not be cast until after the centers are struck, and no part of the coping or railing shall be cast until the spandrel wall is completed. For large arches and for structures composed of two or more arches, the contractor shall prepare plans showing the sections and giving the sequence of concreting that he proposes to use, which plans shall be approved before this part of the work is started. When concrete is to be left smooth to receive the waterproofing.
- (d) Puddling, tamping and spading shall be done sufficient to bring about the close filling of the forms and to expel as much as possible of entrained air. The larger aggregate shall be spaded away from the forms and the forms tapped on the outside to insure a dense mortar coat and smooth finish. Care shall be exercised to place the concrete around the reinforcing steel without disturbing same.

SECTION 10. DEPOSITING IN WATER

- (a) Concrete shall be deposited in water only with the approval of the State Engineer. The method and appliances used shall be approved by the Engineer and the work done under his supervision. The concrete shall be carefully placed in a compact mass in the space in which it is to remain and shall not be disturbed after being deposited. No concrete shall be placed in running water and forms that are not reasonably watertight shall not be used for holding concrete deposited under water.

SECTION 11. CONSTRUCTION JOINTS

- (a) Before new concrete shall be placed on that which has set, special precautions shall be taken to secure union between the two: laitance shall be removed and the old surface shall be thoroughly cleaned and wetted.
- (b) If the Engineer shall so direct, at the end of the day's work or other interruption of the placing of the concrete, dowels or beveled shaped wooden keys shall be placed in the soft concrete, the wooden keys to be removed before additional concrete is placed. Where practicable stones may be used for dowels, same to be embedded to about one-half their depth and left in place.
- (c) So far as possible the location of construction joints shall be planned in advance and the placing of concrete carried continuously from joint to joint. These joints shall be perpendicular, to the principal lines of stress and in general be located at points of minimum shear.

SECTION 12. CURING CONCRETE

- (a) As a general rule forms may be removed from piers, abutments and walls, etc. in three ways; from small culverts, arches and minor structures of like nature, ten to fourteen days; from large and important structures as slabs, girders and large arches, from three weeks to a month. The Engineer may extend these time limits for reason of freezing weather or other conditions that may retard the setting of the concrete.
- (b) Care shall be taken in removing forms so as not to deface or injure the structure. Holes and porous spots shall be filled in a manner satisfactory to the Engineer.
- (c) Bolts, wires, etc., used to hold forms shall be cut off and covered in a neat and workmanlike manner.

SECTION 14. FINISHING CONCRETE

- (a) All top surfaces of walls, abutments, piers, etc., shall be carefully tamped and trowelled to a smooth surface and when setting protected from the direct rays of the sun.
- (b) Expansion joints and the manner of constructing are shown on the "Standard" plans.
- (c) Unless otherwise specified the forms of all ornamental work, railings parapets and all exposed vertical surfaces shall be removed as soon as safety of the work will permit (usually in not less than 12 nor more than 48 hours), and any small cavities filled with mortar of the same mix as used in the concrete. The whole surfacing shall then be rubbed with a wooden float and clean water until all form marks are removed, leaving the surface plain, smooth and uniform in color and appearance. Cement wash will not be allowed.

SECTION 15. PIPES AND CONDUITS

- (a) The location and details of pipes and conduits will be shown on the "Standard" plans.

SECTION 16. DRAINAGE AND WEEP HOLES

- (a) The location and details of weep holes will be shown on the "Standard" plans.

SECTION 17. WATERPROOFING

- (a) Where indicated on the plans concrete shall be waterproofed by incorporating in the mixture hydrated lime in the amount of ten (10) per cent by volume of the cement used. The hydrated lime shall meet the requirements of the "Standard Specifications" for hydrated lime of the American Society for Testing Materials, Serial designation C-6-15; and shall be of a class known as calcium.
- (b) This material shall be treated as an addition and not as replacing an equal amount of cement.

