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October 31, 2008

Mr. Aaron Yue
Project Manager
California Department of Toxic Substances Control
5796 Corporate Avenue
Cypress, CA 90630

Pamela Innis
U.S. Department of Interior
P.O. Box 25007 (D-108)
Denver, CO 80225-0002

Subject: Technical Memorandum - Summary of Colorado River Bridge Pier Construction and Hydrogeologic Assessment

Dear Mr. Yue and Ms. Innis:

This letter transmits the *Technical Memorandum - Summary of Colorado River Bridge Pier Construction and Hydrogeologic Assessment* describing the results of historical research into the construction methods of the subsurface piers of the BNSF rail bridge, the Highway I-40 bridge, and the historic Red Rock Bridge. This memorandum also presents an evaluation of whether the bridge piers could serve as preferred groundwater flow conduits to surface water.

This work was done in response to the California Department of Toxic Substances Control (DTSC) letter to PG&E dated September 17, 2008 and the U.S Department of Interior (DOI) letter to PG&E dated September 17, 2008, which directed this evaluation and the establishment of a new RMP surface water sampling location at the westernmost BNSF bridge pier. The new sampling location at the downstream side of the westernmost BNSF bridge pier will be sampled over winter 2008-2009, beginning no later than December.

Do not hesitate to contact me at (805) 234-2257 with any questions or comments on this information or the enclosed technical memorandum.

Sincerely,

Yvonne Meeks

Enclosure

Cc: Chris Guerre/DTSC

Summary of Colorado River Bridge Pier Construction and Hydrogeologic Assessment

PREPARED FOR: Pacific Gas and Electric Company

PREPARED BY: CH2M HILL

COPIES: U.S. Department of the Interior
Colorado River Indian Tribes
California Department of Toxic Substances Control

DATE: October 31, 2008

PROJECT NUMBER: 370367.MP.01.02

This memorandum presents a summary of historical information about the construction of bridges across the Colorado River near the Pacific Gas and Electric Company (PG&E) Topock Compressor Station (TCS) near Needles, California. Also presented is an evaluation of whether the present or former bridge piers could serve as preferred pathways for contaminant migration from groundwater to the Colorado River. This information review and technical assessment were performed in response to letters to PG&E from the U.S. Department of the Interior (DOI), dated September 17, 2008 (DOI, 2008) and the California Department of Toxic Substances Control (DTSC), dated September 17, 2008 (DTSC, 2008).

1.0 Summary of Bridge Pier Construction Features

PG&E, assisted by Applied Earthworks and CH2M HILL, researched the construction of three bridges crossing the Colorado River between California and Arizona near the Topock site. In order from north to south, these are the Burlington Northern Santa Fe (BNSF) Railroad Bridge, the Caltrans Interstate Highway I-40 Bridge, and the historical Red Rock Bridge. Figure 1 shows the locations of these bridges. Figure 2 is a 1966 aerial photograph that shows all three bridges before demolition of the Red Rock Bridge.

Research efforts included contacting BNSF and Caltrans, reviewing San Bernardino County historical records, and conducting other historical research. A concerted effort was also made to contact appropriate staff at BNSF to request and obtain relevant information and records. Two primary contacts with BNSF were obtained from the BNSF State Government Affairs Office. Letters were sent to these contacts by mail and e-mail. These letters are included in Attachment A-1. A reply was received from Mr. Matthew Graham with BNSF which included four drawings of the BNSF Railroad Bridge. This letter can be found in Attachment A-1 and the drawings can be found in Attachment A-2.

The relevant historical records and information assembled for each bridge are presented in Attachments A through C. The key features of bridge pier construction for each of the bridges are summarized below, and the specific information sources are cited in the list of references and attachments.

Burlington Northern Santa Fe Railroad Bridge

The BNSF Railroad Bridge (originally Colorado River Bridge / Santa Fe Bridge) was constructed from 1942 to 1945. The bridge consists of seven piers, a west abutment, and an east abutment. The substructure of each pier includes a pair of reinforced concrete cylinders, capped with a 10-foot thick tie-wall that ties the two cylinders together. The tie-walls have a box shape on either end, which is oriented in the north-south direction, which forms a corner, rather than a flat wall, to the river current. The strategy for construction involved the pouring and casting in place of individual reinforced concrete pneumatic caissons at the surface of the working area on the river (Occiello and Sleicher, 1992). A bell-shaped reinforced concrete working chamber was cast with a steel cutting edge located near its bottom margin. The working chamber contained sufficient room for workers, known as "sand hogs," working at the bottom surface of the chamber to dig, drill, and dynamite material off the river bottom for conveyance to the surface.

Once in place, the caisson working chamber was surrounded by a cylindrical pouring form of the diameter of the eventual pier base cylinder. This form extended 8 to 10 feet above the water surface, so that the successive poured sections of concrete cylinder lying above the working chamber would be cured before following the working chamber downward below the level of the river surface. As the steel cutting edge at the bottom of the chamber bit into the river bottom, the sand hogs excavated, lowering the chamber to about 10 to 12 inches per day. When bedrock was finally reached and tested, the working edge of the caisson was definitively seated by excavating a minimum of 2 feet into the bedrock.

The steel structure of the BNSF Railroad Bridge consists of three 350-foot deck truss spans, a 50-foot beam span, three 100-foot deck girder spans on the west end, and a 100-foot deck girder span on the east end. A more detailed description of the construction of the BNSF Railroad Bridge and photographs can be found in Attachment A. As documented in the historical records, this bridge was constructed as, and has remained, a railroad bridge.

Figure 3 presents a generalized cross-section, prepared in 1946 by Walter Robey, of the BNSF Railroad Bridge (Robey, 1946). As shown in the cross-section, Pier 3 is located in the deepest section of the river, and was the deepest pier built. At the time of construction, this was the deepest pneumatic caisson excavation and construction in water-bearing materials in the United States.

Photographs taken during construction of the BNSF Railroad Bridge are also included in Attachment A-3. These photos document the installation of the cone-shaped caissons, pouring of concrete, and construction of the steel superstructure of the bridge. The photographs also show steel sheet piles driven as temporary cofferdams around the caisson work areas. The photographs show that the bridge was constructed working from a temporary railbed supported by what appear to be temporary wooden piles that were not driven to bedrock.

Interstate Highway I-40 Bridge

The Highway I-40 Bridge was constructed by Caltrans from 1962 through 1965. The piers for this bridge were constructed by driving steel piles into the river bottom. The concrete portion of the piers extends down only 20 to 30 feet below the river bottom and rests on the steel piles driven to bedrock. The piles were cut into lengths and sequentially welded together as the driving progressed so that all driving could be done above the surface of the water. The bridge and pier locations are shown on Figure 4. Additional information regarding construction of the Highway I-40 Bridge can be found in Attachment B-2 and as-built drawings of the piers and the bridge itself are included in Attachment B-1.

Red Rock Bridge

The original Red Rock cantilever railroad bridge is shown on an aerial photograph from 1951 (Figure 5). This bridge was used as a rail bridge from the time of its completion in 1891 until 1947. At this point, the bridge was converted into a road bridge, replacing the steel arch National Trials road bridge (labeled as the I-3 gas pipeline bridge in Figure 1) which was built in 1916 and carried Route 66 until 1947. With this replacement, the Red Rock Bridge became a part of the historic Route 66 roadway.

The Red Rock Bridge was built from 1889 to 1891 using pneumatic caisson methods similar to those used to build of the BNSF Railroad Bridge, but with noteworthy differences in materials. The Red Rock Bridge caissons were constructed of heavy timber and weighted down by the first courses of masonry piers above water. The caisson for the western pier was dug from the sand surface (approximately 467 feet elevation) through increasingly indurated sediments to approximately 409 feet elevation. After reaching that depth, the caisson was filled with béton, a rock and cement mixture, before the masonry pier was completed atop the caisson. The pier depth of 409 feet elevation was approximately 7 feet above design depth intended to reach bedrock, but was considered adequate because the caisson rested and was keyed several feet into cemented bouldery sand and gravel. The preceding descriptions are based on an article further describing the planning and construction of Red Rock Bridge (Rowe, 1891), which is included in Attachment C-2. The article includes historical photographs from the time of construction.

The Red Rock Bridge was originally constructed with a long, cantilevered center span. To allow for increased train locomotive weight, a center pier was added to the bridge in 1910-1911 so that the center span no longer acted as a cantilever. It is not known whether the same caisson technique was used in 1910-1911 as was done for the original piers. Drawings and photographs representing the bridge with the center pier are located in Attachment C-1. The Red Rock Bridge was taken out of service after completion of the Interstate Highway I-40 Bridge, and was removed, and the piers were demolished in the 1970s.

2.0 Assessment of Groundwater Migration Pathway

This technical assessment is based on review of aquifer groundwater conditions, bridge pier construction, and current surface water monitoring results. The potential for the existing and historical bridge piers in the Colorado River near the Topock Compressor Station to be preferred migration pathways from groundwater to surface water was evaluated. The approximate locations of all existing and historical bridge piers in the immediate vicinity of the site are shown on Figure 6. Hexavalent chromium (Cr[VI]) groundwater data collected in May 2008 are posted on Figure 6 (CH2M HILL, 2008a).

Assessment of Surface Water and Groundwater Conditions near the Bridge Piers

Cr(VI) is not stable in a chemically reducing environment. In a chemically reducing environment, Cr(VI) will be reduced to trivalent chromium (Cr[III]), which is an insoluble, non-toxic micronutrient (CH2M HILL, 2008b). The oxidation-reduction potential (ORP), measured in millivolts (mV), is the most common and direct measurement of the redox state of groundwater. Historical data from site monitoring wells show that ORP values below (i.e., more negative than) -90 mV are indicative of geochemical conditions in which Cr(VI) is not present.

PG&E conducted a pore water study in January 2006 to assess Cr(VI) occurrence and concentrations at multiple locations upgradient and downgradient of the Topock site and to assess whether geochemical conditions in shallow sediments below the Colorado River favor Cr(VI) reduction. A summary of the 2006 pore water study results is presented in the *RCRA Facility Investigation/Remedial Investigation Report, Volume 2, PG&E Topock Compressor* (RFI/RI Report) (CH2M HILL, 2008b). Figure 7 shows the locations of the pore water sampling that was conducted near the bridges. ORP was measured as a field parameter during the 2006 pore water study. All ORP values at the 64 pore water sampling locations were negative, ranging from -46 to -231 mV and with an overall average of -162 mV. The ORP results, combined with the lack of Cr(VI) detections and other pore water geochemical results demonstrate that geochemical conditions that readily reduce Cr(VI) to Cr(III) are present in the shallow sediments that make up the riverbed over a wide area upstream and downstream from the Topock site. More recently, slant wells have been installed beneath the Colorado River from the Arizona and California shore in the area downstream from the Highway I-40 Bridge. Geochemically reducing conditions and the absence of Cr(VI) was observed in all samples collected during drilling of these wells through the fluvial sediments into bedrock, and in groundwater samples from the wells. Reducing conditions are also observed in wells completed in fluvial sediments near bedrock on the California floodplain near the Interstate Highway I-40 Bridge. Based on all available data, it is likely that reducing conditions extend throughout the entire aquifer beneath the river in the area near the bridges. Thus, it is not likely that Cr(VI) in groundwater would be found in the subsurface near the bridge piers.

Bridge Pier Construction and its Effect on Migration Pathways

The Interstate Highway I-40 Bridge was constructed with driven steel piles, which rely on surface friction to support the load of the bridge. Driven piles compress surrounding sediments during installation and are considered unlikely to create any voids in sediment materials during installation activities. As iron rusts, it creates reducing conditions in the surrounding groundwater, which encourage conversion (or "reduction") of Cr(VI) to Cr(III). One of the techniques for remediating groundwater containing Cr(VI) involves the placement of powdered iron (also referred to as zero-valent iron) in the aquifer. The presence of the iron pilings would therefore tend to enhance rather than degrade the existing reducing conditions in the aquifer.

The BNSF Railroad Bridge and the Red Rock Bridge were constructed using pressurized caisson construction. The BNSF Railroad Bridge construction method leaves steel and concrete in the aquifer material down to bedrock, and would have likely caused more disruption to and less compression of the surrounding sediments than the driven pile construction of the Highway I-40 Bridge. The BNSF bridge piers were constructed in segments by pouring concrete into circular forms at the surface and then excavating out from underneath to sink the pier into the sediments. The soft sediments in the shallower portion of the river bottom would be expected to conform relatively easily to the smooth and circular concrete surface of these piers.

The Red Rock Bridge construction methods utilized heavy timber caisson walls which were filled with rock and cement. These timber caisson walls were left buried in subsurface sediments. The sediments would likely not conform as closely to the rough or uneven timber walls as to the smooth concrete walls of the BNSF bridge piers. In addition, voids could be created as the timber rots; however the microbes involved in breaking down the timber would remove oxygen from the groundwater and enhance the reducing conditions already prevalent in this area. Under reducing conditions, wood decays very slowly. A relatively intact wood fragment recovered from a floodplain monitoring well borehole was dated to approximately 7,000 years in age by radiocarbon methods. Wood fragments were also encountered just above bedrock at a depth of over 100 feet in the PGE-9 wells, located on the Arizona shore a short distance below the Interstate Highway I-40 Bridge (near MW-56, as shown on Figure 1). The reason that the bridge piers needed to extend to bedrock is because the sediments below the riverbed are subject to erosion and re-deposition. This shifting of the riverbed would tend to fill in conduits that could develop from rotting timbers. One of the major challenges encountered when installing the slant wells beneath the river was the caving of the sediments that occurred as the drive pipe was pulled out of the borehole. These boreholes collapsed as soon as the drive pipe was pulled. The same collapse would be expected to occur around any rotting timbers associated with the former Red Rock Bridge piers.

The disturbances created by drilling a well are analogous, although on a smaller scale, to the disturbance from bridge pier construction. When drilling a well, the native sediments are removed from the borehole and inert, aerobic sand and gravel is placed in the borehole. Many monitoring wells have been installed in areas of reducing conditions in the Topock floodplain and beneath the river. In most cases, the geochemical reducing conditions are observed immediately after drilling, even though the aerobic materials have been placed in the boreholes. Typically, the ORP fluctuates (within the reducing range) after well installation and then reaches a new equilibrium after several months or calendar quarters. The reducing conditions are a property of the groundwater that is moving through this area as well as a property of the sediments. Thus, field evidence shows that removing or disturbing sediments or creating a void in the sediments does not substantially alter the geochemistry. The groundwater surrounding the piers would have equilibrated to a preconstruction reducing state within a brief timeframe, likely before the PG&E Topock Compressor Station began operations in 1951.

The Red Rock Bridge piers were reportedly installed in 1891 and 1910-1911 while the bridge piers for the BNSF Railroad Bridge were installed between 1942 and 1945. The Cr(VI) wastewater discharge to Bat Cave Wash occurred from 1951 to 1964. Given this timeline, the railroad bridge piers were in place for a minimum of 6 years prior to the first potential discharge and release of Cr(VI) to groundwater in Bat Cave Wash. Therefore, based on the observations of the equilibration time in the monitoring wells drilled at the site, the aquifer surrounding the bridge piers would have equilibrated to a reducing environment long before any possible Cr(VI) migration through this area. As noted above, even in the unlikely event that a bridge pier did provide a conduit for vertical flow, the available data indicate that there is unlikely to be a zone of oxidized groundwater that would be able to transport Cr(VI) through any conduits that did exist.

Past and Ongoing River Monitoring

From July 1997 through April 2008, surface water samples have been collected from up to 43 surface water sampling locations (some samples collected at multiple depths). The current surface water monitoring program conducted since 2005, includes routine surface water sample collection from nine shoreline locations and nine in-channel stations at specific depths in the Colorado River (Figure 7). This sampling program has shown consistent results with Cr(VI) concentrations in Colorado River water below laboratory reporting limits. Surface water sampling data from October 2006 through October 2007 can be found in the RFI/RI Report (CH2M HILL, 2008b) and results from October 2007 through April 2008 sampling can be found in *Groundwater and Surface Water Monitoring Report, Second Quarter 2008,* PG&E *Topock Compressor Station* (CH2M HILL, 2008c).

PG&E's current river shoreline and in-channel monitoring activity will continue in the future on a quarterly basis during periods of high river level and monthly during periods of low river level. A new in-channel river monitoring location has been added at the westernmost BNSF Railroad Bridge pier, on the downstream side, to provide additional river sampling data as directed by the DTSC and DOI letters (DOI 2008, DTSC 2008). This new location will be sampled during winter 2008-2009 low river-level sampling events that will take place between November 2008 and January 2009.

3.0 Conclusions

Based on this assessment, and the results of the comprehensive pore water and river sampling to date, the following conclusions are made:

- Reducing conditions are present in the bed of the Colorado River to the depth of bedrock in the slant monitoring wells below the Interstate Highway I-40 Bridge and in vertical wells on both sides of the river near the bridges. In this geochemical environment, Cr(VI) would not be stable.
- The driven steel pile methods used for the Interstate Highway I-40 Bridge pier construction would have resulted in compaction of the sediments and would not likely have created any preferential pathways for flow. Subsequent corrosion of the steel would enhance the reducing conditions.
- The pre-formed concrete caisson methods used to construct the BNSF Railroad Bridge would have likely resulted in a relatively small disturbance of the sediments around the smooth, cylindrical concrete caisson. The soft sand below the river bottom would have quickly caved in and conformed to the caisson.
- The rock and concrete filled timber caissons used for the former Red Rock Bridge would likely provide more opportunity for vertical conduits as the timber rots; however, the rotting timber would enhance the reducing conditions and the soft, unstable sediments beneath the river would tend to fill the cavities relatively quickly.
- Temporary oxidizing conditions in the groundwater caused by construction of the Red Rock Bridge and BNSF Railroad Bridge piers would likely have equilibrated to

surrounding reducing conditions prior to the chromium discharge to groundwater associated with the Topock Compressor Station operations.

- Based on the available information concerning the extent of the Cr(VI) plume, the prevalence of the reducing conditions in the fluvial sediments, the construction methods for the bridge piers, and the characteristics of the sediments below the river bottom, the bridge piers supporting the BNSF Railroad Bridge, the Interstate Highway I-40 Bridge, and the former Red Rock Bridge do not appear to pose any significant risk as preferred migration pathways for Cr(VI) from groundwater to surface water.

4.0 Certification

This memorandum was prepared by CH2M HILL under the supervision of the professional whose seal and signature appears herein in accordance with currently accepted professional practices. The technical assessment presented is based on the historical information and the results and hydrogeological and geochemical evaluation of the sampling and investigation studies cited in this memorandum. No warranty, expressed or implied, is made.

REGISTERED GEOLOGIST
PAUL F. BERTUCCI
8/31/10
No. CEG 1977
CERTIFIED ENGINEERING GEOLOGIST
STATE OF CALIFORNIA

Paul F. Bertucci, C.E.G.
California Certified Engineering Geologist, No. 1977

Report Reviewed by:

Jay Piper
CH2M HILL Project Manager

5.0 References

California Department of Toxic Substances Control (DTSC). 2008. Letter to PG&E. "Bridge Footings Concerns at the PG&E Topock Compressor Station, Needles, California". September 17.

CH2M HILL. 2008a. *Quarterly Performance Monitoring Report and Evaluation, May through July 2008, PG&E Topock Compressor Station, Needles California.* August 29.

_______. 2008b. *RCRA Facility Investigation/Remedial Investigation Report, Topock Compressor Station, Needles, California; Volume 2 – Hydrologic Characterization and Results of Groundwater and Surface Water Investigation.* July.

_______. 2008c. *Groundwater and Surface Water Monitoring Report, Second Quarter 2008, PG&E Topock Compressor Station, Needles California.* August.

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Robey, Walter Earl. 1946. *Construction of New Santa Fe Railway Bridge over the Colorado River at Topock, Arizona*. Urbana, Ill.: Unpublished Thesis, University of Illinois.

Rowe, S. M. 1891. *Red Rock Cantilever Bridge*. Transactions of the American Society of Civil Engineers, No. 518, Dec. 1891.

U.S. Department of the Interior (DOI). 2008. Letter to PG&E. "PG&E Topock Compressor Station Remediation Site – Transmittal of DOI and DTSC Direction for Additional Assessment of Bridge Piers". September 17.