SECTION 18. RUBBLE CONCRETE

- (a) In Class "B" Concrete in plain piers, abutments and retaining walls, having sections two feet thick or more "one man" stone may be used. When such stone is used, it shall be clean, sound and hard, and each piece shall be completely surrounded by a layer of concrete not less than six inches thick. The stone shall be thoroughly wetted before placing in the concrete.

REINFORCEMENT

SECTION 1. DESCRIPTION

- (a) All concrete reinforcement shall consist of square twisted, deformed or plain bars, expanded metal, wire cloth or structural steel shapes, as called for on the plans or as specified. Unless specifically shown, otherwise, the sizes of bars shown on the plans are in all cases for the side of the square bar. If other sections are used the area shall be equivalent to that indicated. On all deformed bars the minimum sectional area of the bar will be considered the effective area.

SECTION 2. MATERIAL

- (a) Unless otherwise specified all square twisted, deformed and plain bars shall meet the requirements of the Standard Specifications for Billet-Steel Concrete Reinforcement Bars of the American Society for Testing Materials, Serial Designation A 15-14.
- (b) Where purchased from warehouses in small lots reinforcement may, at the discretion of the Engineer, be accepted subject to the bending test only.

SECTION 3. EXPANDED METAL AND WIRE CLOTH

- (a) Expanded metal or wire cloth shall be manufactured from material fulfilling the requirements of the Standard Specifications of the American Society for Testing Materials for Billet-Steel Concrete Reinforcement Bars, Serial Designation A 15-14

SECTION 4. STRUCTURAL STEEL SHAPES

- (a) The steel for structural shapes shall fulfill the requirements of the Standard Specifications of the American Society for Testing Materials for Structural Steel for Bridges, Serial Designation A 7-16.

SECTION 5. PLACING REINFORCEMENT

- (a) When placed, all reinforcement shall be free from dirt, oil, paint, grease, mill-scale, loose or thick rust.
- (b) Where bending is required, it shall be accurately done and all reinforcement shall be placed in the exact position shown on the plans, and shall be so securely held in position by wiring to and blocking from the forms and by wiring together at intersections, that it will not be displaced during deposition and compacting of the concrete.
- (c) Placing and fastening of reinforcement in each section of the work shall be approved by the Engineer before any concrete is deposited in the section.

SECTION 6. SPLICING REINFORCEMENT

- (a) Whenever it is necessary to splice reinforcement at points other than those shown on the plans, drawings showing the location of the splices shall be submitted and approved before the reinforcing steel is ordered. Splices shall be avoided at points of maximum stress, they shall, where possible, be staggered; and shall be designated to develop the strength of the bar. Where spliced by lapping, the bars shall be securely wired together and the lap shall be long enough to develop the strength of the bar without exceeding a bond stress of 80 pounds per square inch for plain bars or 100 pounds per square inch for bars having a mechanical bond.

SECTION 7. BASIS OF PAYMENT

- (a) Reinforcing steel will be furnished by the State. Placing reinforcement will be paid for at the contract price per pound or per square foot as stated in the proposal for the material complete in place, which price will include all equipment, tools, labor, wire or other materials used for fastening reinforcement in place.

STEEL

GENERAL

Unless specifically stated otherwise all steel, fabrication of members, erection, painting, measurement, and payment shall conform to the Standard Specification for Steel Highway Bridges, United States Department of Agriculture Bulletin No. 1259, and supplemented by the following:

All truss connections shall be fully developed for gross section in compression members and for net section in tension members.

All lateral and sway connections shall be fully developed for net section.

Erection stress diagrams must be checked by the contractor and he shall assume full responsibility for stability during erection.

The erection scheme as outlined in the plans is what is considered the most economical, however, if the contractor wishes to use some other method of erection he has the privilege to do so but it is understood that only the metal used in the finished structure will be paid for under this contract. In the event of a change of the erection scheme involving a re-design of the approach spans, the contractor shall submit plans for approach spans which plans must meet the approval of the State Engineer.