Figures

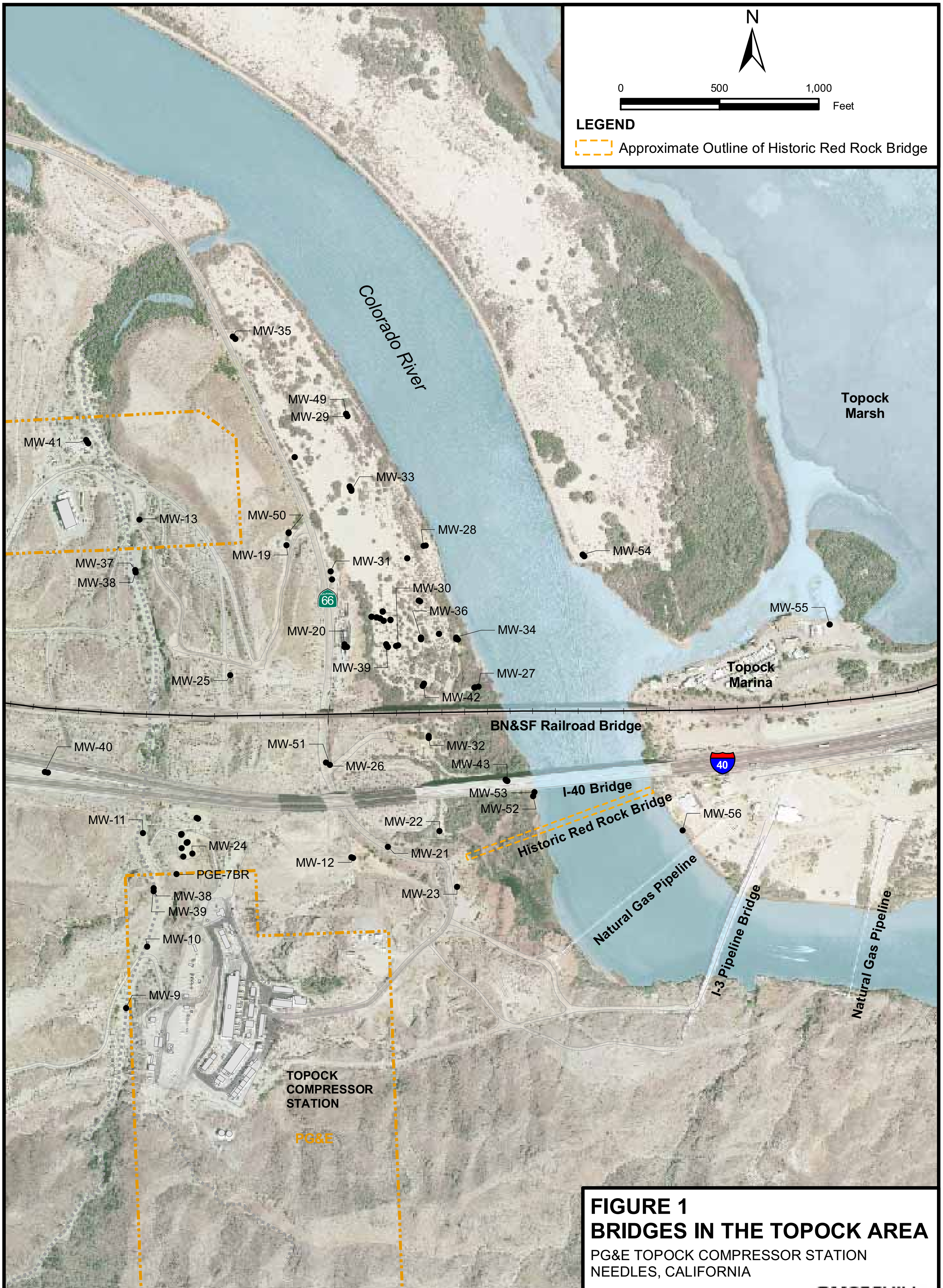

FIGURE 1
BRIDGES IN THE TOPOCK AREA
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL

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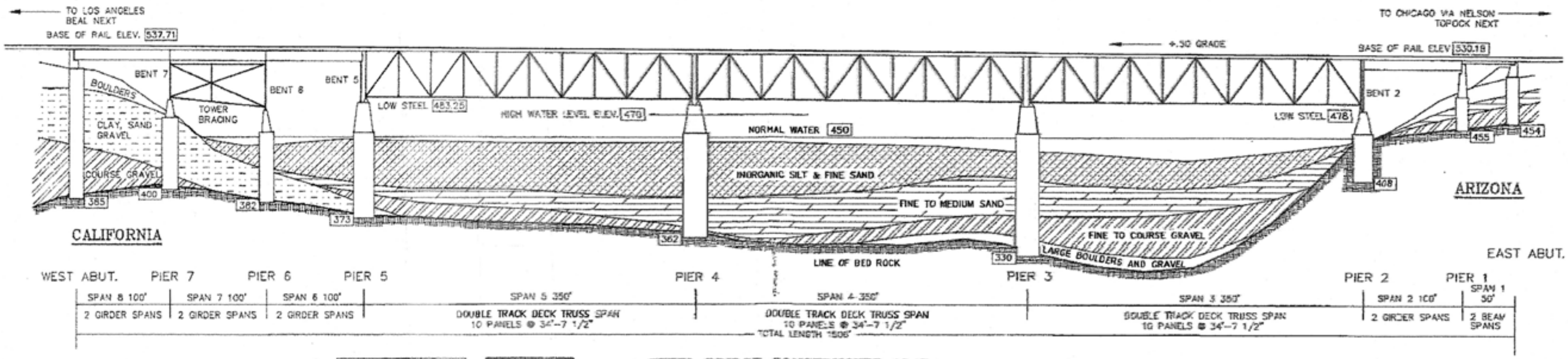
TOPOCK_AREA_BRIDGES.PDF PJOYCE1 10/14/2008 15:27:26

Date: 10/06/66
Flight/Frame(s): 08-SBd 7-2, 7-3
Source: California Department of Transportation
1120 N Street
Sacramento, CA 94273

FIGURE 2
AERIAL PHOTOGRAPH
OCTOBER 6, 1966
SUMMARY OF COLORADO RIVER BRIDGE
PIER CONSTRUCTION AND
HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL



STEEL BRIDGE CONSTRUCTED 1945

FROM ROBEY 1946

1946 BRIDGE PIER CYLINDER DATA			
PIER	CYL. DIA	DEPTH	BOTTOM ELEV. OF CYL.
E ABUT	14	61	454
1	14	34	455
2	22	49	408
3	22	129	330
4	24	94	362
5	22	84	373
6	16	74	382
7	16	65	400
W ABUT	16	129	385

1946 BRIDGE WEIGHTS	
SPAN	WEIGHT TONS
SPAN 1	84
SPAN 2	164
BENT 2	33
SPAN 3	1844
SPAN 4	1838
SPAN 5	1834
BENT 5	33
SPAN 6	169
BENT 6	118
SPAN 7	174
BENT 7	32
SPAN 8	186
TOTAL	[illegible]

NOTE:
1. ALL CYLINDERS EXTEND A MINIMUM OF 2 FEET INTO BED ROCK.
2. 1945 BRIDGE DESIGNED TO CARRY COOPER'S E-72 LOADING

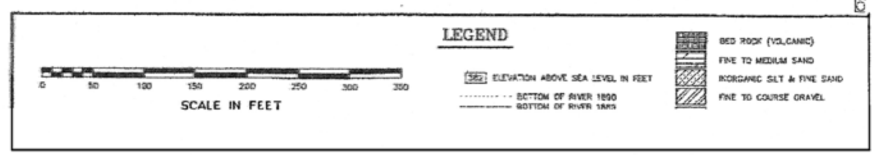


FIGURE 3
RIVER CROSS SECTION AT BNSF RAILROAD BRIDGE
SUMMARY OF COLORADO RIVER BRIDGE PIER CONSTRUCTION AND HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA
CH2MHILL

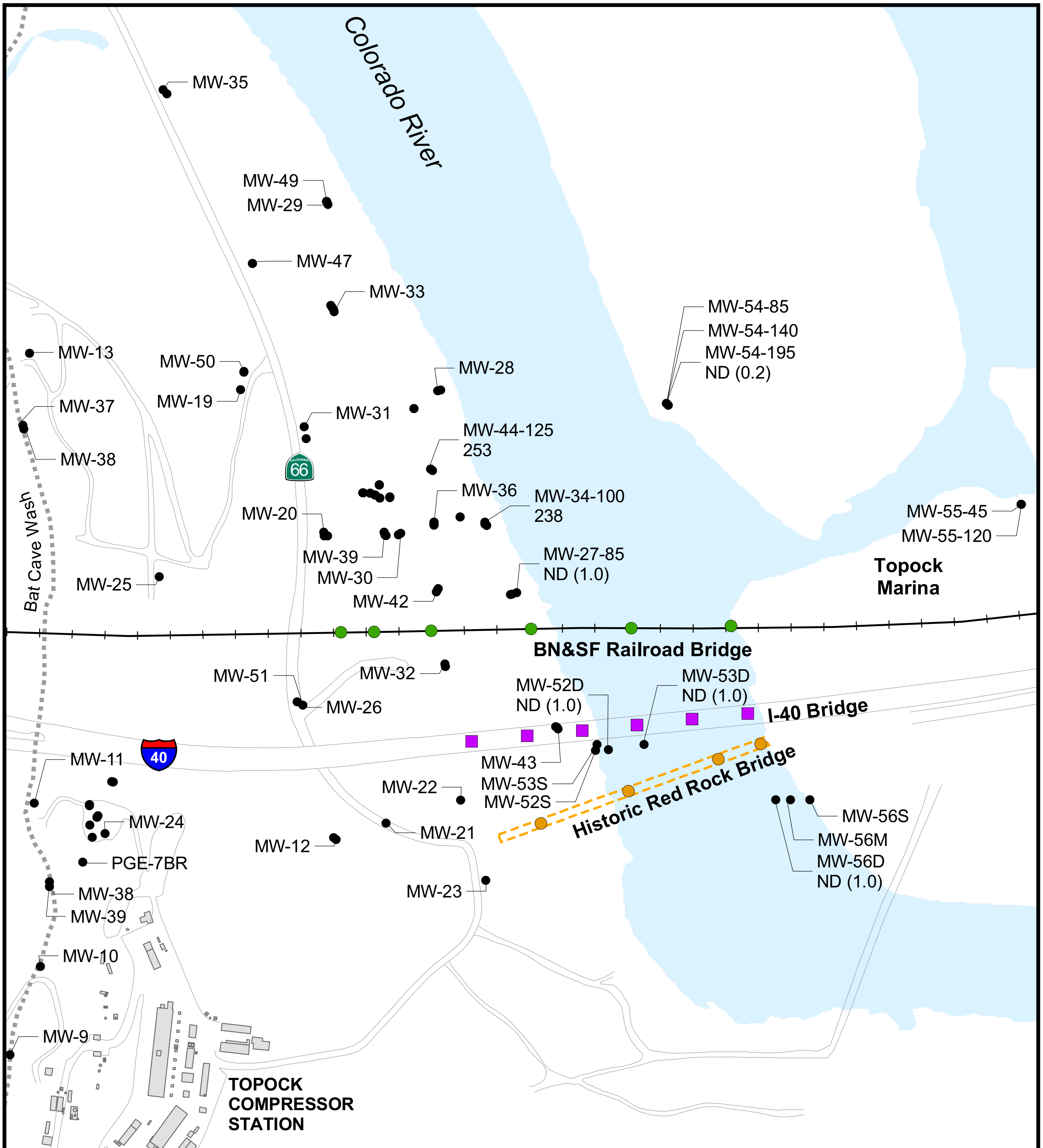
FIGURE 4
HIGHWAY I-40 BRIDGE

SUMMARY OF COLORADO RIVER BRIDGE
PIER CONSTRUCTION AND
HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL

FIGURE 5
VIEW OF BRIDGES AT TOPOCK, 1951
SUMMARY OF COLORADO RIVER BRIDGE PIER CONSTRUCTION AND HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL



LEGEND

- Monitoring Well/Well Cluster Location
- Approximate Location of BN&SF Railroad Bridge Piers
- Approximate Location of I-40 Bridge Piers
- Approximate Location of Former Red Rock Bridge Piers
- Approximate Outline of FormerRed Rock Bridge

MW-55-45 ND (0.2) — Well identification and Cr6 result, ND is non-detect, units are µg/L
Data Posted at key locations of the Lower Depth Interval of Alluvial Aquifer from May 2008 (June 2008 for AZ Wells)

0 500 1,000 Feet

N

FIGURE 6
CURRENT AND HISTORICAL BRIDGE PIER LOCATIONS
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL

BAO \\ZINFANDEL\PROJ\PACIFICGASELECTRICCO\TOPOCKPROGRAM\GIS\MAPFILES\2008\RMP\BRIDGE_LOCATIONS_CR6RESULTS.MXD 10/31/2008 13:38:02

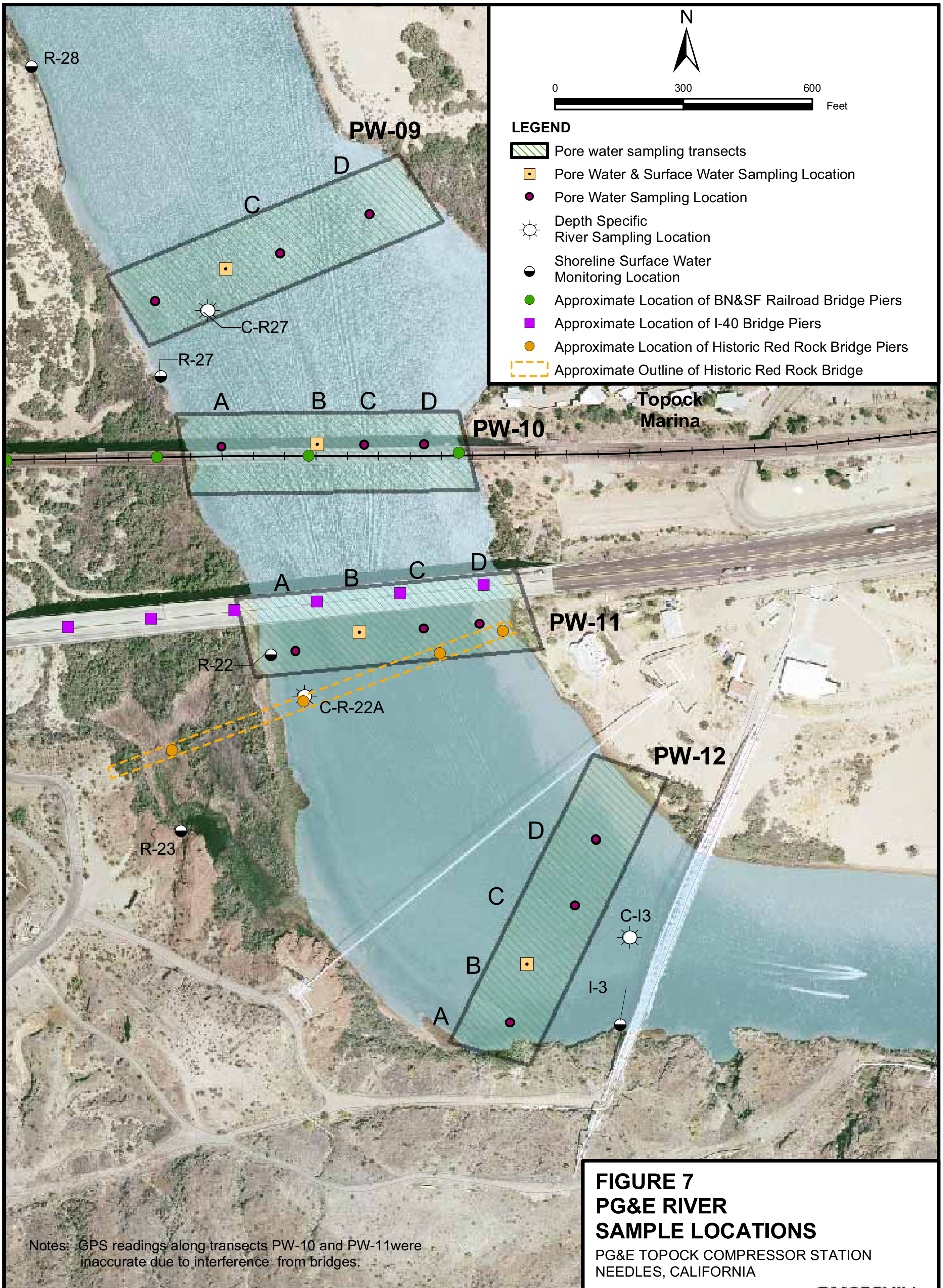


FIGURE 7
PG&E RIVER
SAMPLE LOCATIONS
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

Attachment A
BNSF Railroad Bridge
Historical Documentation

Attachment A-1
PG&E and BNSF Letters

Pacific Gas and Electric Company

A. Glenn Caruso
Senior Cultural Resources Specialist

Gas T&D - Remediation

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September 29, 2008

Chris Obmann, Supervisor Structures
740 Caregie Drive
San Bernadino, CA 92408

Dear Mr. Obmann:

The United States Department of the Interior and the California Department of Toxic Substances Control recently directed Pacific Gas & Electric Company ("PG&E") to conduct an assessment of the bridge footings at the Burlington Northern and Santa Fe Railroad ("BNSF") railroad bridge across the Colorado River near Needles, California. I have enclosed copies of DOI's and DTSC's respective letters to PG&E directing PG&E to perform this assessment.

PG&E is in the process of investigating and remediating groundwater containing hexavalent chromium resulting from historic wastewater disposal at a PG&E natural gas compressor station on the California side of the river. The Colorado River Indian Tribes recently expressed concern to DOI and DTSC that the BNSF bridge footings might act as a pathway for subsurface groundwater containing chromium to migrate to the river. As a result, DOI and DTSC directed PG&E to make an assessment of the bridge footings.

DOI and DTSC specifically directed PG&E to "use its best efforts to identify and obtain any existing written documentation regarding the construction and condition of the current railroad bridge footings, including consulting publicly available records, requesting records or information from the BNSF Railroad, and using available means to obtain BNSF records if not provided by BNSF upon request."

As directed by DOI and DTSC, this letter requests that BNSF provide PG&E with any existing written documentation regarding the construction and condition of the current railroad bridge footings at the BNSF railroad bridge over the Colorado River near Needles California. DOI and DTSC have directed PG&E to complete our assessment by October 31, 2008. As a result, it is important for PG&E to have access to any relevant documents as soon as possible.

We would be happy assist BNSF in any way possible in the search for the documents sought by DOI and DTSC. In addition, we would be happy to answer any questions or provide additional information. I look forward to speaking with you regarding this issue.

Very truly yours,

A. Glenn Caruso

A. Glenn Caruso
Senior Cultural Resources Specialist

cc: Edward Phillips

Pacific Gas and Electric Company

A. Glenn Caruso
Senior Cultural
Resources Specialist

Gas T&D - Remediation

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September 29, 2008

Edward Phillips, Manager,
Environmental Operations
740 Carnegie Drive
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A. Glenn Caruso

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Senior Cultural Resources Specialist

cc: Chris Obmann

MATTHEW P. GRAHAM
Manager Environmental Remediation

BNSF Railway Company

740 East Carnegie Drive
San Bernardino, CA 92408-3571
Telephone: (909) 386-4081
Fax: (909) 386-4087
E-mail: **Matt.Graham2@BNSF.com**

October 17, 2008
01003663

Mr. A. Glenn Caruso
Pacific Gas and Electric Company
Mail Code B16A
P. O. Box 770000
San Francisco, CA 94105

Dear Mr. Caruso:

Please refer to your letter dated September 29, 2008, addressed to Messrs. Edward Phillips and Chris Obmann, both with the BNSF Railway Company. Your request for information has been passed to me for response.

Enclosed please find copy of BNSF's (formerly ATSF Railway) drawings depicting railway bridge construction plans at Topock, Arizona.

We are providing this information with the expectation that you will provide BNSF copies of any Pacific Gas and Electric Company (PG&E) assessment or comprehensive technical response which may indicate that PG&E contamination or plumes are impacting BNSF property or structures.

If you have questions or require further information, please contact me at the above number and address.

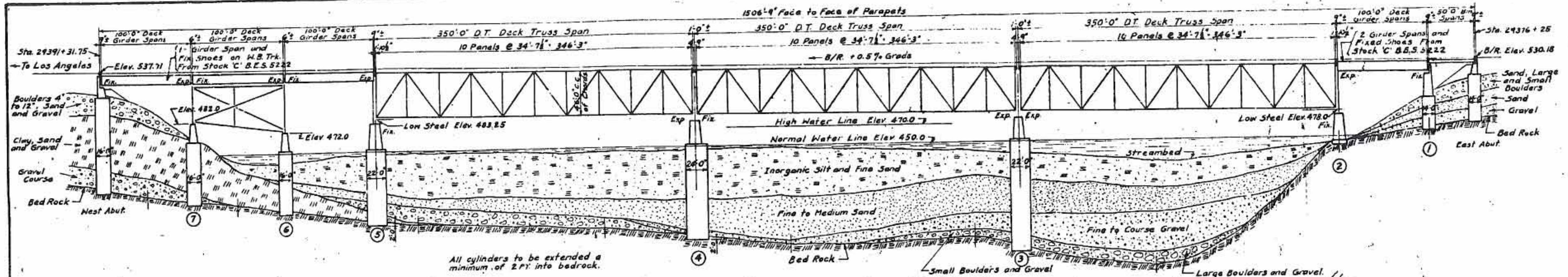
Sincerely,

Matt Graham

Enc.

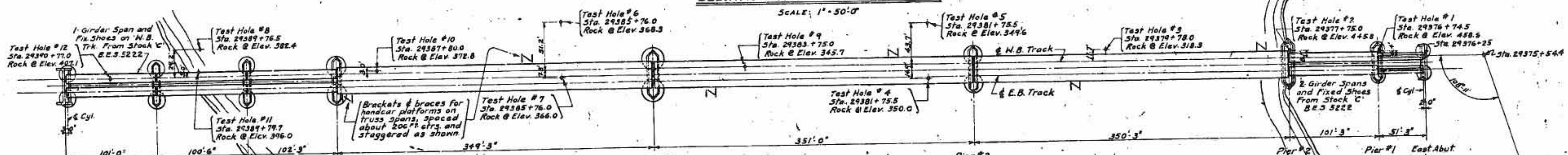
Cc: Ms. Pamela S. Innis, DOI Topock Remedial Project Manager
Mr. Aaron Yue, Department of Toxic Substances Control

Attachment A-2
BNSF Drawings



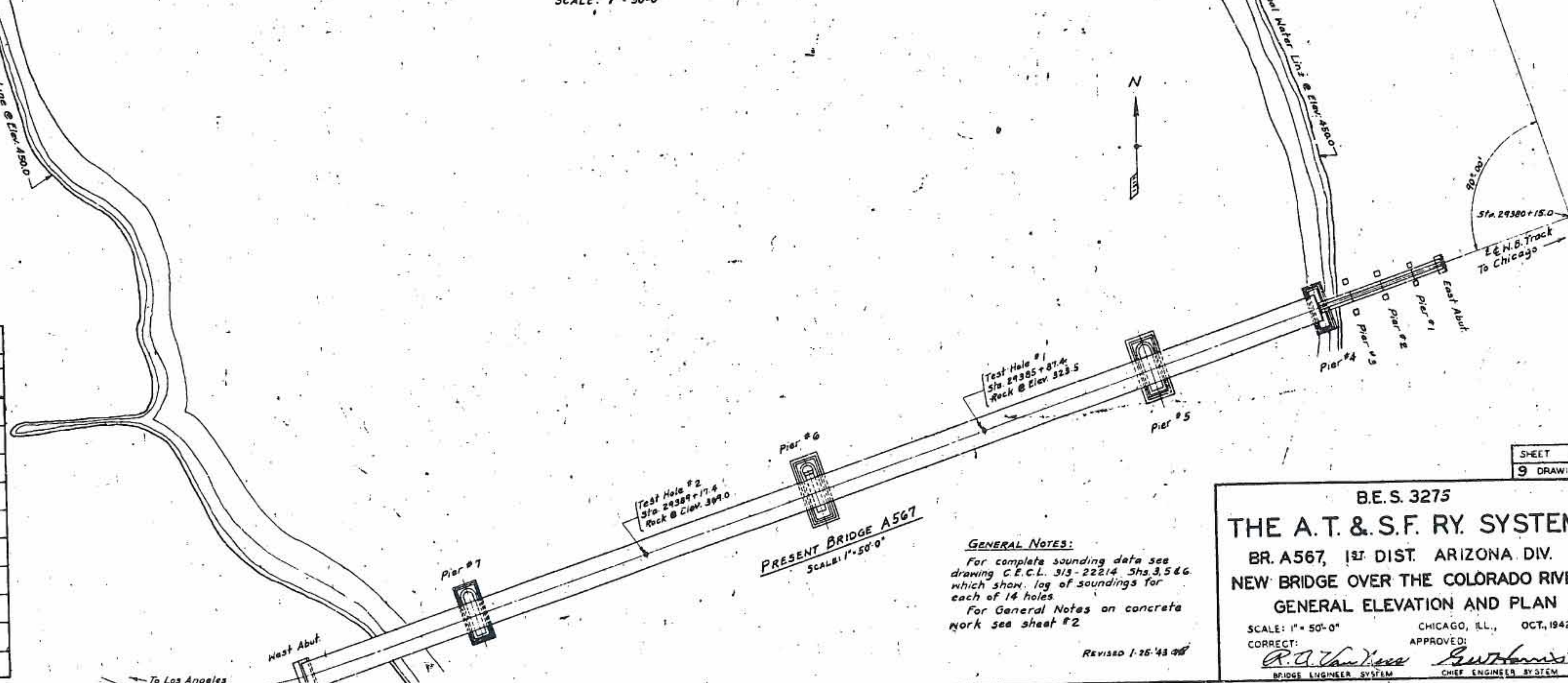
ELEVATION AND SOUNDING PROFILE

SCALE: 1" = 50'-0"



PLAN OF NEW BRIDGE AND TEST HOLE LOCATIONS

SCALE: 1" = 50'-0"



PRESENT BRIDGE A567

SCALE: 1" = 50'-0"

ESTIMATED QUANTITIES							
	CONCRETE - CU. YDS.			REINFORCING STEEL TONS	EXCAVATION - CU. YDS.		
	FOUNDATION		NEATWORK				
	2000#	3000#	3000#		COMMON	LOOSE ROCK	SOLID ROCK
EAST ABUTMENT	230	390	90	7.0			
PIER #1	150	235	325	7.0			
PIER #2	155	—	590	0.2			
PIER #3	560	*2680	485	12.5			
PIER #4	550	*2780	550	18.0			
PIER #5	430	*1850	635	16.0			
PIER #6	285	*740	230	9.0			
PIER #7	285	655	230	9.0			
WEST ABUTMENT	430	1120	150	12.0			
TOTAL	3075	10450	3285	95.7			

* Includes concrete between cylinders as shown.

GENERAL NOTES:

For complete sounding data see drawing C.E.C.L. 313-22214 Shs. 3, 5 & 6 which show log of soundings for each of 14 holes.

For General Notes on concrete work see sheet #2

REVISED 1-26-'43

SHEET 1
9 DRAWINGS

B.E.S. 3275

THE A.T. & S.F. RY. SYSTEM

BR. A567, 1ST DIST. ARIZONA DIV.

NEW BRIDGE OVER THE COLORADO RIVER

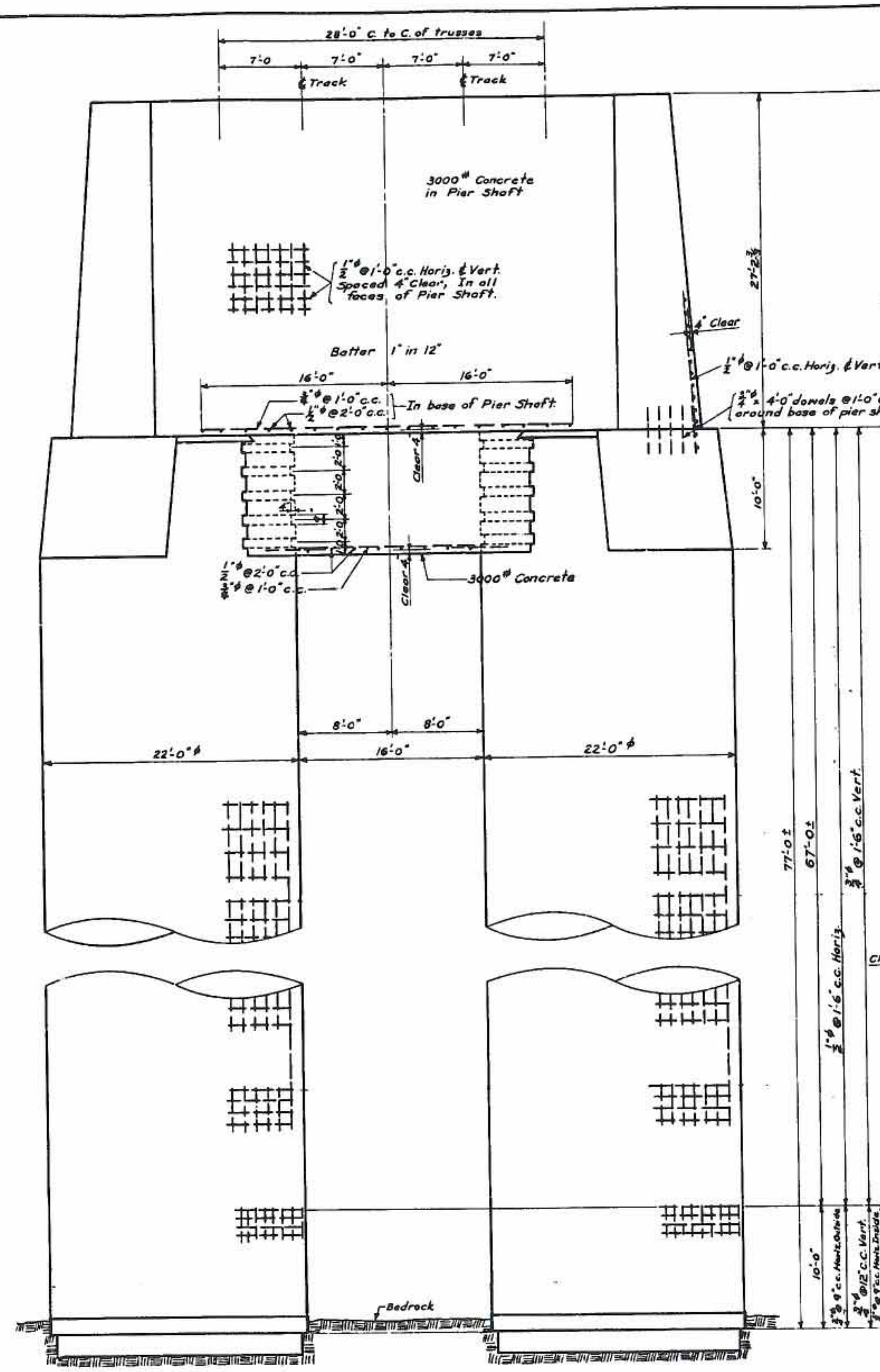
GENERAL ELEVATION AND PLAN

SCALE: 1" = 50'-0"   CHICAGO, ILL., OCT., 1942.

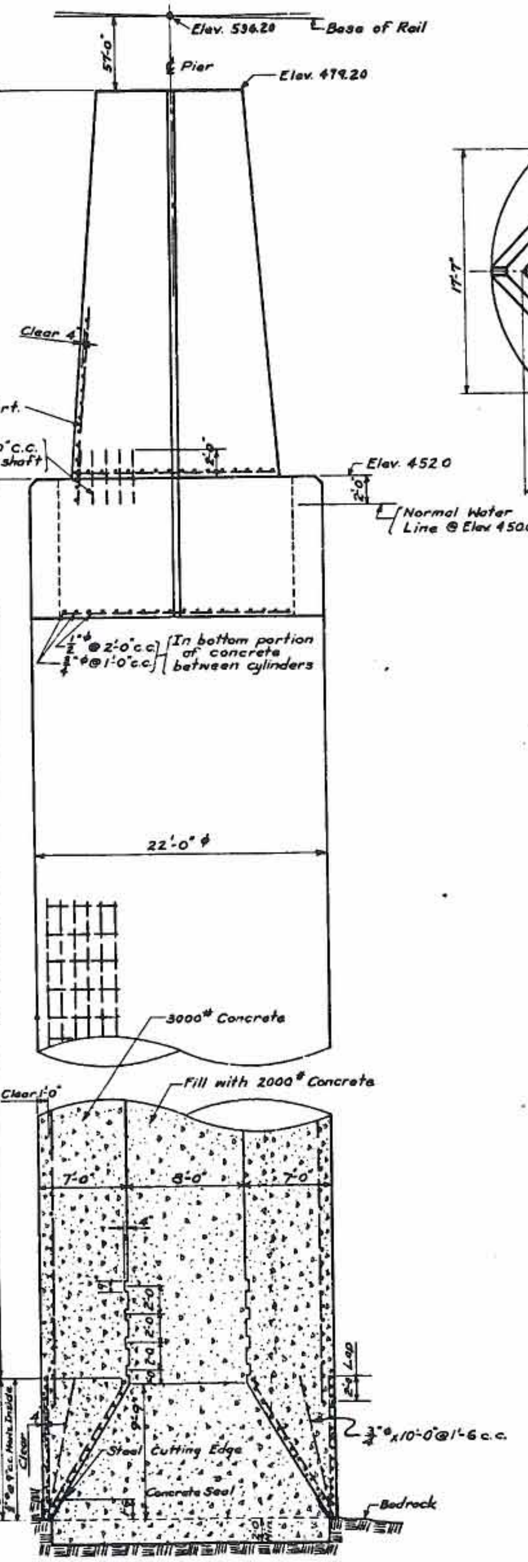
CORRECT: R. A. Van Ness — BRIDGE ENGINEER SYSTEM

APPROVED: [signature] — CHIEF ENGINEER SYSTEM

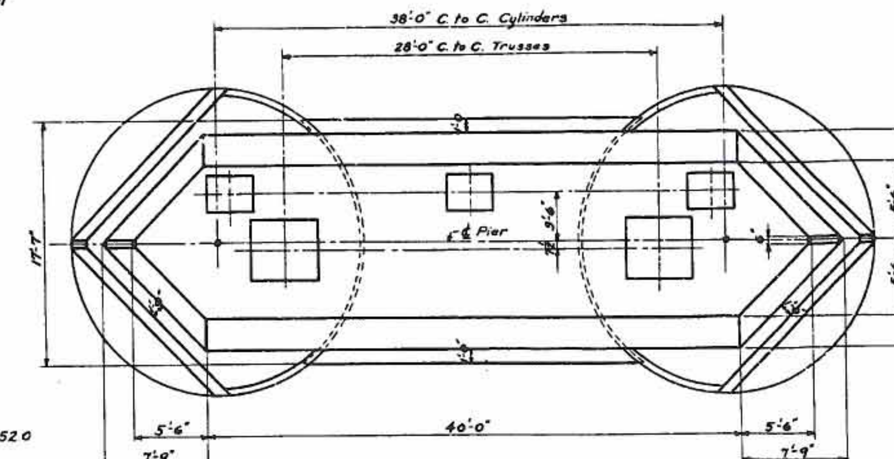
MADE BY:
CHECKED BY:
EXAMINED BY:



ELEVATION



END ELEVATION AND PART SECTION



PLAN OF PIER TOP

For General Notes on concrete work see Sheet #2. For details of cutting edge see sheet #2.

ESTIMATED QUANTITIES

FOUNDATION	2000# CONCRETE	430 Cu. Yds.
	3000# CONCRETE	1850 Cu. Yds.
NEAT WORK	3000# CONCRETE	635 Cu. Yds.
REINFORCING STEEL		18.0 TONS

SHEET 7
9 DRAWINGS

B.E.S. 3275

THE A.T. & S.F. RY. SYSTEM

BR. A 567, 1ST DIST., ARIZONA DIV.

NEW BRIDGE OVER THE COLORADO RIVER

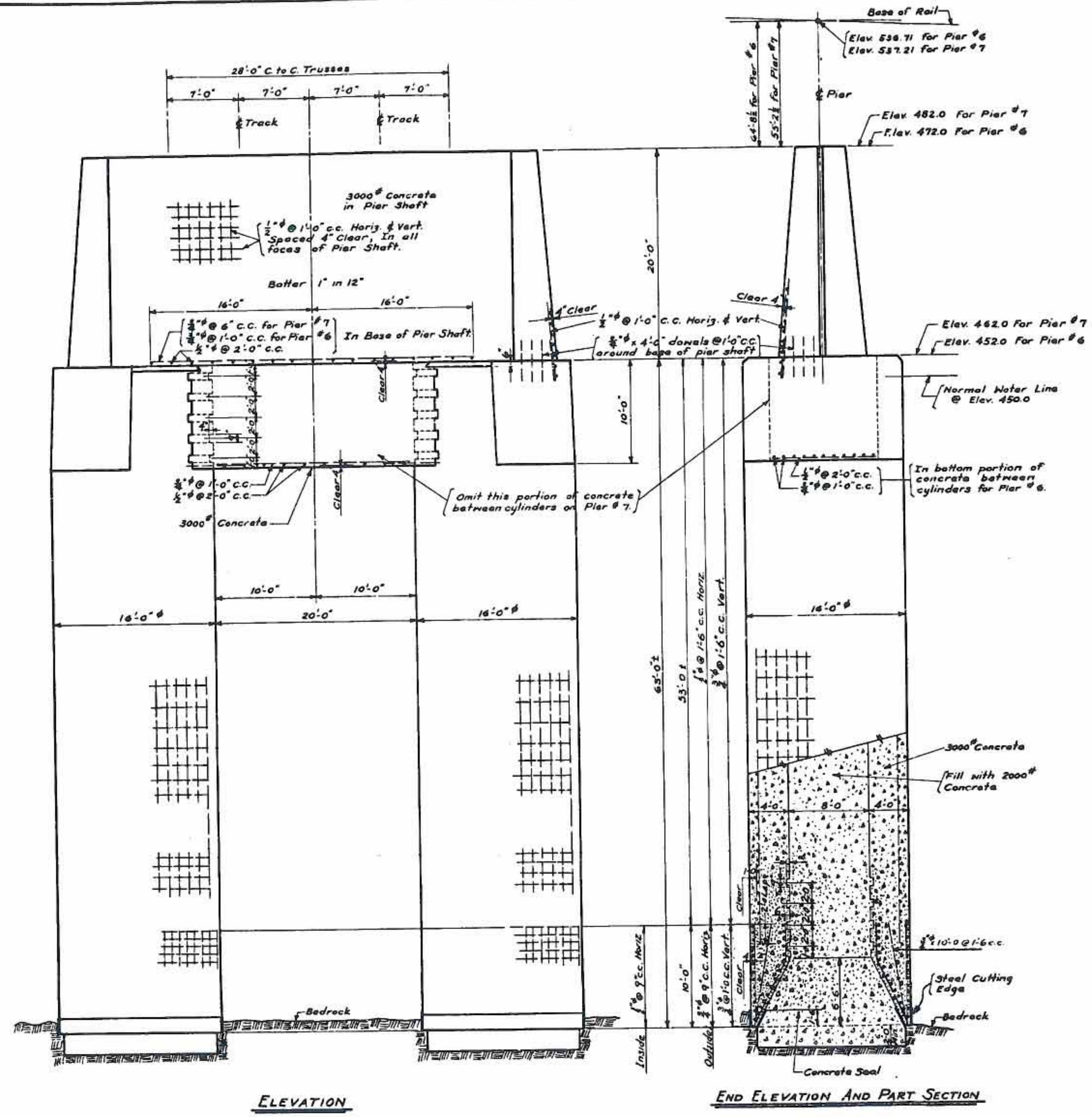
DESIGN OF PIER #5

SCALE: 3/16"=1'-0" CHICAGO, ILL., OCT., 1942

CORRECT: R. A. Van Ness — BRIDGE ENGINEER SYSTEM

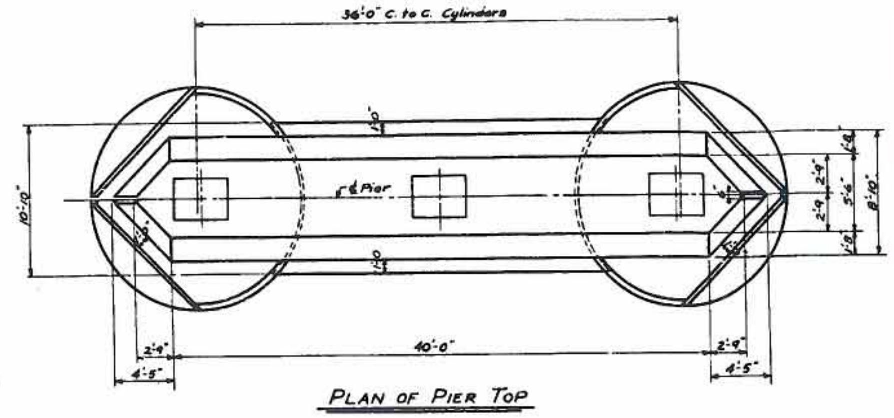
APPROVED: G. W. Harris — CHIEF ENGINEER SYSTEM

MADE BY
CHECKED BY
EXAMINED BY



ELEVATION

END ELEVATION AND PART SECTION



PLAN OF PIER TOP

For General Notes on concrete work see Sheet #2. For Details of Cutting Edge See Sheet #2.

ESTIMATED QUANTITIES

		PIER #6	PIER #7
FOUNDATION	2000# CONCRETE	285 CU. YDS.	285 CU. YDS.
	3000# CONCRETE	740 CU. YDS.	655 CU. YDS.
NEAT WORK	3000# CONCRETE	230 CU. YDS.	230 CU. YDS.
REINFORCING STEEL		9.0 TONS	9.0 TONS

SHEET 3
9 DRAWINGS

B.E.S. 3275

THE A.T. & S.F. RY. SYSTEM

BR. A567, 1ST DIST. ARIZONA DIV.

NEW BRIDGE OVER THE COLORADO RIVER

DESIGN OF PIER #6 AND #7

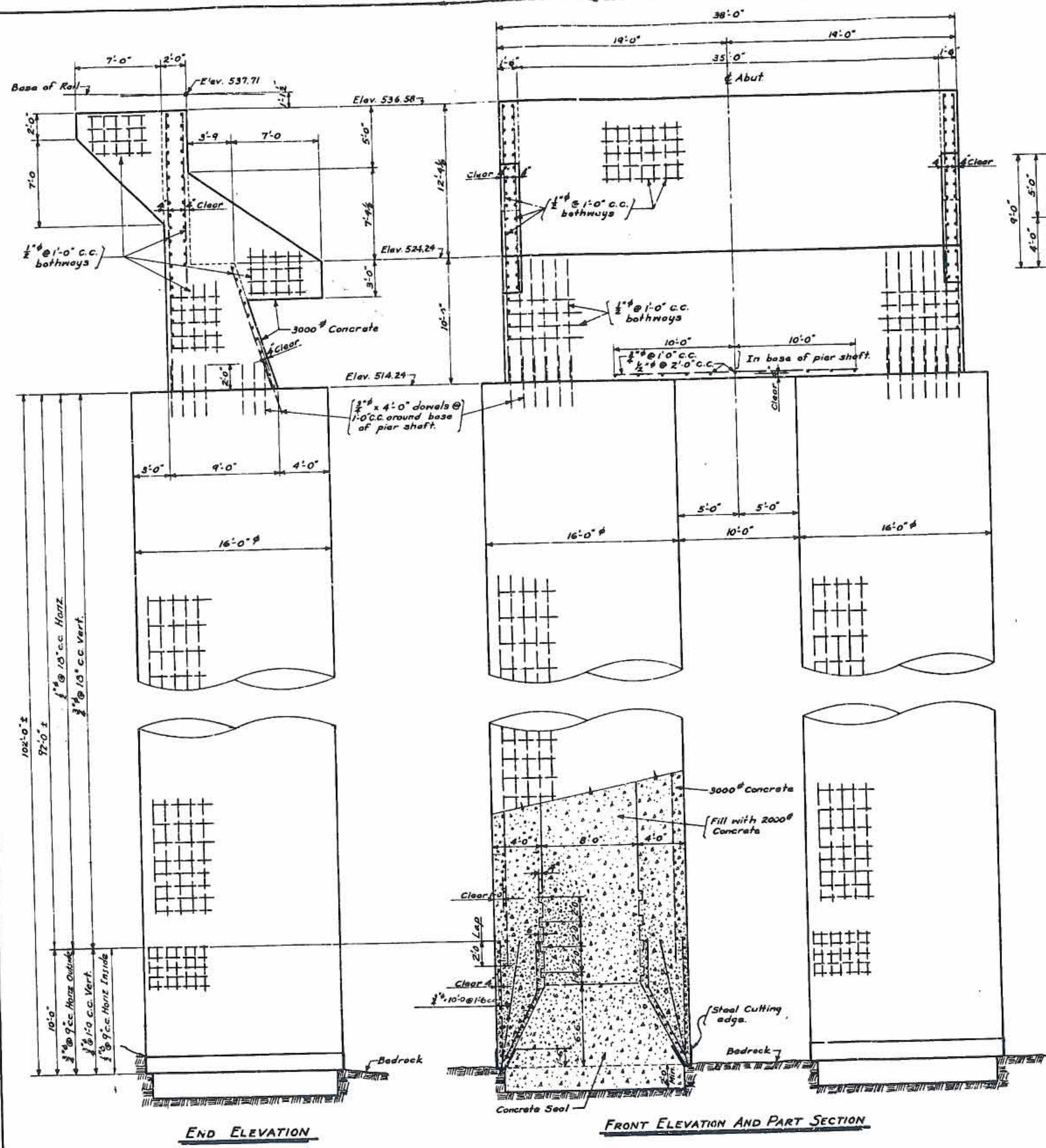
SCALE: 3/16" = 1'-0" CHICAGO, ILL., OCT., 1942

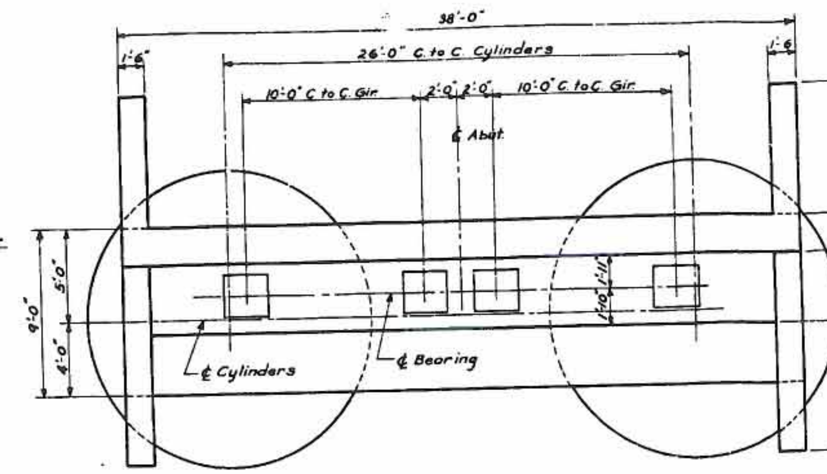
CORRECT: R. A. Van Ness — BRIDGE ENGINEER SYSTEM

APPROVED: [signature] — CHIEF ENGINEER SYSTEM

Rev. 10/30/42

MADE BY:
CHECKED BY:
EXAMINED BY:





Plan View

For General Notes on concrete work See Sheet #2. For Details of Cutting Edge See Sheet #2.

Estimated Quantities

Foundation	2000# Concrete	430 Cu. Yds.
	3000# Concrete	1120 Cu. Yds.
Neat Work	3000# Concrete	150 Cu. Yds.
Reinforcing Steel		12.0 Tons

Sheet 9
9 Drawings

B.E.S. 3275

THE A.T.&S.F. RY. SYSTEM

BR. A 567, 1ST DIST., ARIZONA DIV.