In the event heavier erection loads are used, than are provided for in the design, and which necessitates increase in members, the contractor shall furnish such additional metal in members at no expense to the State.

Wind ties, as shown upon the plans, shall be provided by the contractor during erection and he shall assume responsibility for their stability.

The design of the arch members is based on "Alternate 2 - Floor System". The right is reserved to adopt either of the three alternates and to make such revisions in the sections of the members as may be required for this substitution. The right is also reserved to make such revisions in the design as are required by the Federal Government or to make such revisions as are necessary to change the design from a three hinge arch to a two hinge arch under action of the deck and live load and no allowance for anticipated profits will be made for any of these revisions nor will such revisions invalidate and conditions of the contract. Notice of such revisions will be given within 30 days after the date of the award of the contract.

Shop plans shall be submitted in triplicate for checking and no fabrication of steel work shall commence until approval of these plans is given. The contractor shall assume the responsibility of any material ordered before the shop plans are approved. After the approval of these shop plans, the contractor shall furnish six sets of approved shop plans, two sets of which shall be on cloth. Approval of shop plans will be general and such approval will not relieve the contractor from any responsibility whatsoever, and the contractor will be held liable for all errors in detailing or fabrication.

The contractor shall check the position of the arch abutments and shoes as determined by the engineer and shall take full responsibility as to their correct distance apart and for the correct closure of the arch at the center hinges.

CAMERON BRIDGE

The bridge across the Little Colorado at Cameron was designed for a total load of ten (10) tons. As some of the members for the new Grand Canyon Bridge are in excess of this weight, the Cameron Bridge must be strengthened if loads in excess of the design load are to be hauled across this bridge.

There will be furnished the contractor a sketch of the proposed strengthening to increase the total load permissible to fifteen (15) tons.

This sketch is furnished the contractor as a help to the solution of the problem and in the event it or any other method is used, the contractor assumes full responsibility for damage to existing bridge and loss of material of any description, and such damaged portions of the bridge or materials lost shall be replaced at the contractors expense, ordinary wear being excepted.

In the event the contractor wishes to use a method of strengthening this bridge other than that furnished by the State, plans shall be submitted which must meet the approval of the State Engineer, such approval will not relieve the contractor of any responsibility for damage to the bridge or loss of materials.

SHOP ASSEMBLING

General reaming will be required, and all arch members shall be shop assembled, sub-punched, reamed and match marked; floor system connections shall be sub-punched and reamed to steel template.

FABRICATION

The contractor shall furnish for this purpose two steel tapes of 200' length; these tapes to be standardized and one to be used in the shops for laying out the material, the other to be used in the field for the use of the engineer in fixing the position of the shoes of the structure, and both of these tapes shall, after fabrication of the structure, become the property of the State Highway Department. In laying out steel work and making templates, all measurements shall be made by standardized tape as furnished by the contractor and correct for a temperature of 60° F. For the purpose of the above, the tape in use may be kept immersed in water at the specific temperature, and all measurements made, so far as possible, under conditions where the work is not subject to direct rays of sunlight or blasts of extreme heat or cold. In laying out the work in the field, the same conditions will be adhered to with particular reference to fixing the exact distance between centers of pins of arch span at the time of concreting the last pier. Camber shall be provided by shortening or lengthening the members an amount equal to the deformation caused by double the dead load stress.