NEW BRIDGE OVER THE COLORADO RIVER

DESIGN OF WEST ABUTMENT

SCALE: 1/4" = 1'-0" CHICAGO, ILL., OCT. 1942

CORRECT: [signature] BRIDGE ENGINEER SYSTEM

APPROVED: [signature] CHIEF ENGINEER SYSTEM

Rev. 10/30/42

MADE BY:
CHECKED BY:
EXAMINED BY:

Attachment A-3
Construction History and Photos

Summary of BNSF Bridge Construction History by David Earle, Applied Earthworks

David D. Earle
Earle and Associates
3335 East Avenue Q-6
Palmdale, CA 93550
10/16/2008

The 1942-1945 AT&SF Colorado River Bridge: Introduction

In 1940 and 1941, the Atchison, Topeka, and Santa Fe Railway put survey crews in the field to lay out engineering plans for a proposed new railway bridge to be built across the Colorado River at Topock, Arizona. The decision to replace the existing Red Rock Bridge, built in 1889-1890, was motivated by concern over the fact that both heavier locomotive loads and deterioration of structural members in the bridge had necessitated a 10 mph speed limit on the bridge. The rather tight ten degree radius of the approach tracks at the west end of the crossing structure also necessitated a 10 mph speed limit, and the gantlet track installed on the bridge in 1923 effectively limited the bridge to single track traffic (Occhiello and Schleicher 1992ba:11-12). Both the Topock location and a river crossing site several miles south of Needles were considered by AT&SF officials for a replacement double track bridge, but the requirement to build a bridge some five miles in length at the site nearer to Needles made the latter alternative economically unfeasible (Means 1941:21-23, Occhiello and Schleicher 1992b:3). While the decision to replace the existing bridge was made prior to United States entry into World War II, the phenomenal increase in rail traffic density on the line brought by the war confirmed the necessity of the replacement construction. The railroad undertook the bridge construction as part of a major overhaul of its infrastructure in southern California (San Bernardino Sun 1945:11).

Approach grading for the new bridge structure commenced in September of 1942, and the bridge was inaugurated for general use on March 7, 1945 (Desert Magazine 1945:29, Myrick 1998: , Railway Age 1945). The Kansas City Bridge Co. began foundation work on the bridge on November 16, 1942 and finished this work on July 1, 1944. The steel structure work was carried out by the American Bridge Co. beginning in September of 1942 (Myrick 1998:90-94, Occhiello and Schleicher 1992b:6, 9, 10). As of 1948, the bridge was among the six largest in the Santa Fe system (Armitage 1948:160). It was 1506 ft., 9 in. long, with double track and three 350-foot deck truss spans, a 50-foot beam span, three 100-foot deck girder spans on the west end and a 100-foot deck girder span on the east end. The steel superstructure of the bridge weighed 6,500 tons. A Santa Fe bridge engineer named Walter Earl Robey was involved in the construction of the bridge, and described the construction project in a Master's Thesis submitted to the railroad engineering program at the Univeristy of Illinois Urbana-Champaign in 1946 (Robey 1946, Simmons-Boardman Publishing Corp. 1954:611).

The 1942-1945 AT&SF Colorado River Bridge Substructure

River Channel Conditions at the Bridge Site

As defined by some twelve test bore holes excavated in 1941-1942, the bed of the river under the proposed bridge right-of-way consisted of circa 80-105 ft. of alluvial deposits overlying bedrock, and underlying a river channel varying between 5 and 25 ft. in depth. The location and depths of the bore holes are shown in Table 1 and Figure 1 Occhiello and Schleicher 1992a:5). Both the river channel and the depth to bedrock were slightly deeper in the east half of the river, with the deeper part of the channel lying between piers 2 and 3. Thick layers of silt, sand, and gravel overlay a thin stratum of boulders and gravel sitting on bedrock on this east side of the river. This boulder stratum was absent under the west half of the bridge right-of-way over the river (Figure 2).

A fluvial alluvial geology report prepared by consulting geologist Thomas Means for the AT&SF was completed before the borings at the Topock bridge site had been completed (Means 1941). Means had been tasked by AT&SF to evaluate both the alluvial geology of the Topock crossing site and that of an alternative proposed crossing location south of Needles. Means observed that the recent building of dams on the Colorado River had created conditions of flood control encouraging consideration of the alternative site (Means 1941:1).

Means had observed that the intromission of the upriver end of the impoundment area of Parker Dam into the Topock Gorge and the narrows above it would appear to reduce river flow sufficiently to contribute to the aggrading of the river bottom at the Topock bridge site (Means 1941:1,18-19). He noted as well that even well before the building of Parker Dam the Colorado River bed in Mohave Valley had been aggrading, perhaps as much as 10 feet since 1902-1905. He also assumed that the flow of de-silted water from newly constructed Boulder Dam would in future cause the degrading of the river bed in the upper valley north of Needles. He did not rule out, however, that future floods exceeding the retention capacity of Boulder Dam could cause scouring of the river bottom at Topock (Means 1941: 5-6, 8, 25). Robinson Rowe (1940), on the other hand, in a highway bridge study of Topock crossing and other potential bridge sites in the Mohave Valley, expressed confidence that the aggrading processes at Topock associated with Parker Dam would provide a stable sub-fluvial environment for future bridge pier construction (Rowe 1940:1).

Bridge Pier Construction

Both 'as planned' and 'as built' elevation drawings of the 1942-1945 Colorado River bridge superstructure and substructure have been consulted (Atchison, Topeka, and Santa Fe Railway 1942, Occhiello and Sleicher 1992b:8-9, Robie 1946). The substructure of the bridge consists of a west abutment, an east abutment, and seven piers, numbered 1-7 consecutively from east to west on the technical drawings. Pier 2 was located partially within the river, and piers 3 through 6 were constructed on river bottom. Piers 1 and 7 were located above and outside the normal elevation of the river, calculated at the time at 450 ft. above mean sea level. As planned, the bridge substructure pier bases would include six north-south oriented pairs of reinforced concrete cylinders capped with a 10-foot thick tie-wall tying the cylinders together. The seventh pier, Pier 2, on the east shoreline, was planned without a base of paired concrete cylinders, but as built, this seventh pier was based with a pair of concrete cylindrical columns like all the other piers. The diameter of the concrete cylinders in the piers varied between 14 ft. and 24 ft. The dimensions and characteristics of the individual piers are discussed below.

The strategy for construction involved the pouring and casting in place of individual reinforced concrete pneumatic caissons at the surface of the working area on the river (Occiello and Sleicher 1992b:6-9). A bell-shaped reinforced concrete working chamber was cast, with a steel cutting edge located near its bottom margin. The working chamber, shaped something like a large version of a 1960s space capsule, contained sufficient room for 'sandhogs' working at the bottom surface of the chamber to dig, drill, and dynamite material off the river bottom for conveyance to the surface. The initial casting of the working chamber for each of the piers to be placed in the river was planned to be carried out on an artificial sand island, above river water level. This built-up 'sand island' was to be contained by steel bulkheads and pilings driven into the river bottom. However, the Kansas City Bridge Co., contractors for the bridge substructure, found it necessary to use this approach only for piers 3 and 6. The other river pier sites featured river alluvium exposed at or above the current river level, which could be used as a base for the casting. Once poured, the caisson working chamber was surrounded by a cylindrical pouring form of the diameter of the eventual pier base cylinder. This form extended some 8-10 ft. above the water surface, so that the successive poured sections of concrete cylinder lying above the working chamber would be cured before following the working chamber downward below the level of the river surface. The working chamber was fitted with chimney-like vertical passage and air lock above it to permit transfer of personnel to and from the chamber, and transport of excavated 'muck' to the surface. Once thus readied, the chamber, fitted in its hollow vertical form, received the first pouring of additional concrete on top of the working chamber, which weighted it down against the pneumatic air pressure pumped into the chamber to prevent leaking of water from the riverbed. As the steel cutting edge at the bottom of the chamber bit into the river bottom, the 'sand hogs' excavated, lowering the chamber perhaps 10-12 inches per day. As the working chamber worked its way downward, the pouring of the concrete was continued to keep the upper surface of the chamber-and-column high above water level, as noted above. The access way to the working chamber was correspondingly lengthened. When bedrock was finally reached and tested, the working edge of the caisson was definitively seated by excavating a minimum of two feet into the bedrock.

The working chamber and the access flue were then abandoned and filled with concrete to create a solid reinforced concrete cylinder extending from at least two feet within bedrock to above the water surface. The cylinders were then linked by a massive tie wall ten feet thick. This tie-wall formed a single-cast body consisting of quadrangular-shaped 'boxes' of reinforced concrete erected on top of the cylinders joined by a rectangular block of concrete traversing over the open space between the cylinders. This tie-wall had the 'box-shaped' elements at each end oriented at 45 degrees to present a 'wedge' or 'point' to the north-south river current.

The decision to use the cylinder and tie wall approach for constructing the pier bases was stated by Occhiello and Schleicher (1992b:6) as motivated by considerations of economy or cost-containment. The cylinder approach was calculated to use significantly smaller quantities of concrete than would a rectangular caisson. However, the fact that plans for bridge construction were finalized during early and mid-1942, in the midst of concern about early wartime shortages of construction and other materials, may have made this economy appear doubly attractive. As it was, a wartime shortage of steel for the bridge superstructure, despite the assignment of Priority 3 to the project, delayed the completion of the bridge by many months.

Cement and Concrete Production for the Bridge Substructure

Both concrete aggregate and cement were supplied by the Santa Fe Railway to the Kansas City Bridge Co. for the substructure work. Santa Fe in turn had a contract with Sharp and Fellows Contracting Co. of Los Angeles for the provision of aggregate. Sharp and Fellows had been contracted to construct concrete track culverts and bridges and excavate new right-of-way for the new AT&SF track alignment west of the Topock crossing. The firm had set up an aggregate mining and processing facility that was apparently located in lower Bat Cave Wash. This site also furnished aggregate for bridge pier construction (Occhiello and Schleicher 1992b:5-6).

Cement used in the preparation of concrete was regular Portland cement, Type I, shipped in 1,200-bag carloads that were delivered every other day to the concrete mixing shed on the Arizona side of the river. Mixed concrete was transported on a temporary trestle from the Arizona side to the pier sites, where rail-mounted cranes lifted and lowered steel pour buckets into place to pour concrete into the pier bases (Ochiello and Schleicher 1992b:4-7). Two different apparent schedules or types of concrete are listed in production estimates for the different piers, with a 2000# and 3000# type to be used for the cylinders, and a 3000# type to be used for the neatwork bridge supports above the cylinders. The specific material formulas for these schedules have not yet been identified, but these designations appear to refer to types of concrete graded by compressive strength of the concrete-aggregate-water mix in pounds per square inch at 28 days after pouring, with 2000 PSI and 3000 PSI values indicated (Atchison, Topeka, and Santa Fe Railway 1942, Dufour and Schantz 1943:349).

The Bridge Piers

Characteristics of individual piers are described below, based principally on data from Occhiello and Schleicher (1992b:8-9) and Atchison, Topeka, and Santa Fe Railway (1942). The depth of individual pairs of piers includes the 10 ft. high reinforced concrete tie wall capping and joining the cylinders. The upper surface of the tie-wall served as a base for the rectangular neatwork piers directly supporting the bridge superstructure. The distances between piers given below were measured between the center lines of the piers. The diameter, vertical length, and bottom elevation data for each pier appears in a table on the 1945 'as built' elevation drawing for the Bridge. Data on the approximate width (north-south) of the piers was calculated from the 1942 'as planned' plan drawing, as noted below (Occhiello and Sleicher 1992b:8, Atchison, Topeka, and Santa Fe Railway 1942).

East Abutment:

The East Abutment was located on the river embankment approximately 150 ft. east of the 450 ft. level shore of the Colorado River. The reinforced concrete cylinders in the east abutment were 14 ft. in diameter and 61 ft. in depth, capped by a rectangular neatwork bridge support approximately 20 ft. tall. The total north-south width between the outer (north and south) edges of the cylinders was approximately 39-40 ft., as indicated by measurements taken from the 1942 'as planned' plan view of the bridge. The base of the abutment cylinders was at the 454 ft. level. The cylinders were installed through direct excavation of the cylinder shafts without use of caissons.

Pier 1:

Pier 1 was located at a lower and more westerly point on the east embankment of the Colorado River in relation to the East Abutment, at a distance of approximately 95 ft. from the 450 ft. level east shore of the river, and 50 ft. west of the East Abutment. The cylinders for this pier were 14 ft. in diameter and 34 ft. in depth. The total north-south width between the outer (north and south) edges of the cylinders was approximately 44 ft., as indicated on the 1942 'as planned' plan view of the bridge. The base of the abutment cylinders was at the 454 ft. level. The base of the cylinders were at an elevation of 455 ft. The rectangular neatwork bridge support capping the cylinders in pier 1 was approximately 38 ft. in height. The cylinder shafts for the pier were also directly excavated. Some 7.0 tons of reinforcing steel were shown as allotted to this pier on the 1942 'as planned' bridge drawing.

Pier 2:

The east margin of Pier 2 was located at the east shoreline of the Colorado River (450 ft. level). It was sited 100 ft. west of Pier 1. This pier had been specified in the 1942 'as planned' drawings as consisting of a neatwork bridge support and pedestal resting on exposed bedrock just underwater at the east shoreline. The 'as built' data show that a change of plan was made so as to install a pair of cylinders, 22 ft. in diameter and 49 ft. deep, reaching a bottom elevation of 408 ft. The total north-south width between the outer (north and south) edges of the cylinders was approximately 55 ft., as indicated on the 1942 'as planned' plan view of the bridge. The cylinder bores were excavated using pneumatic caissons. Approximately 45 ft of bedrock was excavated in this way, by far the deepest penetration of bedrock by any of the pier cylinders used to support the bridge. Pier 2 provided the easterly support for the easternmost of the three 350 ft. main superstructure spans across the river, making stability and flood-resistance of the pier a must. The base of the abutment cylinders was at the 454 ft. level. Some 0.2 tons of reinforcing steel were shown as allotted to this pier on the 1942 'as planned' bridge drawing, before the decision was made to install reinforced concrete cylinders as pier bases. The actual amount of reinforcing steel used is not known.

Pier 3:

Pier 3 was located in the westerly part of the deepest portion of the river channel, and was the deepest pier built. It supported the central and eastern 350 ft. main spans of the bridge. It was located 350 ft. west of Pier 2. The pier cylinders were 22 ft. in diameter and 129 ft. in depth. The total north-south width between the outer (north and south) edges of the cylinders was approximately 50 ft., as indicated on the 1942 'as planned' plan view of the bridge. The pier is believed to have been, at the time of construction, the deepest pneumatic caisson excavation and construction in water-bearing materials in the United States. The installation of Pier 3 presented major difficulties because of the depth of the pier base at an elevation of 330 ft., and a depth below 450 ft. water level (river surface) of 124 ft. (Occhiello and Schleicher 1992b:8-9). Excavation at such a great depth below water surface presented a technical problem because of the air pressure required in the caisson working chamber exceeding limits allowed under Arizona law. The north cylinder of the pier was excavated first, with the working chamber hitting river bedrock on the west side of the caisson at elevation 338. With some difficulty it was possible to drive 3/4 in. reinforcing rods through the boulders and gravel overlying the bedrock on the east side of the caisson to determine the depth of bedrock there. This proved to be 330 ft. It was calculated that excavating to that depth with the working chamber would require a pressure as high as 54 PSI in the chamber. Arizona law limited pneumatic caisson PSI to 50 lbs., and attempts to get a waiver permitting 54 PSI operations failed. Then the railroad attempted to persuade federal officials to temporarily lower the water level behind Parker Dam so as to lower the water level at Topock, decreasing pressure requirements. This request was refused. It was finally possible to get Arizona officials to grant a waiver to operate the working chamber at 52 PSI, and work proceeded .

Pier 3 was excavated through approximately 30 ft. of inorganic silt and fine sand, 33 ft. of fine to medium sand, 24 ft. of fine to coarse gravel, and 15 ft. of large boulders and gravel to reach bedrock. It was the only pier to encounter the large boulder and gravel stratum.

The rectangular neatwork bridge support capping the cylinders was approximately 25 ft. in height. Some 17.5 tons of reinforcing steel were shown as allotted to this pier on the 1942 'as planned' bridge drawing.

Pier 4:

Pier 4 supported the westerly and center 350 ft. main superstructure spans. It was located 350 ft. west of Pier 3. The cylinders for this pier were 24 ft. in diameter, and thus the widest used. The cylinders extended 94 ft. deep, reaching an elevation of 362 ft. The total north-south width between the outer (north and south) edges of the cylinders was approximately 58 ft., as indicated on the 1942 'as planned' plan view of the bridge. The bedrock surface at Pier 4, unlike that at Pier 3, was relatively level rather than sloping. The pneumatic caisson excavation penetrated approximately 60 ft. of inorganic silt and fine sand, and 43 ft. of fine and medium sand, before reaching a 3-6 ft. layer of fine to coarse gravel and then bedrock.

The rectangular neatwork bridge support capping the cylinders was approximately 25 ft. in height. Some 18.0 tons of reinforcing steel were shown as allotted to this pier on the 1942 'as planned' bridge drawing.

Pier 5.

This pier supported the west end of the westerly of the three main 350 ft. superstructure spans. It was sited at 350 ft. west of Pier 4. The pier cylinders were 22 ft. in diameter and 84 ft. deep, extending downward to a bottom elevation of 373 ft. The total north-south width between the outer (north and south) edges of the cylinders was approximately 55 ft., as indicated on the 1942 'as planned' plan view of the bridge. The pneumatic caisson excavation for the pier passed downward through approximately 46 ft. of inorganic silt and fine sand, 8-10 ft. of fine to medium sand, 12-13 ft. of fine to coarse gravel, and a 12-15 ft. thick stratum of non-riverine origin clay-sand-gravel extending from the west bank of the river under the river sediments. The rectangular neatwork bridge support extended approximately 30 ft. above the support cylinders. Some 16.0 tons of reinforcing steel were shown as allotted to this pier on the 1942 'as planned' bridge drawing.

Pier 6:

Pier 6 was located 100 ft. west of pier 5, and was the last pier from east to west to penetrate water-bearing recent river-bottom sediments. The cylinders of the pier were 16 ft. in diameter and 74 ft. deep, reaching an elevation of 382 ft. The total north-south width between the outer (north and south) edges of the cylinders was approximately 52 ft., as indicated on the 1942 'as planned' plan view of the bridge. The pneumatic caisson excavation penetrated approximately 27 ft. of inorganic silt and fine sand, up to 5-7 ft. of fine to medium sand, and 31 ft. of the non-riverine clay-sand-gravel stratum mentioned above, before encountering bedrock. The rectangular neatwork bridge support for Pier 6 extended approximately 22 ft. above the support cylinders. Some 9.0 tons of reinforcing steel were shown as allotted to this pier on the 1942 'as planned' bridge drawing.

Pier 7:

Pier 7 was located 100 ft. west of Pier 6, and its east face was sited upslope from and approximately 25 ft. west of the 450 ft. level west shoreline of the Colorado River. The cylinders for the pier were 16 ft. in diameter and 65 ft. deep, reaching an elevation of 400 ft. The total north-south width between the outer (north and south) edges of the cylinders was approximately 52 ft., as indicated on the 1942 'as planned' plan view of the bridge. Pneumatic excavation penetrated approximately 65 ft. of non-riverine clay-sand-gravel and 20 ft. of a coarse non-riverine gravel before encountering bedrock. The rectangular neatwork bridge support for Pier 6 extended approximately 18 ft. above the support cylinders. Some 9.0 tons of reinforcing steel were shown as allotted to this pier on the 1942 'as planned' bridge drawing.

West Abutment:

The West Abutment was sited 100 ft. west of Pier 7, upslope on the west embankment of the Colorado River. Its cylinders were 16 ft. in diameter and 129 ft. deep, reaching an elevation of 385 ft. Pneumatic caisson excavation penetrated approximately 20 ft. of boulders, 60 ft. of non-riverine clay-sand-gravel, and 55 ft. of non-riverine coarse gravel before reaching bedrock. The rectangular neatwork bridge support for Pier 6 extended approximately 22 ft. above the support cylinders. Some 12.0 tons of reinforcing steel were shown as allotted to this pier on the 1942 'as planned' bridge drawing.

Sources Consulted

Information on the design and construction of the 1942-1945 AT&SF railway bridge was collected at several institutions. The 1942 'as planned' technical drawing of the bridge was consulted at the California Railway Museum Library in Sacramento, Ca., and the geological engineering reports on the Topock crossing were reviewed at the Water Resources Center Archive at the University of California, Berkeley. Other publications relating to the bridge were consulted at the Tomás Rivera Library at the University of California, Riverside. The Santa Fe Railway Historical Society of Temple, Texas kindly provided a copy of the 1992 Occiello and Schleicher article on the 1942 bridge, and the staff of the Engineering Library at the University of Illinois at Urbana- Champaign provided information about the 1946 Robey thesis on the bridge construction. Larry Occhiello, one of the authors of the 1992 article on the bridge, provided me with further information about the Robey thesis and the preparation of the 1992 article and the illustrations it contained, including the elevation view plan of the bridge. Phil Serpico, railroad historian specializing in the AT&SF, also provided valuable assistance in tracking down information about the bridge. The bridge site at Topock had been previously visited on several occasions, and the construction of the predecessor Red Rock Bridge had been previously researched at the Needles Public Library and the San Bernardino County Museum.

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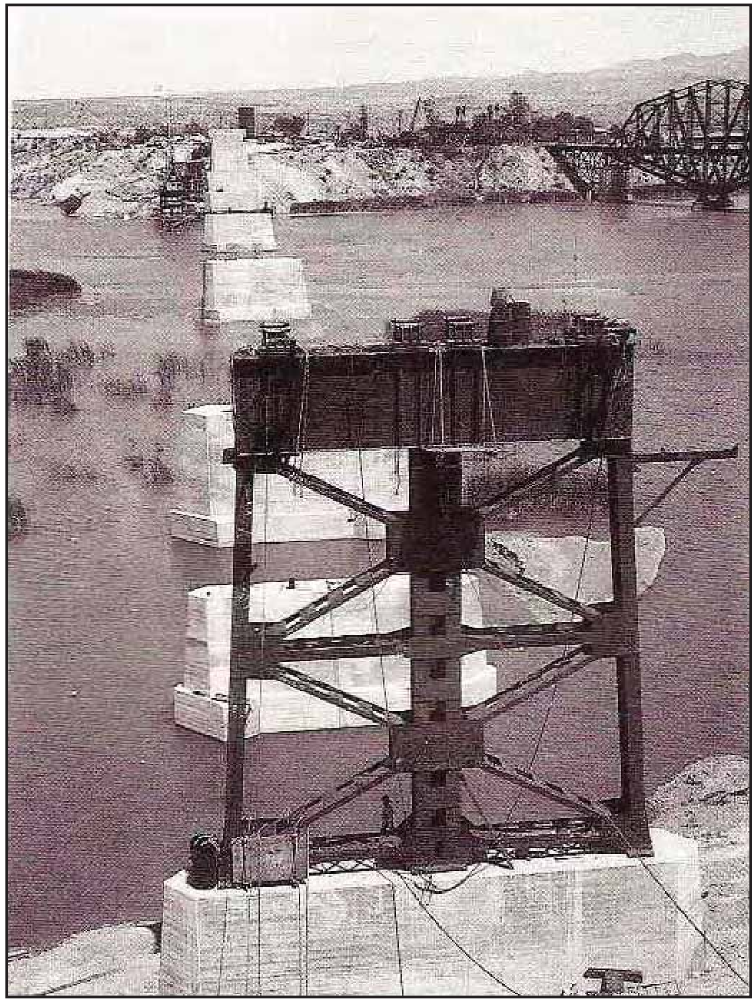
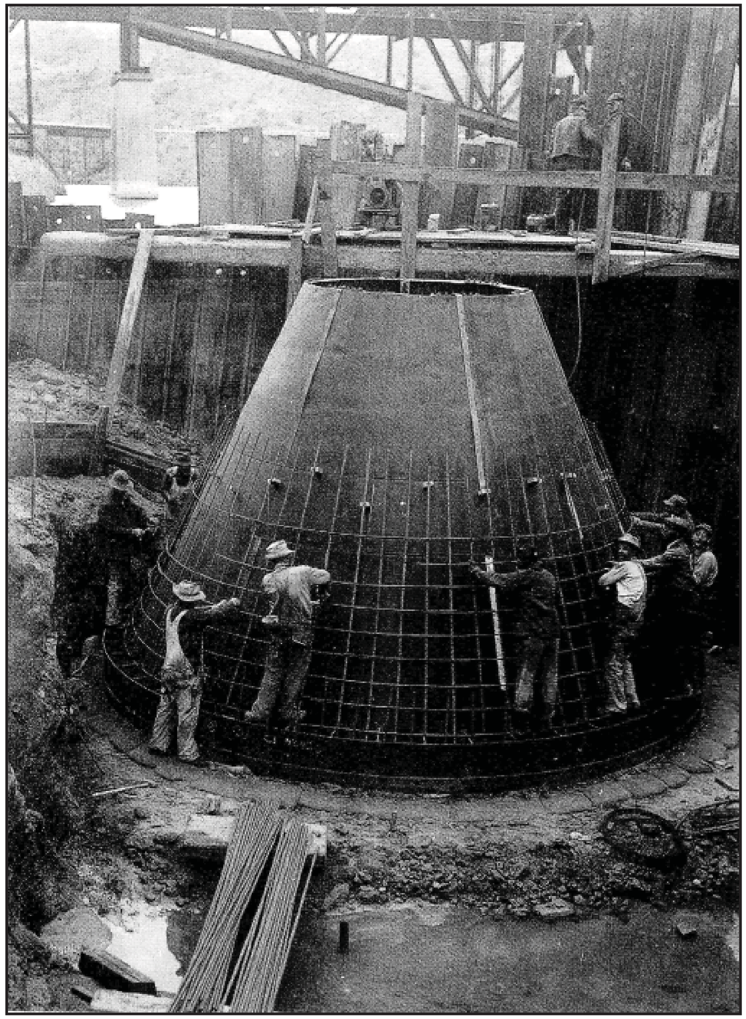


First steel on the main bridge is represented here by the bent on Pier 7. The date is June 1, 1944. This photograph is looking east from the California side of the BNSF Bridge, with the Red Rock Bridge seen in the background.

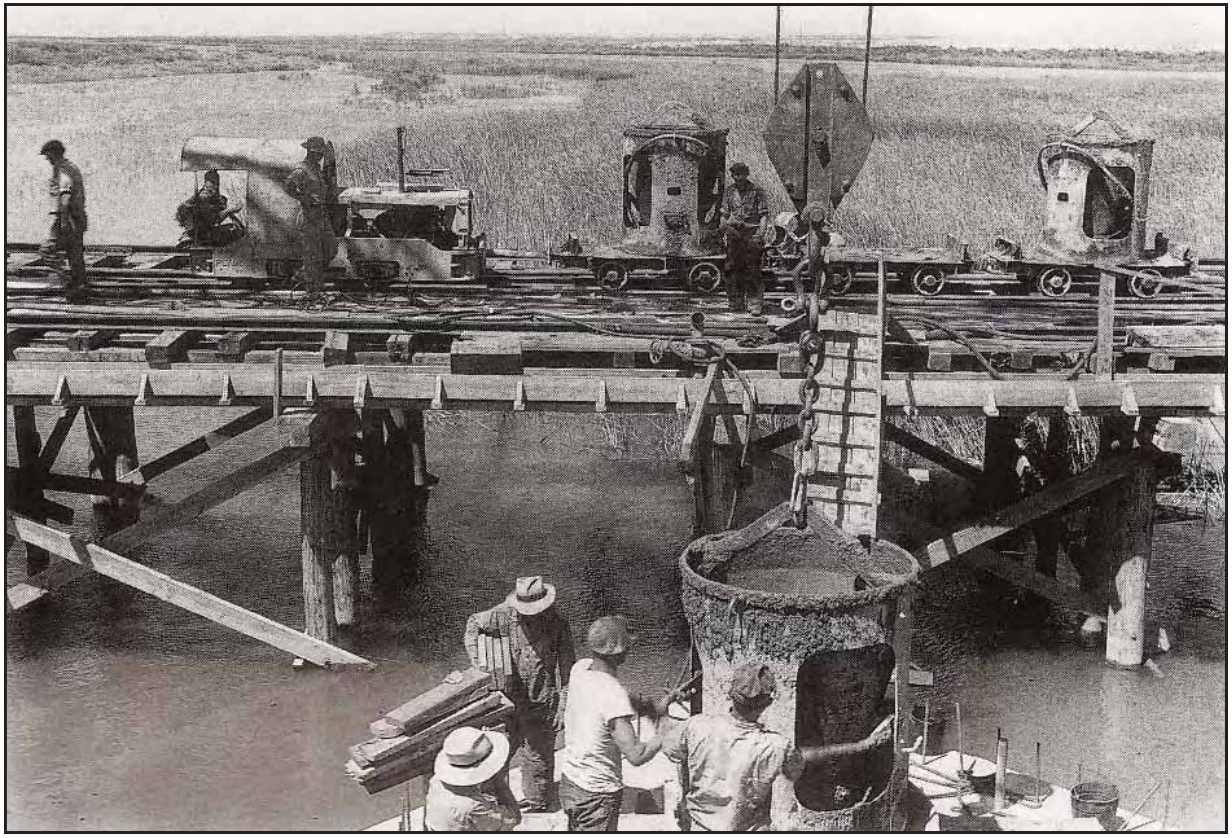
PHOTO A-1
SUMMARY OF COLORADO RIVER BRIDGE
PIER CONSTRUCTION AND
HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA



Placing the reinforcing bar for the cutting edge on the south cylinder for Pier 2. The hoop shaped cutting edge, on which some of the workers are standing, rests on sandbags to keep the conical shape level. The sandhogs worked inside this cone shaped caisson as they lowered the cylinder inch by inch. This photograph is looking south with the Red Rock Bridge and what is now the I-3 Pipeline Bridge seen in background.

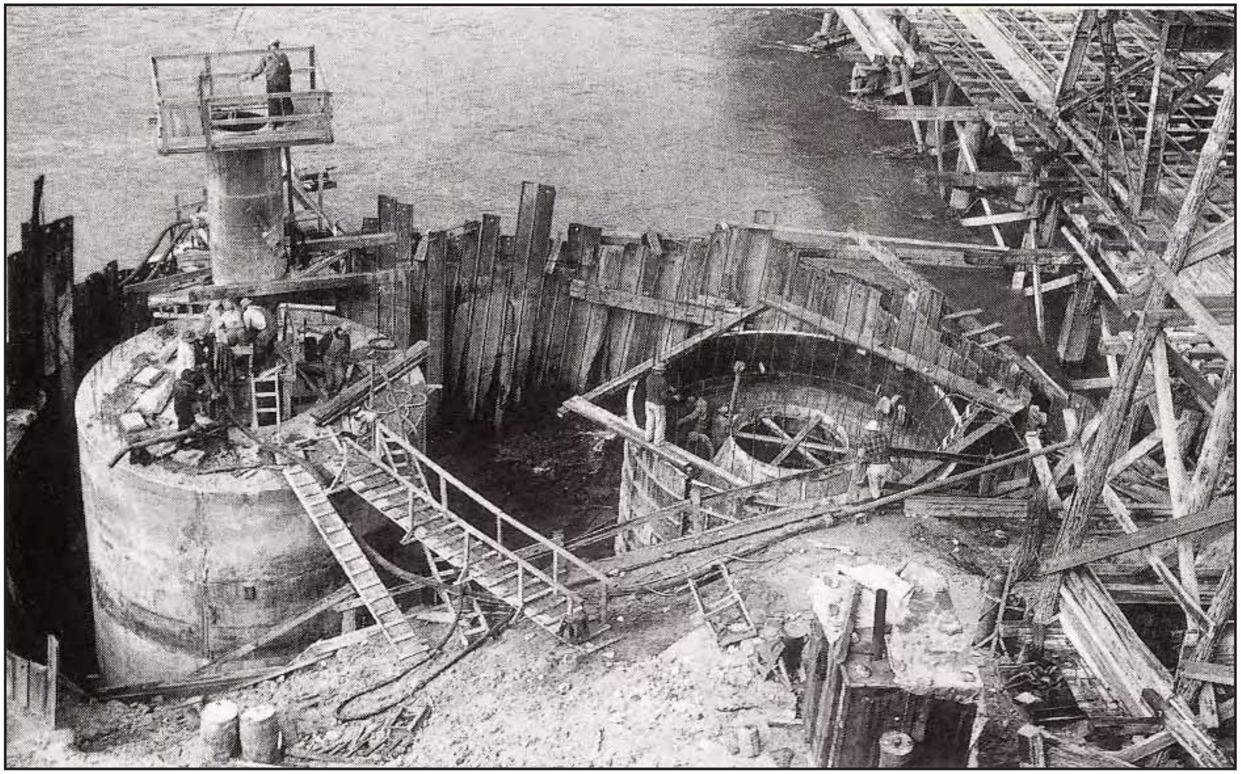
PHOTO A-2
SUMMARY OF COLORADO RIVER BRIDGE PIER CONSTRUCTION AND HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL



Concrete pour completing the seal of the south cylinder of Pier 5 occurred on August 19, 1943. Note the “Plymouth” loco in the left center of the photo. This photograph looking north documents the infilling with concrete of a completed caisson.

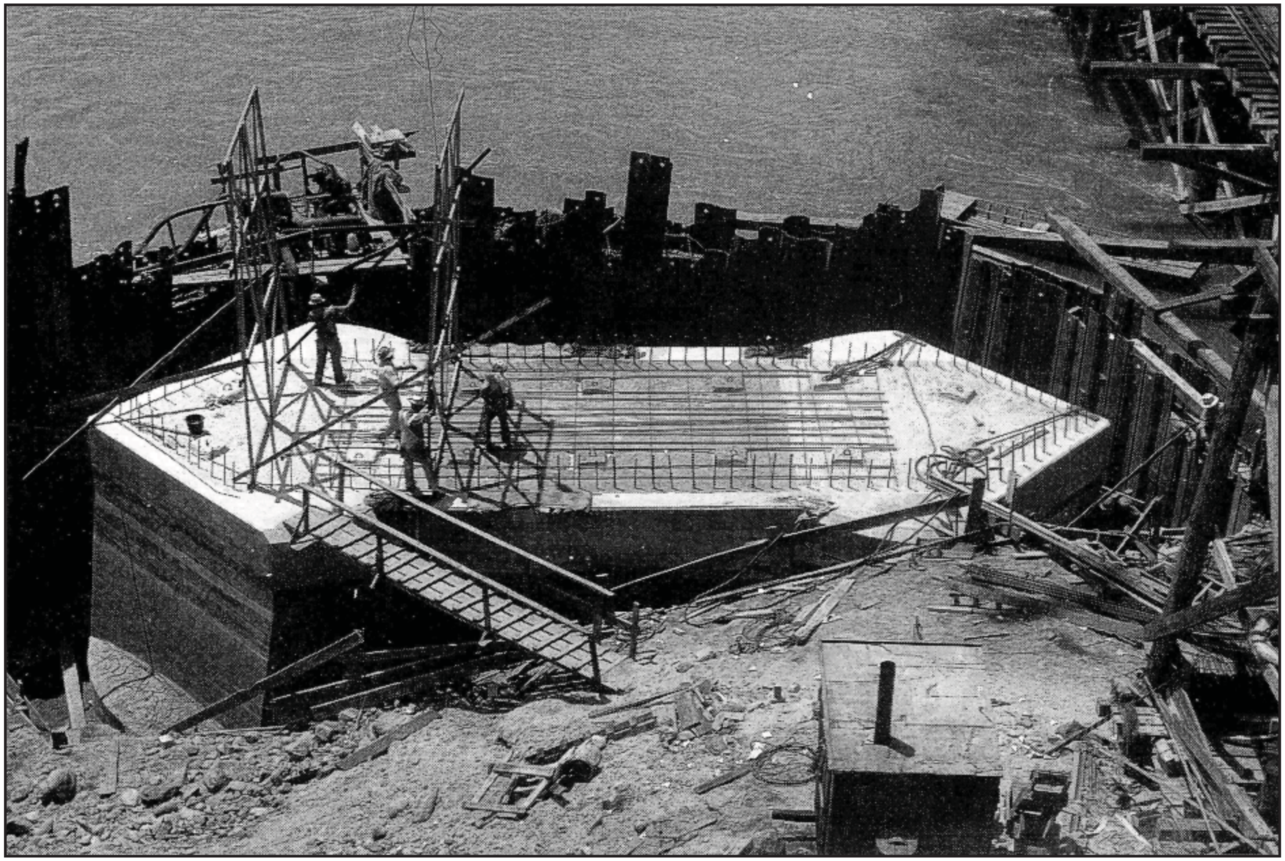
PHOTO A-3
SUMMARY OF COLORADO RIVER BRIDGE
PIER CONSTRUCTION AND
HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA



Concrete is about to be poured in the Pier 2 cylinder on the right on top of the cutting edge. This cylinder will then be lowered to bed rock by the sandhogs excavating inside the bell shape. The left cylinder has already commenced its descent. The man lock and material lock shafts are in place on top of the cylinder. Once the cylinders have reached “the bottom”, the central hole and conical cavity will be filled with concrete.

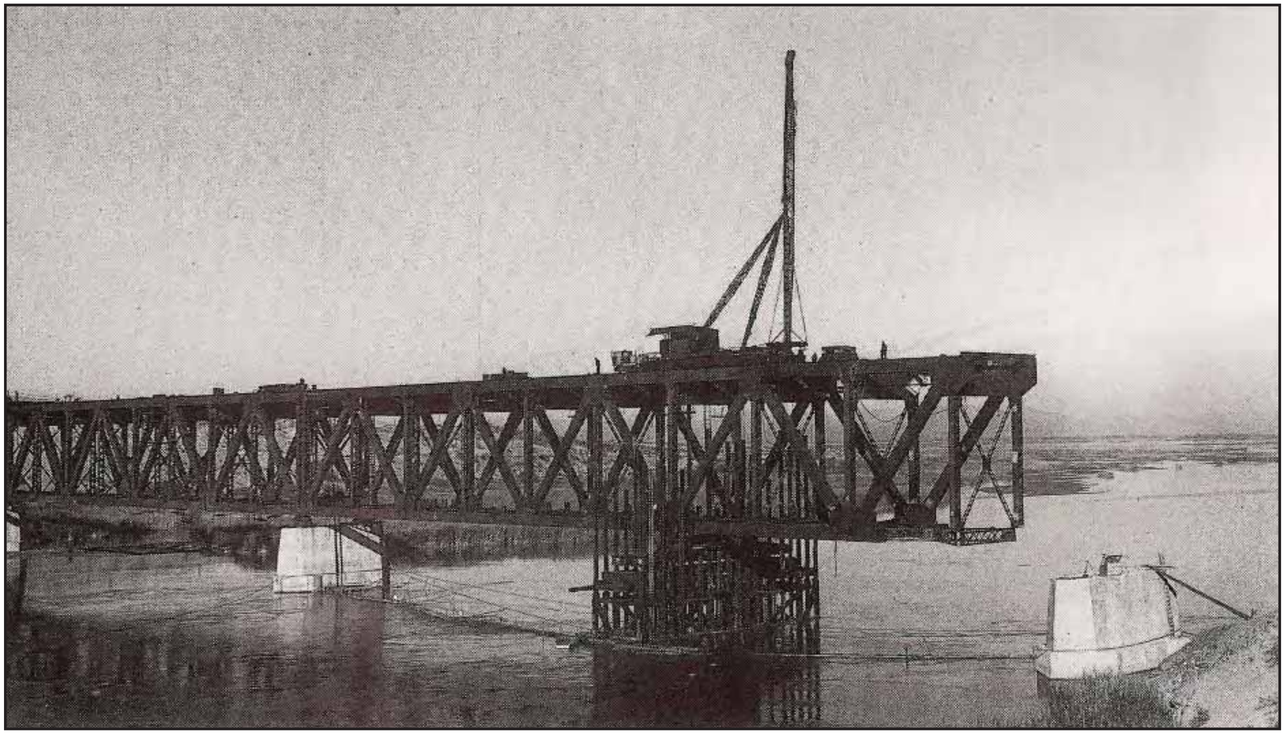
PHOTO A-4
SUMMARY OF COLORADO RIVER BRIDGE
PIER CONSTRUCTION AND
HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL



The tie wall between the two cylinders of Pier 2 is now complete and ready for construction of the “neat” work (that portion of the pier above the water level). This photograph looks west from the same vantage as photo 4, and shows the tie wall between caissons being built inside a temporary steel sheet pile cofferdam.

PHOTO A-5
SUMMARY OF COLORADO RIVER BRIDGE
PIER CONSTRUCTION AND
HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA



Erection of Spam 3 nears Pier 2 on the day before New Year's Eve, 1944. Spans 4 and 3 were constructed using only one temporary falsowork bent each. This photograph looks northwest.

PHOTO A-6
SUMMARY OF COLORADO RIVER BRIDGE
PIER CONSTRUCTION AND
HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

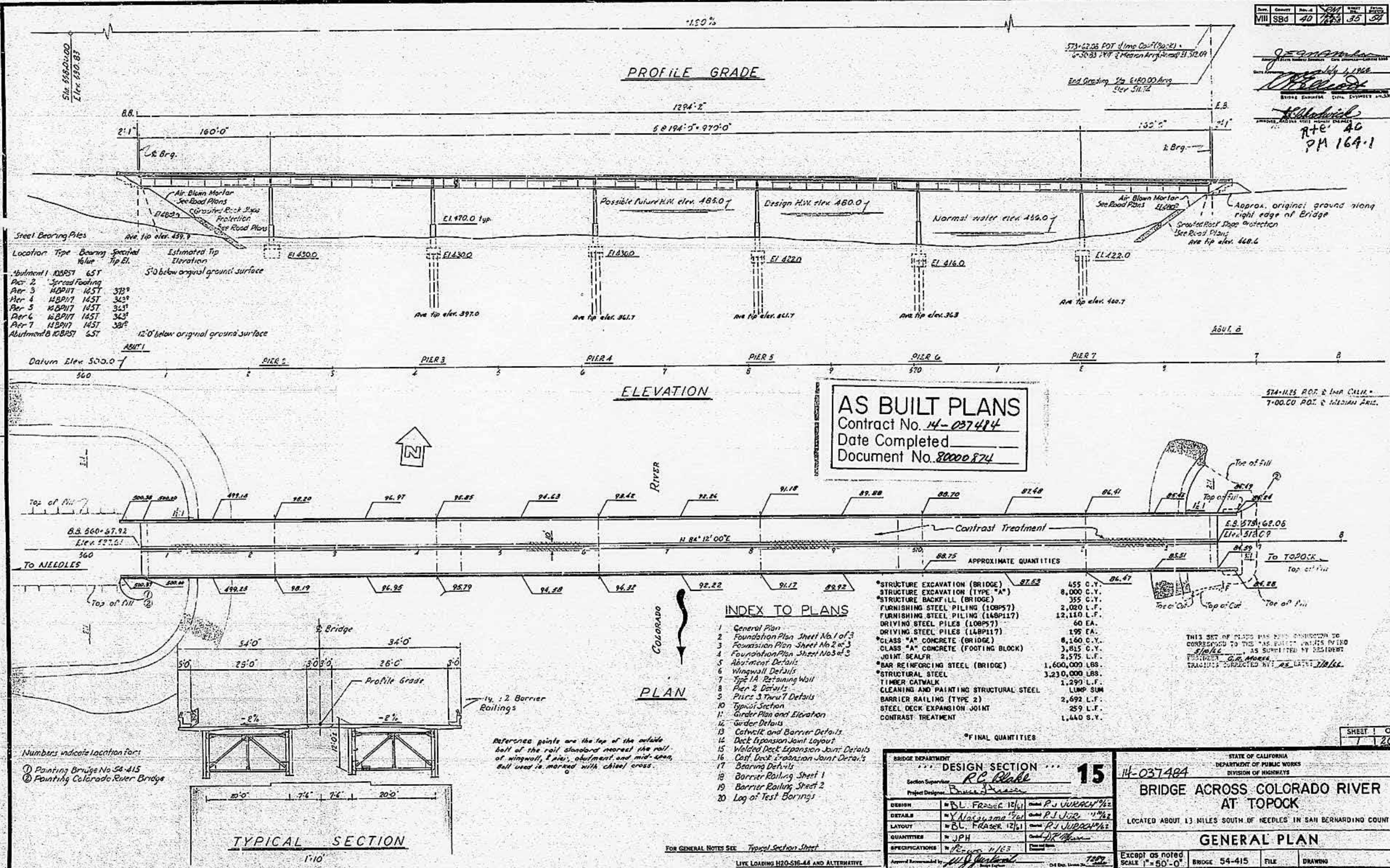
This May 1943 photo looking toward the Arizona side shows work on the north cylinders of the piers. The concrete pour on the near cylinder (Pier 6) is about to commence. This photograph shows the temporary trestle, apparently supported by shallow wooden piles, used to support construction.