ERECTION

If two-hinged design is used, the center connection shall be drilled and riveted after the structure is swung. The entire structure shall be riveted before the concrete floor is poured. If arch is changed from three hinge to two hinge as provided, the center connection shall be made without initial stress at a temperature of 60° F. If it is necessary to make this connection at a temperature other than 60° F., the engineer shall compute the stress set up in the center top chord member by the difference of temperature between 60° F. and that at which the connection is actually to be made, and such stress, whether in tension or compression shall be articulated caused in the member and the connection shall be made under such circumstances, and preferably on a cloudy day or after sunset. The shortening or elongation of the member necessary to produce the stress may be measured by an extensometer furnished by the State Highway Department, the contractor to furnish and erect such appliances as may be necessary to produce said stress and to mount such extensometer and to mark the member as directed for the purpose of measurement. The joint at which the final connection is made may also be manipulated by loading the structure, in case the temperature variation is small, in such a manner that after the connection is made, and the load removed, the stress in the center top chord member will be such as to correspond with the stress due to the temperature variation.

PAINT

Shop Coat:

All structural steel shall be given one (1) shop coat of No. 501 Superior Graphite Paint, or equal, before it is loaded for shipment.

Field Painting:

The first field coat shall be applied of No. 32 Superior Graphite Paint, or equal. The second field coat shall be applied not less than one (1) week after the application of the first field coat and shall be of No. 30 Superior Graphite Paint, or equal.

COSTS AND ACCEPTANCE

The manufacturer of each brand of paint submitted for acceptance under these specifications, or any contractor desiring to use any particular paint for the work to be done under these specifications shall file with the Engineer a certificate of analysis and manufacturer's guarantee, setting forth the trade name or brand of the paint to be furnished, together with a facsimile copy of the label (if the material is of the ready mixed type) and a typical analysis showing the percentage of each of the chemical elements in the pigment and vehicle. The Manufacturers Guarantee shall provide that all paint furnished under these specification shall conform to the certified analysis as filed and to the statement of the various percentages of the ingredients on the receptacle or container. The Manufacturers Guarantee shall be sworn to by a person having legal authority to bind the Manufacturing Company by his acts.

Samples of paint for testing shall consist of at least a one-quart sample from every five (5) barrels in a consignment. These samples may be tested individually or as a composite representing not more than twenty-five (25) barrels. Samples shall be submitted for test at least thirty (30) days before the paint represented by the samples is to be used. No paint shall be accepted for use until it has received the written approval of the Engineer.

From time to time during the process of the work samples of the paint being used may be taken and subjected to laboratory tests, at the discretion of the Engineer. A material difference in composition and working quality of these samples, as compared with the original samples or as compared with the Manufacturers Guaranteed Analysis may be considered sufficient cause for rejection of the defective materials and for suspension of payments on the work already done with them.

BASIS OF PAYMENT

Measurement of quantities and payment for fabrication and erection will be made on a pound price basis as specified in Paragraph 52, Section 1, Division II of Bulletin 1259, and this payment shall be full compensation for furnishing materials, shop plans, labor, tools, equipment, templates, patterns, and for all work incidental thereto which is necessary to manufacture, fabricate, paint, ship, haul and erect all structural steel, castings, rivets, bolts, pins, nuts, and all parts required for the complete erection of the bridge. Payment will be made only on that material which is included in the completed bridge, and all material used in erection which is not a part of the completed structure shall be paid for by the contractor without compensation. The contractor shall submit complete shipping invoices in triplicate with each shipment which shall show the scale weights of the individual pieces and the net weights of all crated and boxed pieces.

PARTIAL PAYMENTS

Partial payments will be paid as provided in specifications on all items except structural steel. No estimate will be allowed on structural steel until the closure of the arch at the crown, at which time an estimate of ninety percentum of the steel complete in place will be allowed. After which partial payments will be allowed on structural steel as it is completed in place and in accordance with the specifications.

ADDENDUM TO
NAVAJO BRIDGE

HAER No. AZ-28

Spanning Colorado River on Alt. US 89 at Marble Canyon
Page ~~Marble Canyon~~ vicinity
Coconino County
Arizona

PHOTOGRAPHS

ADDENDUM TO
NAVAJO BRIDGE
Spanning the Colorado River at U.S. Highway 89 Alternate
Page Vicinity
Coconino County
Arizona

HAER No. AZ-28

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