PHOTO A-7

SUMMARY OF COLORADO RIVER BRIDGE
PIER CONSTRUCTION AND
HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

Attachment B
Interstate Highway I-40 Bridge
Historical Documentation

Attachment B-1
Caltrans Drawings and Text



AS BUILT PLANS
Contract No. 14-037484
Date Completed
Document No. 80000874

INDEX TO PLANS

APPROXIMATE QUANTITIES

*STRUCTURE EXCAVATION (BRIDGE)	455 C.Y.
STRUCTURE EXCAVATION (TYPE "A")	8,000 C.Y.
*STRUCTURE BACKFILL (BRIDGE)	355 C.Y.
FURNISHING STEEL PILING (10BP57)	2,020 L.F.
FURNISHING STEEL PILING (14BP117)	12,110 L.F.
DRIVING STEEL PILES (10BP57)	60 EA.
DRIVING STEEL PILES (14BP117)	195 EA.
*CLASS "A" CONCRETE (BRIDGE)	8,160 C.Y.
CLASS "A" CONCRETE (FOOTING BLOCK)	3,815 C.Y.
JOINT SEALFR	2,575 L.F.
*BAR REINFORCING STEEL (BRIDGE)	1,600,000 LBS.
*STRUCTURAL STEEL	3,230,000 LBS.
TIMBER CATWALK	1,290 L.F.
CLEANING AND PAINTING STRUCTURAL STEEL	LUMP SUM
BARRIER RAILING (TYPE 2)	2,692 L.F.
STEEL DECK EXPANSION JOINT	259 L.F.
CONTRAST TREATMENT	1,440 S.Y.

*FINAL QUANTITIES

For General Notes See Typical Section Sheet
Live Loading H20-S16-44 and Alternative

SHEET 1 OF 20

BRIDGE DEPARTMENT
DESIGN SECTION 15
Section Supervisor RC Blake
Project Designer Bruce Fraser

DESIGN	By BL Fraser 12/61	Checked P.J. Jurach 1/62
DETAILS	By Y Nagayama 12/61	Checked P.J. Jur. 1/62
LAYOUT	By BL Fraser 12/61	Checked P.J. Jurach 1/62
QUANTITIES	By JPH	Checked
SPECIFICATIONS	By 11/63	Plans and Specs. Compared

Approval Recommended by — Bridge Engineer — Civil Eng. License No. 7259

14-037484
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

BRIDGE ACROSS COLORADO RIVER AT TOPOCK

LOCATED ABOUT 13 MILES SOUTH OF NEEDLES IN SAN BERNARDINO COUNTY

GENERAL PLAN

Except as noted SCALE 1"=50'-0" | BRIDGE 54-415 | FILE | DRAWING

PRELIMINARY DRAWING No. P-54415 — 1 | REVISION DATES
Disregard prints bearing earlier revision dates

I HEREBY CERTIFY THAT THIS IS A TRUE AND ACCURATE COPY OF THE ABOVE DOCUMENT TAKEN UNDER MY DIRECTION AND CONTROL ON THIS DATE IN SACRAMENTO, CALIFORNIA PURSUANT TO AUTHORIZATION BY THE DIRECTOR OF PUBLIC WORKS.
DATE 2-14-72 SIGNATURE TITLE SR RMO

MICROFILM - STATE OF CALIFORNIA - DEPARTMENT OF PUBLIC WORKS - MICROFILM

35

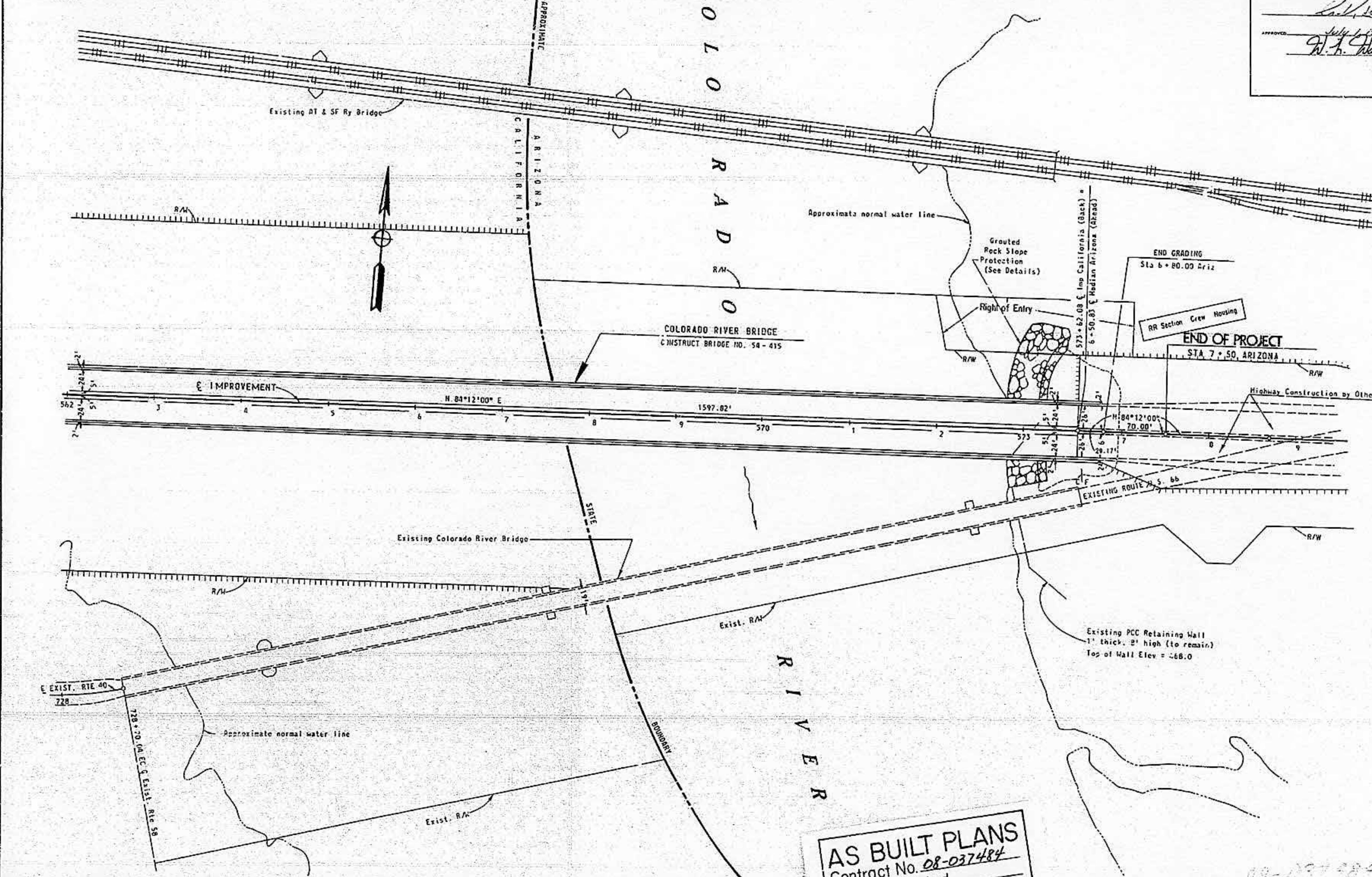
NOTE: FOR RIGHT OF WAY DATA, TOPOGRAPHY, AND ACCURATE ACCESS DETERMINATION, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.

DIST. REG. NO.	STATE	FEDERAL PROJECT NO.	FISCAL YEAR	SHEET NO.	TOTAL SHEETS
7	CALIF.				

DIST.	COUNTY	ROUTE	PM	SHEET NO.	TOTAL SHEETS
VIII	SBd	40	164.2/164.8	6	54

APPROVED July 1, 1964

W. L. Warren



Project Engineer	Date	Design Engineer	Date	Approval Recommended By	Date
[illegible]	7/63	[illegible]	7/63	[illegible]	9/63

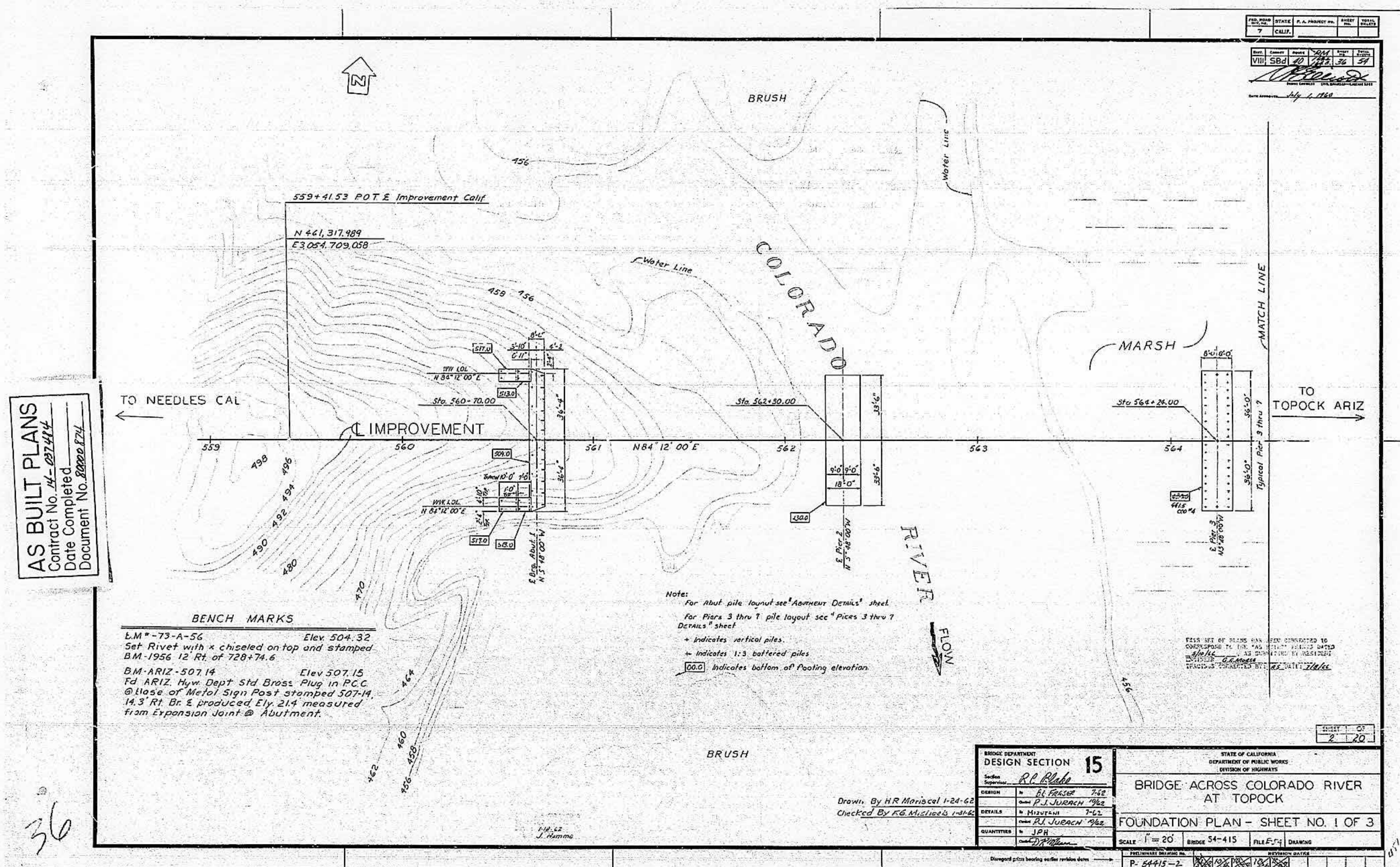
AS BUILT PLANS

Contract No. 08-037484

Date Completed

Document No. 80000418

6



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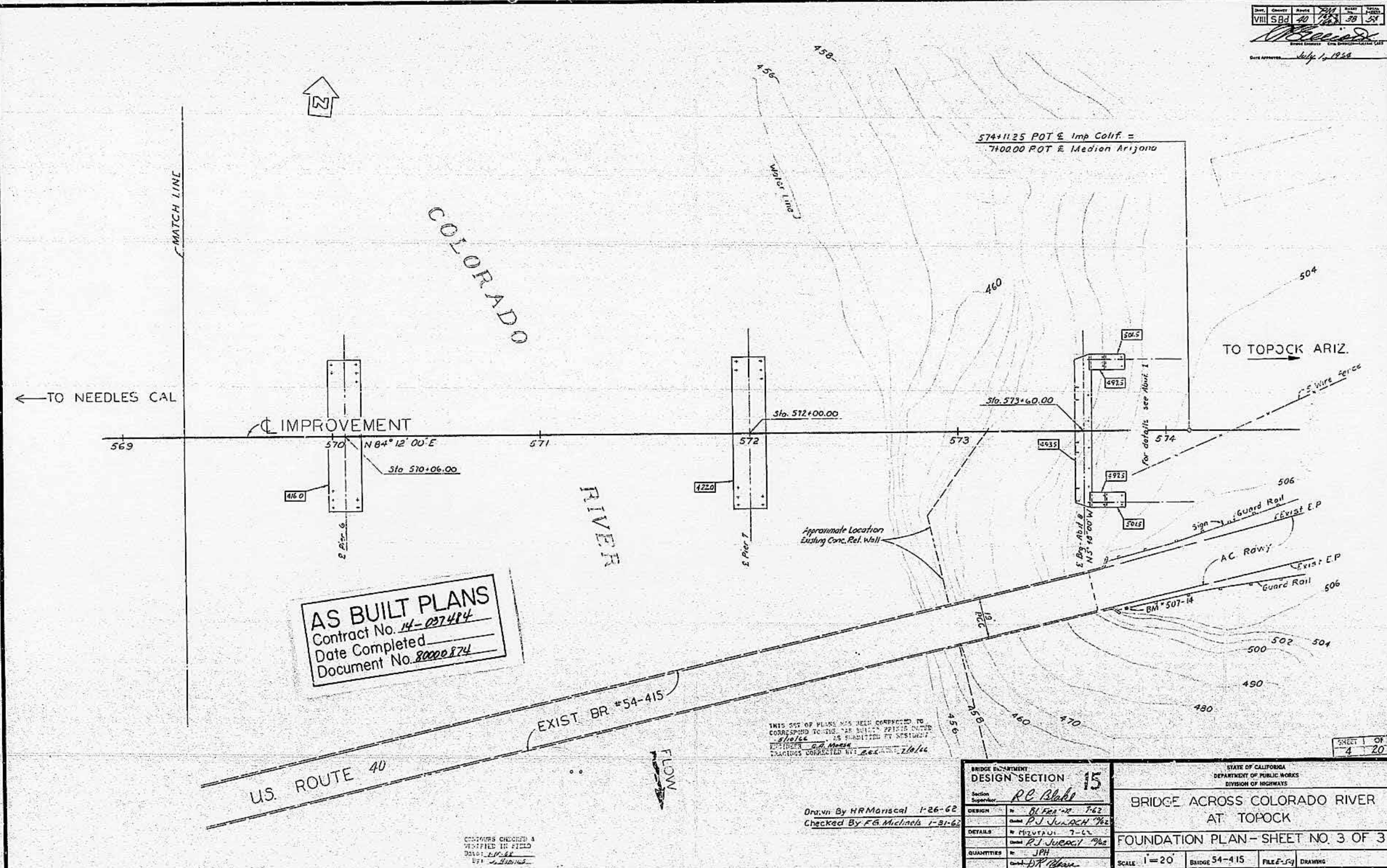
DATE 2-17-72 SIGNATURE TITLE SR RDIO



AS BUILT PLANS
Contract No. 14-037484
Date Completed
Document No. 80000874

THIS SET OF PLANS HAS BEEN CORRECTED TO CORRESPOND TO THE "AS BUILT" PRINTS DATED 5/10/66, AS SUBMITTED BY RESIDENT ENGINEER G.A. Morse
TRACINGS CORRECTED BY: R.E.K. DATE 7/8/66

CONTOURS CHECKED & VERIFIED IN FIELD

Drawn By HR Mariscal 1-26-62
Checked By FG Michaels 1-31-62

BRIDGE DEPARTMENT
DESIGN SECTION 15
Section Supervisor RC Blake

DESIGN	By	BL Frazier 1-62
	Checked	PJ Jurach 1/62
DETAILS	By	Mizutani 7-62
	Checked	PJ Jurach 1/62
QUANTITIES	By	JPH
	Checked	DR Nelson

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

BRIDGE ACROSS COLORADO RIVER AT TOPOCK

FOUNDATION PLAN - SHEET NO. 3 OF 3

SCALE 1" = 20' BRIDGE 54-415 FILE E-54 DRAWING

SHEET 4 OF 20

Dist. VIII County SBd Route 40 Sheet 38 Total 58

Date approved July 1, 1962

PRELIMINARY DRAWING No. P-54415-4

Disregard prints bearing earlier revision dates →

38

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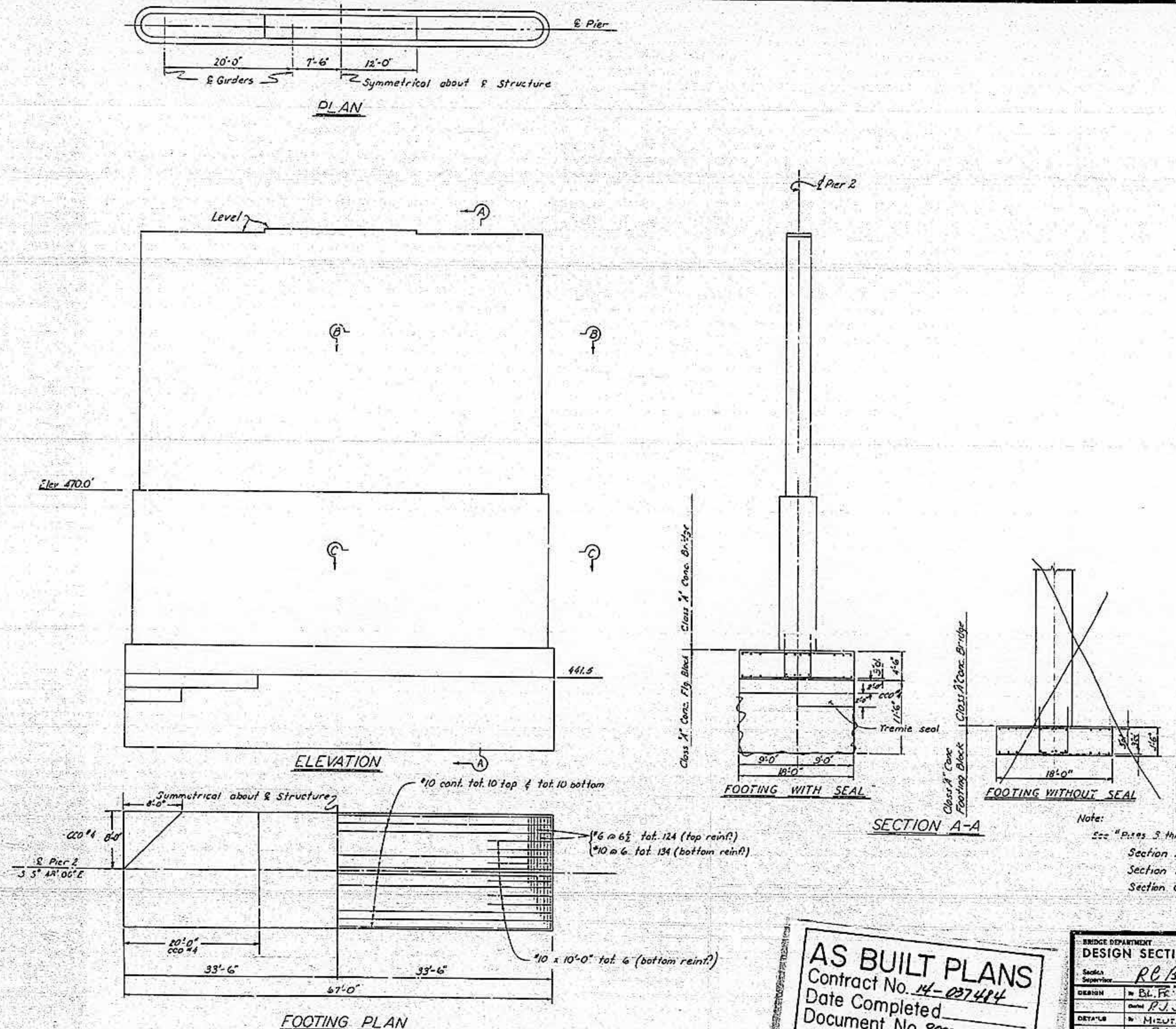
DATE 2-14-72 SIGNATURE TITLE SR RMO

SCALE 1" = 50'
SCALE 1" = 10' or 1" = 100'
SCALE 1" = 20'
SCALE 1" = 40'
MICROFILM - STATE OF CALIFORNIA - DEPARTMENT OF PUBLIC WORKS - MICROFILM

FED. ROAD DIV. NO.	STATE	F. A. PROJECT NO.	SHEET NO.	TOTAL SHEETS
7	CALIF.			

DIST.	COUNTY	ROUTE	P.M.	SHEET No.	TOTAL SHEETS
IV	SM	40		12	54

July 1, 1960



Note:

See "Piers 3 thru 7 Details" sheet for:

Section A-A Pier wall reinf.

Section B-B

Section C-C

THIS SET OF PLANS HAS BEEN CORRECTED TO CORRESPOND TO THE "AS BUILT" RECORDS DATED 5/18/66, AS SUBMITTED BY RESIDENT ENGINEER A.C.A. Morse. TRACINGS CORRECTED BY: [illegible] DATE: 7/66

NOTE: Seal course to be placed only when ordered by the Engineer. Seal thickness shown for estimating purposes only. The thickness to be used will be determined in the field by the Engineer. When seal is not used, the bottom of the reinforced footing shall be placed at the elevation shown for bottom of seal.

SHEET	OF
8	20

AS BUILT PLANS
Contract No. 14-037484
Date Completed
Document No. 80000874

BRIDGE DEPARTMENT
DESIGN SECTION 15

Section Supervisor RC Blake

DESIGN	By BL. FR[illegible]ER 10-62
	Checked R.J. JURACH 10/62
DETAILS	By MIZUTANI 9-62
	Checked R.J. JURACH 10/62
QUANTITIES	By J.P.H.
	Checked [illegible]

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

BRIDGE ACROSS COLORADO RIVER
AT TOPOCK

PIER 2 DETAILS

SCALE ⅛" = 1'-0" BRIDGE 54-415 FILE DRAWING

Disregard prints bearing earlier revision dates →

PRELIMINARY DRAWING No. P-54415-16 REVISION DATES

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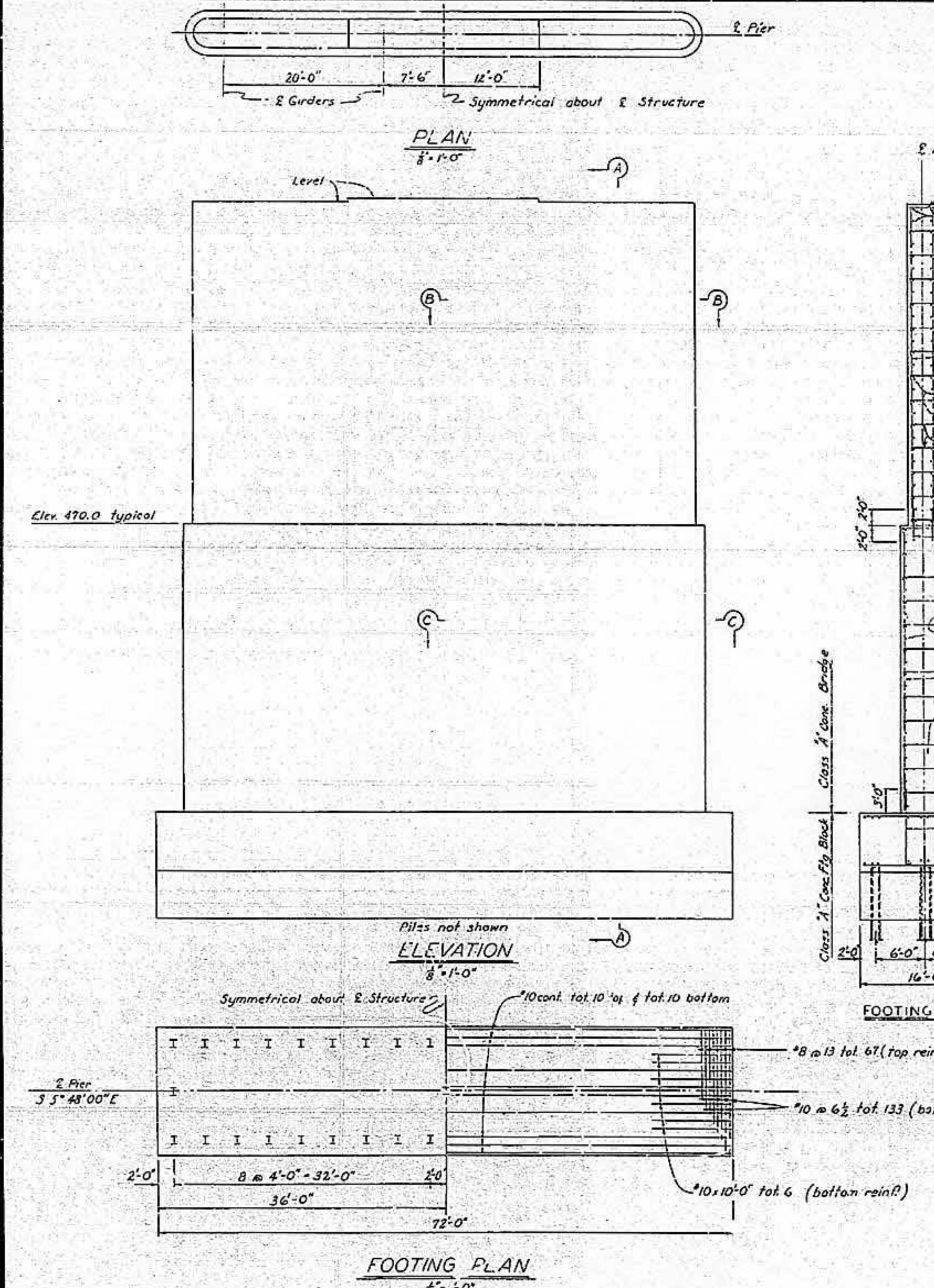
DATE 2-14-77 SIGNATURE [signature] TITLE SR RMO

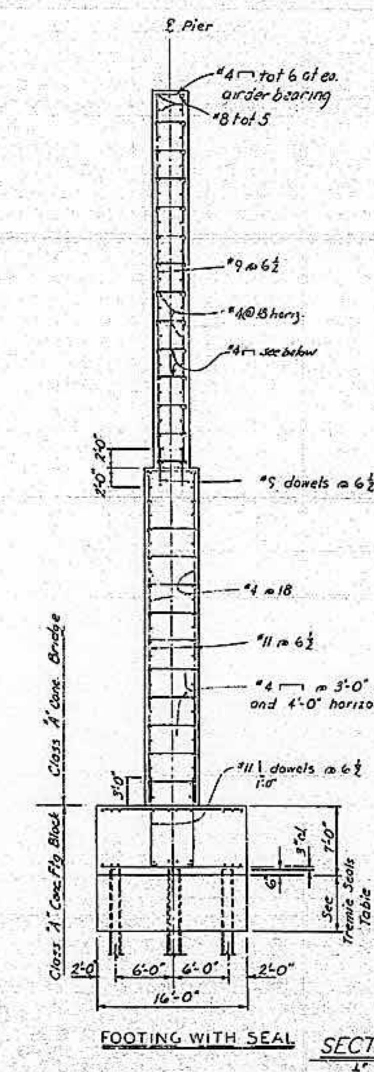
42

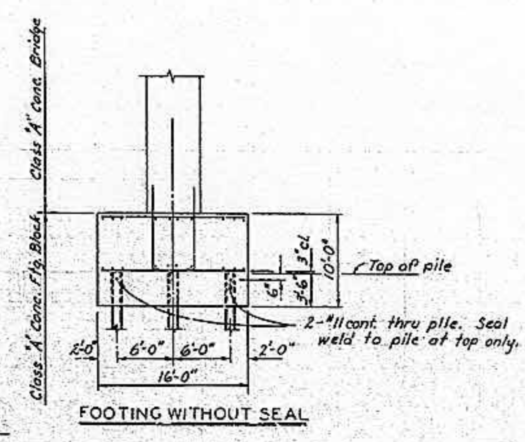
FED. ROAD DIV. NO.	STATE	F. A. PROJECT NO.	SHEET NO.	TOTAL SHEETS
7	CALIF.			

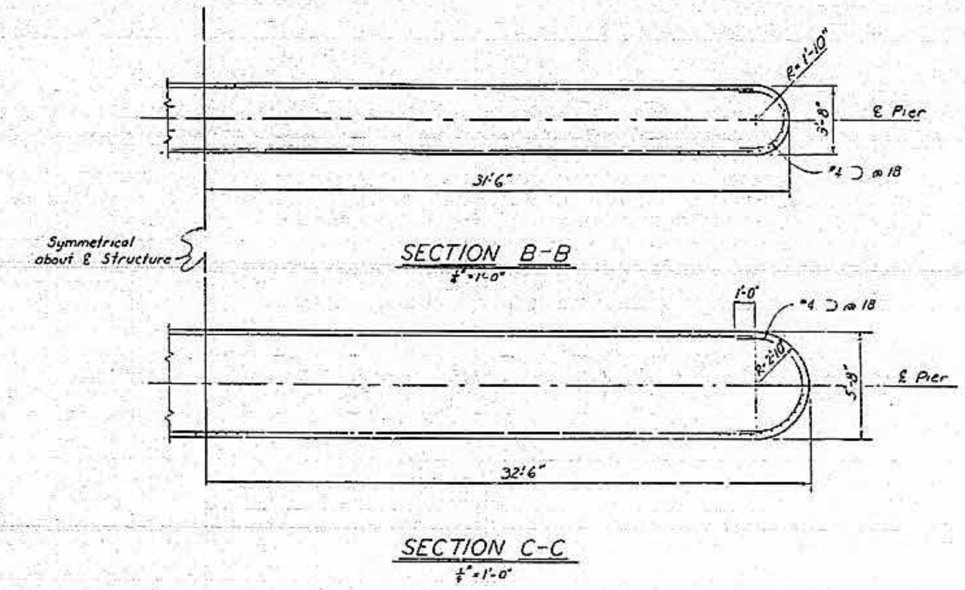
DIST.	COUNTY	ROUTE		SHEET NO.	TOTAL SHEETS
VIII	SBd	40		43	54

DATE APPROVED July 1, 1969









TREMIE SEALS TABLE		
Pier No.	~~Estimated~~ Seal Thickness	Minimum Seal (if required)
3	5'-0"	~~3'-0"~~
4	5'-0"	~~3'-0"~~
5	7'-0"	~~3'-0"~~
6	8'-0"	~~3'-0"~~
7	6'-0"	~~3'-0"~~

THIS SET OF PLANS HAS BEEN CORRECTED TO CORRESPOND TO THE "AS BUILT" PRINTS DATED 5/10/66, AS SUBMITTED BY RESIDENT ENGINEER G. A. Moese
TRACINGS CORRECTED BY: A.S. DATE: 7/8/66

NOTE: Seal course to be placed only when ordered by the Engineer. Seal thickness shown for estimating purposes only. The thickness to be used will be determined in the field by the Engineer. When seal is not used, the bottom of the reinforced footing shall be placed at the elevation shown for bottom of seal.

SHEET 9 OF 20

AS BUILT PLANS
Contract No. 14-037484
Date Completed ______
Document No. 80000874

BRIDGE DEPARTMENT
DESIGN SECTION 15
Section Supervisor R C Blake

DESIGN	By Bl. Fraser	6-62
	Checked P.J. JURACH	10/62
DETAILS	By MIZUTANI	7-62
	Checked P.J. JURACH	10/62
QUANTITIES	By JPH	
	Checked	

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

BRIDGE ACROSS COLORADO RIVER AT TOPOCK

PIERS 3 THRU 7 DETAILS

SCALE As Noted | BRIDGE 54-415 | FILE | DRAWING

Disregard prints bearing earlier revision dates →
PRELIMINARY DRAWING No. P-54415-8
REVISION DATES 12/7

43

I HEREBY CERTIFY THAT THIS IS A TRUE AND ACCURATE COPY OF THE ABOVE DOCUMENT TAKEN UNDER MY DIRECTION AND CONTROL ON THIS DATE IN SACRAMENTO, CALIFORNIA PURSUANT TO AUTHORIZATION BY THE DIRECTOR OF PUBLIC WORKS.
DATE 2-14-77 SIGNATURE ______ TITLE SR RMC

SCALE 1" = 50' — MICROFILM - STATE OF CALIFORNIA - DEPARTMENT OF PUBLIC WORKS - MICROFILM — SCALE 1" = 20'

VII-SBd-58-F

Post K as corr
8-13-62
[illegible]

Colorado River Bridge
at Topock
Bridge No. 54-415

August 9, 1962

Mr. T. L. Sommers:

A foundation study at the site of the proposed Colorado River Bridge at Topock was completed in May 1962. Subsurface information was obtained from twelve rotary sample borings and two cone penetration tests.

Geology

Three general types of earth materials are present at the site. The youngest, recent river deposits, have partially backfilled the bedrock channel which is incised through the base of Quaternary Alluvium (Pleistocene), and into the underlying Tertiary formation (Pliocene or Late Miocene). The Recent river deposits at the site are below the river surface, except where they form the low island. They are loose to slightly compact, and sandy in the highest part, but contain gravel as high as elev. 410 in some locations and trend toward higher gravel content and greater density with depth. Quaternary alluvium at both shores was deposited as alluvial fan material, being composed of dense poorly sorted angular sand and gravel.

NoP The underlying Tertiary formation, red sandstone and conglomerate, has been mapped and described in the Needles-Goff region northwest of the site (J. Miller, 1944, California Journal of Mines & Geology, Vol. 40, No. 1). It is moderately well consolidated clay cemented conglomerate with some sandstone layers and is very dense by the soils classification. Pile penetration of several feet into this material is anticipated at some locations.

The unconformable contact between the Quaternary and Tertiary formations is undulating where observed in road cuts southwest of the site, but is at elevations 455± 5 on both sides of the river.

The nearest mapped fault is about 10 miles to the west, but a fault can be inferred along the base of the Mohave Mountains about one-half mile south of the site.

Foundation recommendations

Foundation recommendations are based on structure support locations shown on the General Plan, Preliminary Drawing ~~No. 5~~ No. 54415-1, ~~dated February 1, 1962~~. 2/1/62.

It is recommended that 65 ton design load 10 BP57 steel H sections be used for abutment support. Abutment piles driven thru more than five feet of fill should be driven in holes drilled thru the approach fills. The holes should be made six inches larger than pile diameters and extend to the original ground.

Piles at abutment No. 1 are estimated to penetrate about five feet into original ground. The twelve foot pile penetration requirement should be waived at this support since adequate bearing will be obtained with the short pile.

Piles at abutment No. 8 are estimated to penetrate a depth of twelve feet into original ground.

It is recommended that footing foundations be used for support of pier No. 2. Footing can be placed at or below elevation 435 with design loads of 7 TSF.

It is recommended that pier Nos. 3 thru 7 be supported by piles. One hundred forty-five ton design load 14 BP 117 steel H sections are the recommended pile type.

Listed below are specified pile tip elevations.

Support number	Specified pile tip elevation	Assumed pile footing block elevation	Point of fixity of pile
Pier 3	373	425	412
Pier 4	363	425	400
Pier 5	363	417	*
Pier 6	363	411	*
Pier 7	381	422	415

* Pile should be considered fixed for its entire length.

It is anticipated that some bent piles may have bearing prior to the specified pile tip elevation. In that event, overdriving and jetting may be required to obtain the specified pile tip elevation.

Report by G. S. Smiley

C. E. Marek

GSS:mig
cc: TLSommers-2
CEMarek-2
Dist Mtls
RE file
LA Prel File

ORIGINAL SIGNED BY
C. E. MAREK

CALIFORNIA DIVISION OF HIGHWAYS

BRIDGE DEPARTMENT

October 21,1965

08-SBd-40-160.9/164.8
14-037484 (554)
I-040-2(6)154
Colorado Riv Br at Topock

Mr. D.F. Downing:

Reference is made to Section 6.2 of the Bridge Construction Records and Procedures.

All subsurface excavation and pile driving has now been completed on the above noted contract. At the Marina Road UC Br No 54-670 foundations are supported on 10BP42 steel piling which were driven to 45 ton bearing using a Vulcan 50C hammer with swinging leads supported by a 25 ton Bay City truck crane. Holes were predrilled for abutment piles as specified and no difficulty was encountered in reaching the specified tip elevation and bearing.

At the Colorado River Bridge, Br No 54-415, abutments are supported on 10BP57 steel piling which were driven to 80 ton bearing using a McKiernan-Terry 11B3 hammer mounted on a Manitowoc 2900 truck crane with swinging leads. Holes for abutment piles were predrilled to elevations specified in Special Provisions. Piles were specified to penetrate at least 5'-0" below OG at abutment 1 and 12'-0" below OG at abutment 8. The bearing value for abutment piles shown on sheet 35 of the Contract Plans specified 65 ton piles whereas Section 11-1.15 of the Special Provisions specified that abutment piles be driven to 80 tons. This discrepency could account for an overrun of 28.3% on furnishing steel piling 10BP57. Piles at abutment 1 & 8 penetrated ten to fifteen feet deeper than estimated.

Pier 2 is the only location where piles were not specified and this was due to a very dense red conglomerate, which is so prevalent in this area, being close to the original ground surface. Plans provided for a 11'-6" tremie seal with bottom of seal at elevation 430. Sheet piles were driven to refusal on the North, East & South sides of the footing with penetration being only 14' to 20' below OG (460). Excavation disclosed the very dense red cemented conglomerate sloping downward toward the river and slightly upstream with the elevation at the edge of the footing nearest the river being 446 ± . CCO #4 was issued to eliminate the tremie seal and raise the footing elevation to 441.5.

OCT 22 1965

BRIDGE ENGR.
ADMINISTRATION
CLERICAL
CONSTRUCTION
MAINTENANCE
PLANNING
ADV. PLAN
PRELIMINARY
PLANN. COOR.
GEOLOGY
SEC. O...
FILE
ACTION

The excavation was kept dewatered by means of a 3" submersible pump.

Piers 3 through 7 are supported on 14BP117 steel piles driven to a bearing value of 145 tons. Piles were spliced, prior to driving, in lengths long enough to permit all driving to be done above the water surface. Piles were located in proper position by means of a timber template constructed within the cofferdam and were driven to approximately 10 feet above specified tip elevation with a Model VHD-2 Vulcor Vibro-Hammer. Penetration and bearing value was then obtained by means of a Vulcan 140C hammer mounted on a Manitowoc 2900 truck crane with swinging leads.

No difficulty was encountered driving piles in piers 4,5 & 6 and bearing was obtained approximately 3 feet below specified tip elevation. At piers 3 & 7 piles did not, in every case, reach specified tip. Piles at these two piers penetrated to rock formation which I presume to be the same red conglomerate shown on the Log of Test Borings. This formation again slopes downward towards the North. Piles refused after penetrating a few inches into this formation.

The final quantity for furnishing 14BP117 was only 2.35% under the original estimate.

Gordon A. Morse
Gordon A Morse
Resident Engineer

cc: Sacto
file

Attachment B-2
David Earle Document on I-40 Construction

David Earle
Earle and Associates
Palmdale, Ca.
10/20/2008

Background on Construction of the Interstate 40 Highway Bridge Crossing the Colorado River at Topock, Arizona.

The construction of the Interstate highway bridge formed part of a discontinuous plan of construction of the Mojave Desert portion of the superhighway- individual projects and segments along the right of way were developed in a piecemeal fashion. The routing of Interstate 40 in California was officially adopted in segments by the California Highway Commission between August 1954 and January 1963, with the Topock and Needles area having been established first in 1954. In 1960, the Bureau of Public Roads confirmed the Needles routing of the Interstate (Los Angeles Times 1965b).

In 1961, Rex Whitton, who had served as Chief Engineer of the Missouri Highway Department, was named Director of the Bureau of Roads by President Kennedy, and is widely credited by highway historians with saving the Interstate highway program in the wake of widespread scandal at the end of the Eisenhower Administration. Whitton and his staff apparently felt themselves under pressure to 'rationalize' highway routing and expenditure, since in December of 1962 these officials proposed building Interstate 40 from San Bernardino to Topock by way of Twentynine Palms rather than following the current Route 66 through Barstow, in order to save 50 miles of distance (Los Angeles Times 1962). This proposal was later abandoned. Then in February of 1963, Whitton announced that the route of I-40 west of Kingman, Arizona would be reconsidered. A proposal was made to change the route from the original right-of-way following Route 66 to Topock and Needles, and redirected northwest to Searchlight, Nevada, to join with Interstate 15 near Ivanpah, California. It was claimed by Whitton that this new route would save 115 miles of right-of-way and $30 million in construction costs. However, in September of 1963 the Topock-Needles route was reconfirmed from Washington (Jefferson City Post-Tribune 1965). In July of 1964 it was announced that bids would be opened by the California Division of Highways on September 3rd for construction of a 1,300 ft. long steel span girder bridge to carry a reinforced concrete four lane highway deck across the Colorado River at Topock. The bridge was estimated to cost $3.15 million, and to involve 18 months of construction. At the time of the bid announcement, it was stated that California would contribute $1.85 million for the project, and Arizona the balance (Los Angeles Times 1964).

As of the first week of January 1965, the E.L. Yeager Co. of Riverside had been given a contract to build an Interstate-40 overpass over Santa Fe railway right-of-way in Needles. A ten miles stretch of Interstate 40 was being built in the Daggett area, and the Interstate bridge was already under construction at Topock (Los Angeles Times 1965a). Then in April of 1965, Whitton announced that the re-routing of Interstate 40 by way of Searchlight, Nevada was again under consideration, despite the fact that the highway departments and public officials of California and Arizona considered the route of

Interstate 40 settled, particularly since construction between Kingman and Barstow via Needles was already underway (Los Angeles Times 1965b, Yuma Sun 1965a). Press reports indicated that Whitton was planning to use the Searchlight route due to the alleged savings in construction costs. During the balance of 1965, California and Arizona public figures- governors, senators, congressmen, and highway officials- and the residents of Needles as well, all mobilized to get the Searchlight proposal killed (Jefferson City Post-Tribune 1965, Los Angeles Times 1965c, Yuma Sun 1965b). The Barstow-Needles-Kingman route had already involved the spending of some $27 million, so the notion of a substantial savings of S30 million with the new route seemed hard to sustain. Whitton had initially refused to back down, but it was reported on February 6, 1966 that the Bureau of Roads had just announced that the Topock- Needles route would be followed after all (Fresno Bee 1966).

In late March of 1966, a further controversy developed when various regional newspapers announced that Whitton had asked for a delay in soliciting bids on the Kingman- Needles- Barstow section of the highway. Mohave County area Congressman Senner and Arizona Sen. Fanner had then met with the Kingman, Arizona Chamber of Commerce to discuss the apparent delay, and Senner vowed to speed up action on construction of the route (Tucson Daily Citizen 1966).

It was mentioned in the Los Angeles Times in May of 1965 that the new highway bridge crossing the Colorado River at Topock was scheduled to be completed in March of 1966 (Los Angeles Times 1965b). The adjoining two miles of Interstate divided highway east of the bridge in Arizona was opened to traffic in 1967. However, the next ten mile segment of Interstate 40 in Arizona commencing two miles east of the Topock highway bridge was not opened until 1977 (Arizona @ RockyMountainRoads:2)

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1966 Needles Hails Victory Over LBJ's 'City Hall'. Fresno Bee, 2/6/1966:2-c. Fresno, California.

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1962 High Desert Marshals Forces for Battle Over Rerouting Highway 66. Los Angeles Times, 12/16/1962:F-8. Los Angeles, California.

Los Angeles Times
1964 New Bridge Will Span Colorado: $3.15 Million Project Slated to Start in Fall. Los Angeles Times, 7/20/1964:A-2. Los Angeles, California.

Los Angeles Times
1965a Contract Let For Span on Desert Freeway. Los Angeles Times, 1/8/1965:A-2. Los Angeles, California.

Los Angeles Times
1965b State Road Board Likely to Fight Change in Route of Interstate 40. Los Angeles Times, 5/23/1965:A-6. Los Angeles, California.

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1965c Interstate 40 Routing Plea Made: Four Senators Go Over Head of U.S. Highway Official. Los Angeles Times, 9/9/1965:A-10. Los Angeles, California.

Tucson Daily Citizen
1966 Senner to Probe Delay on Interstate 40 Bids. Tucson Daily Citizen, 3/28/1966:4. Tucson, Arizona.

Yuma Sun
1965a Oppose Abandoning Interstate 40 Job. Yuma Sun, 5/14/1965:2. Yuma, Arizona.

Yuma Sun
1965b Brown Asks Kingman I-40 Route. Yuma Sun, 9/5/1965:2. Yuma, Arizona.

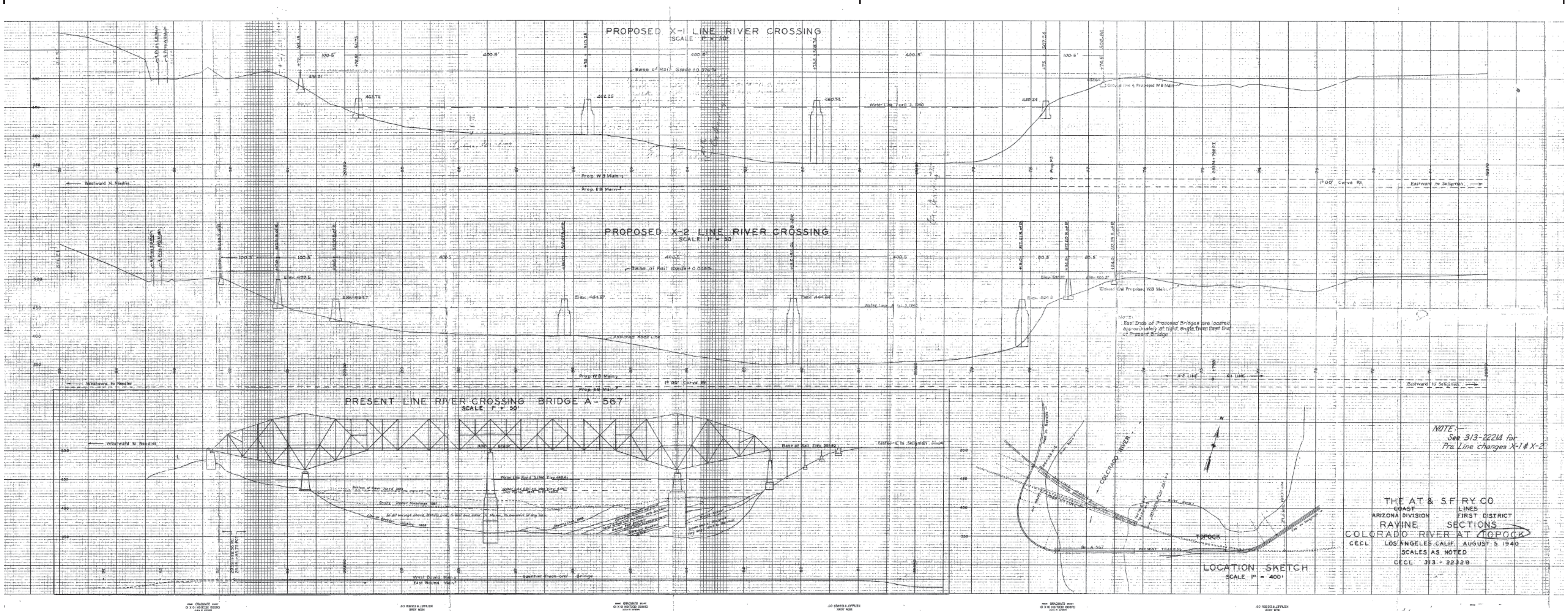
Arizona @ RockyMountainRoads
2008 Interstate 40 Arizona. Construction Timeline for Interstate 40. http://www.rockymountainroads.com/I-040_az.html

Attachment C
Red Rock Bridge
Historical Documentation

Attachment C-1
Red Rock Bridge

ENLARGEMENT 2 (LEFT PORTION)

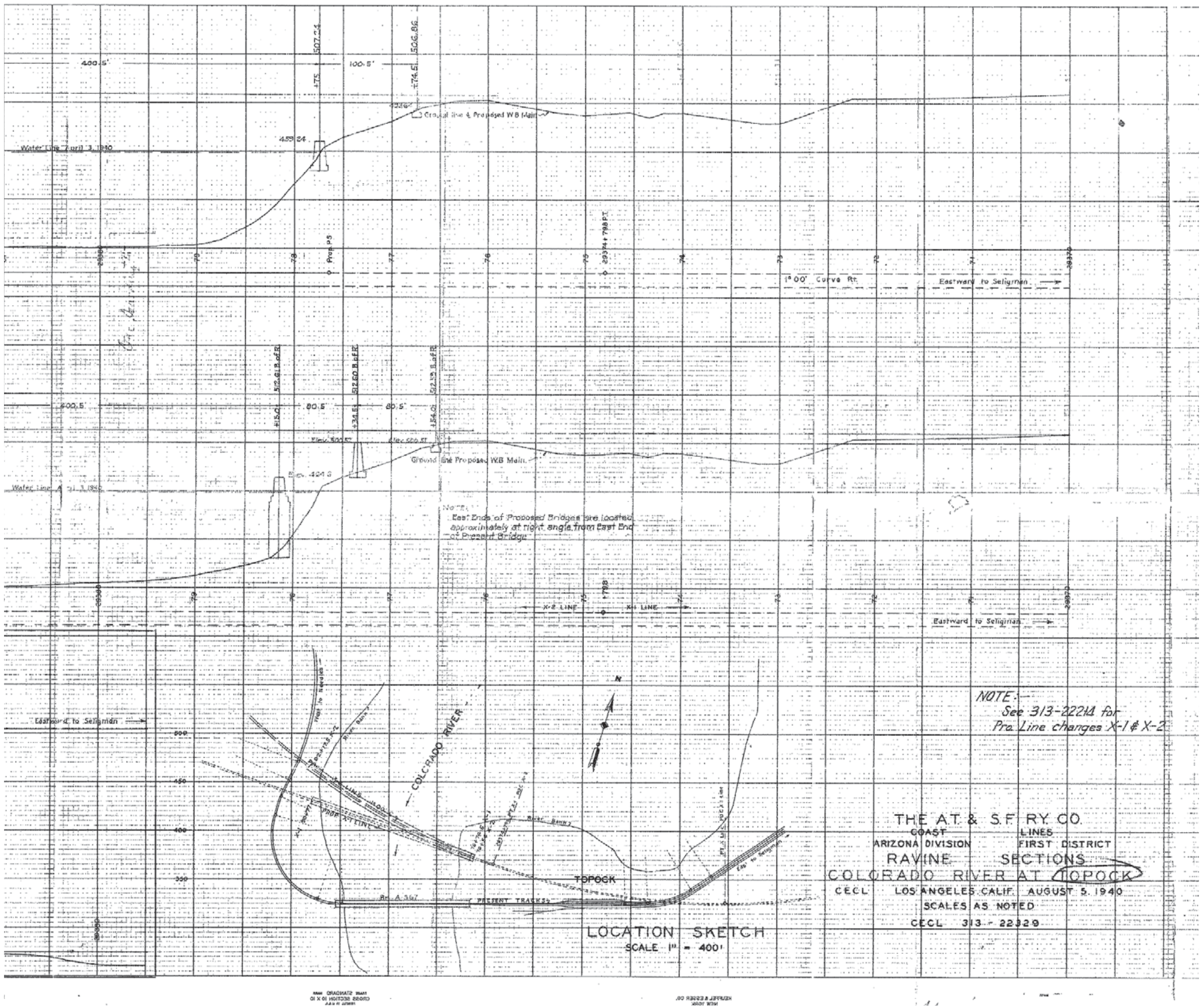
ENLARGEMENT 1 (RIGHT PORTION)



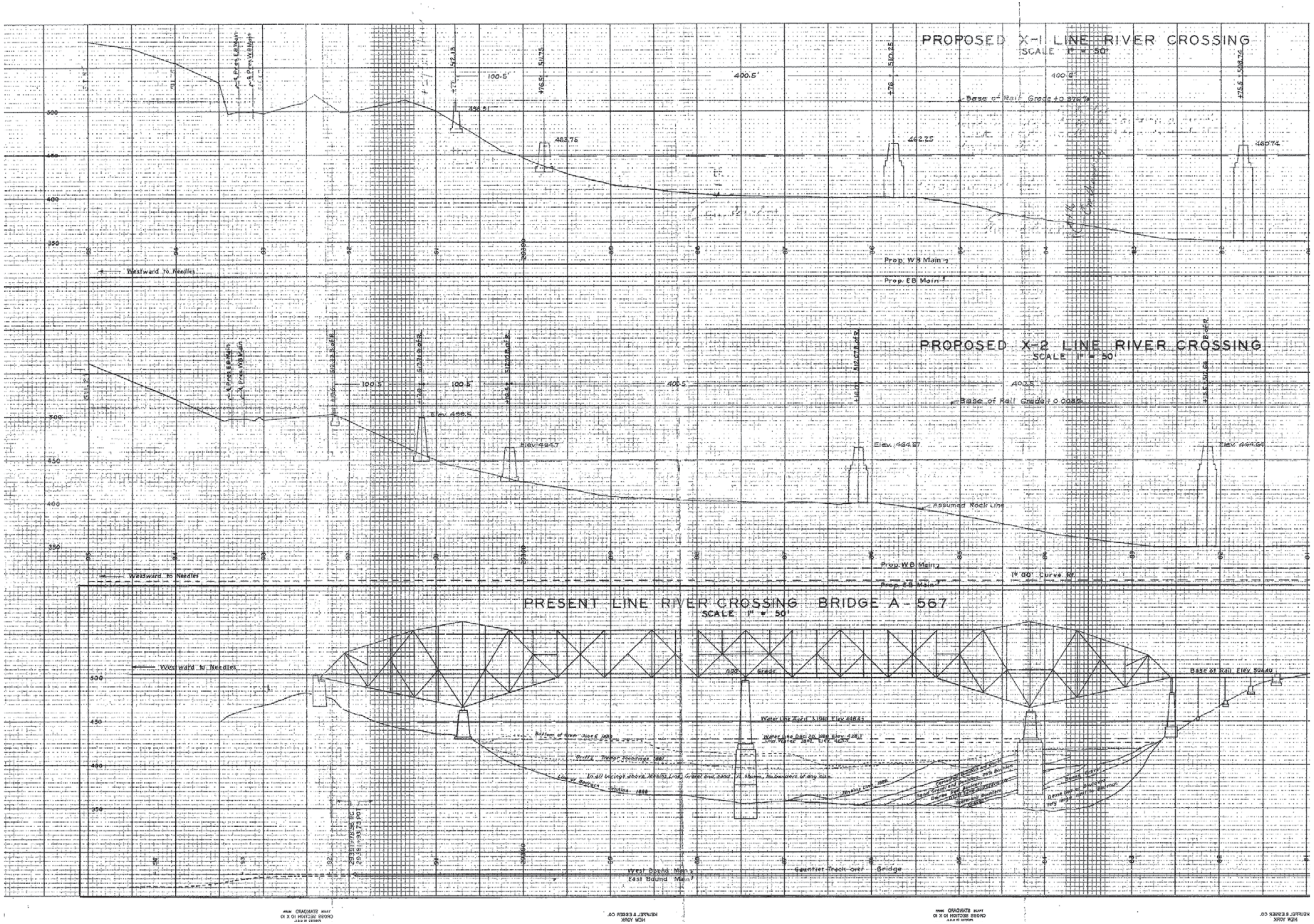
Notes: Historical drawing from Atchinson, Topeka and Santa Fe Railroad, August 5, 1940.
See attached enlargements 1 and 2 for drawing details.

CH2MHILL

ENLARGEMENT 1 (RIGHT PORTION)



ENLARGEMENT 2 (LEFT PORTION)

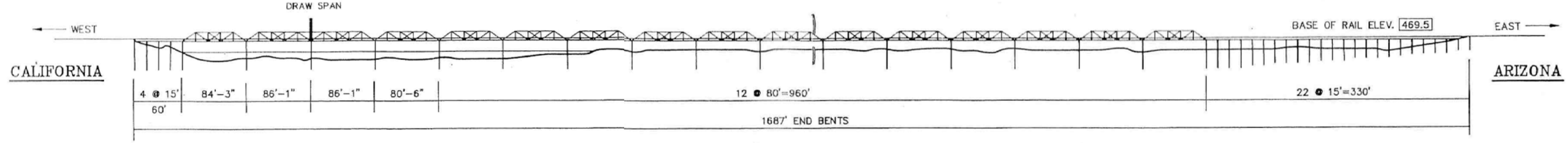


ES092008004BAO Dwg_Orig_Red_Rock_Bridge.ai 092408_lho

CH2MHILL

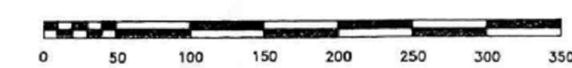
ATLANTIC & PACIFIC NEEDLES CONSTRUCTION BRIDGE

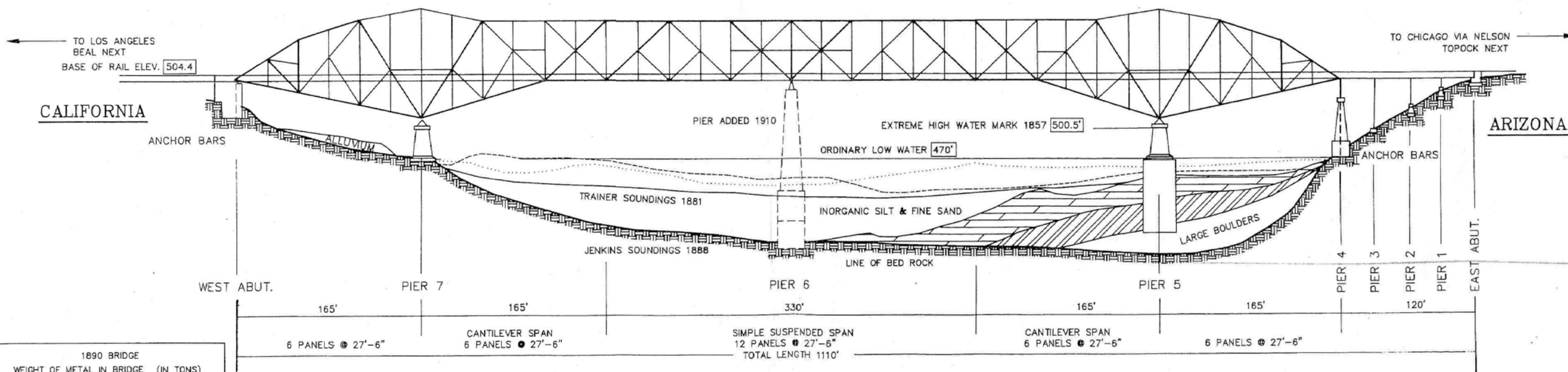
(REMOVED ON COMPLETION OF FIRST BRIDGE)



ATLANTIC & PACIFIC NEEDLES BRIDGE

BRIDGE IN SERVICE 1883–1890





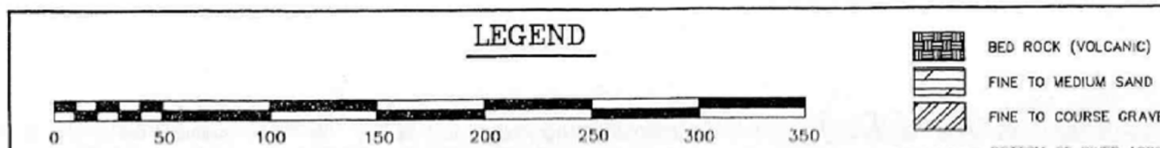
1890 BRIDGE
WEIGHT OF METAL IN BRIDGE (IN TONS)

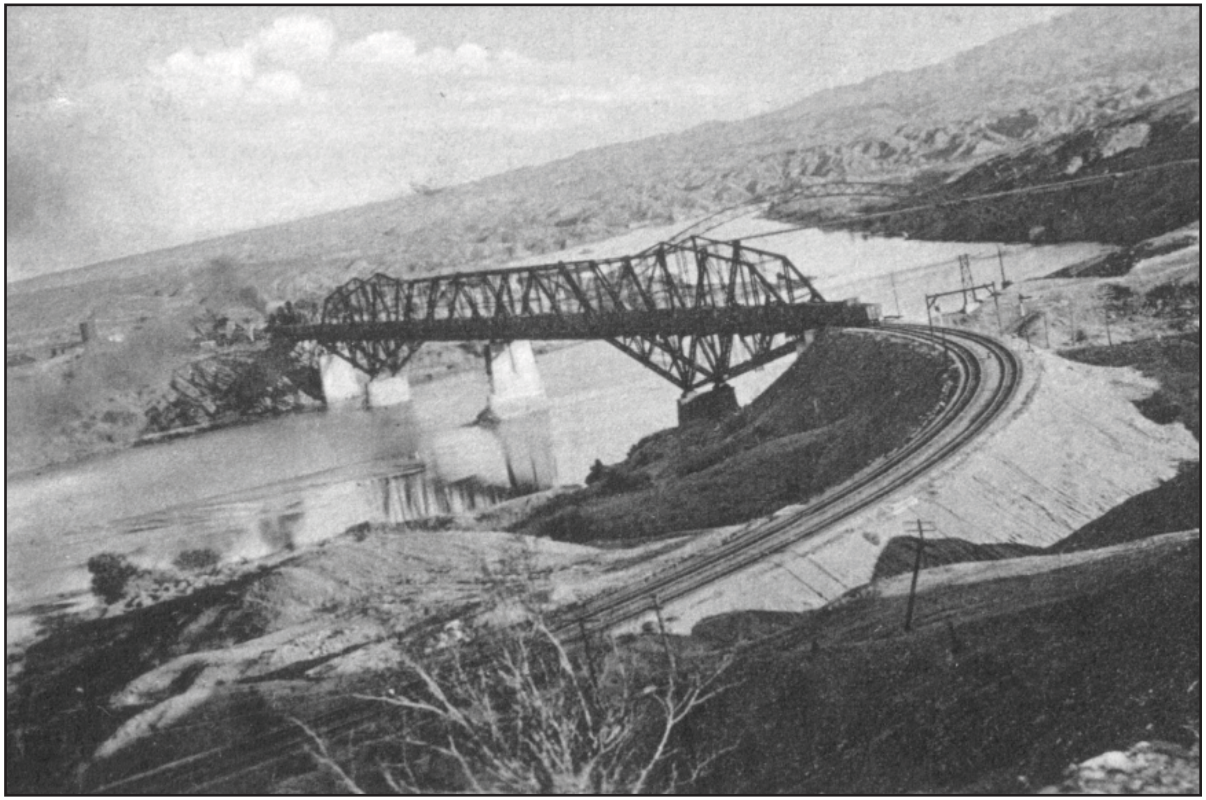
	IRON	STEEL	TOTAL
EAST ANCHORAGE	14	25	39
WEST ANCHORAGE	13	33	46
FLOOR	56	79	135
TWO ANCHOR ARMS	114	371	485
TWO CANTILEVER ARMS	112	348	460
METAL OVER PIERS	33	56	89
EXPANSIVE PANELS	9	55	64
TEMPORARY MEMBERS	31	7	38

ATLANTIC & PACIFIC RED ROCK BRIDGE (CANTILEVER)

STEEL BRIDGE CONSTRUCTED 1890 & MODIFIED 1910
FROM ROWE 1891 & ROBEY 1946

LEGEND





California “and” Arizona Bridge, Needles, California.

PHOTO C-1
SUMMARY OF COLORADO RIVER BRIDGE
PIER CONSTRUCTION AND
HYDROGEOLOGIC ASSESSMENT
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

Attachment C-2
Article by S. M. Rowe, 1891, Describing Construction of the Red Rock Bridge

TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XXV.

JULY TO DECEMBER, 1891.

NEW YORK:
PUBLISHED BY THE SOCIETY
1891.

CONTENTS.

PAPERS.

ERRATA.

By an exchange of tracings in preparing the matter for publication, the long scale to the right on Plates XCIX and C in the November number, page 537, was erroneously inserted.

The *correct* scale for each is that given under the title. The other is about 12 per cent. too small.

The numbers on Plates XCVI and XCVII should be reversed.

Volume XXV, p. 447, fifteenth line from top, "3 400 yards" should read "400 yards."

ILLUSTRATIONS.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

518.

(Vol. XXV.—December, 1891.)

RED ROCK CANTILEVER BRIDGE.

FOUNDATIONS.

By S. M. ROWE, M. Am. Soc. C. E.

WITH DISCUSSION.

As a formal report has already been made to the Atlantic and Pacific Railroad Company, through its General Manager, D. B. Robinson, the purpose of this paper will be to outline the history of the construction of the bridge; the causes that led to its construction, and to give all facts that may be of interest to the civil engineer and the scientist. The original line of the Atlantic and Pacific Railroad, when constructed in 1883, was laid in such a way as to skirt and traverse the valley of the Colorado River for a distance of nearly 8 miles, finally crossing that river about 2½ miles south of what is now Needles Station, on the California side. This point of crossing is 18 miles south of Fort Mohave, near which is fixed the southernmost point of the State of Nevada. Ten miles south of the original bridge, the river valley narrows into what is known as Mohave or Needles Cañon; so named from a small but rugged range of volcanic mountains on the Arizona side. At the head of this cañon is the site of the Red Rock Bridge.

The Colorado River rises in southern Wyoming, draining western Colorado, eastern Utah, a small portion of southern Nevada and eastern California, and about three-quarters of the Territory of Arizona. The drainage area is about 230 000 square miles, most of which is mountainous, consequently its water is always turbid, and the quantity of silt held in suspension and carried forward at the same velocity as the water, is very considerable, amounting, as determined by precipitation of numerous samples, to 1.56 grains per cubic inch of water. The silt when thoroughly dry is found to weigh 59.95 pounds to the cubic foot.

While most of the distance through which the river flows is across a desert, almost rainless (except on rare occasions in which storms of great violence occur), its tributaries rise mainly on the west slope of the Rocky Mountains, where heavy rains are frequent and where the snowfall is sometimes quite heavy. Large accumulations of snow suddenly set free by a sudden thaw or by heavy rain, owing to the great declivity of the land, will cause violent floods and correspondingly severe attrition both on banks and river bed, by which earth, sand, gravel and boulders will be carried forward.

To form some idea of the amount of silt carried forward, take the fine silt above mentioned, much of which is so fine that it requires hours or even days to precipitate it. In the high water of 1884, taking the record as given by Chief Engineer W. A. Drake, who estimated the maximum velocity at 8 miles per hour (which seems from more recent observation to be within bounds), and an approximate area of river at 48 500 square feet; then assuming 5 miles per hour as the mean velocity, giving 384 000 cubic feet of water per second, the 1.56 grains per cubic inch would give 7 900 000 cubic yards of earth, or 6 400 000 tons at 1 620 pounds per cubic yard for each twenty-four hours of that flood. Then taking 50 000 cubic feet per second (about the mean for the year) as the mean amount of water passing, we would have about 160 000 000 cubic yards per day. Add to this the movement of the heavier sands and gravel, which is constantly going forward (though at less velocity), both by the movement of sand bars in the river bed and from cutting away of the banks, and it will be seen that this river is a powerful excavator as well as disintegrator. The Grand Cañon stands as a notable monument of this. In the case in hand, the line, as built, was subject to the latter mode of attack, and from the great depth to which the cutting extended (20 to 40 feet), it was found impracticable to protect the road-bed.

The valley of the Colorado River, for a long distance above the Needles Cañon, is not more than 12 to 20 feet above the ordinary water level, and has been traversed to its bounds by the river channel, and no doubt will continue to be so. Indeed, quite radical changes are taking place yearly. The greatest flood occurs in June, and is usually due to melting snow in the Rocky Mountains; but rises of 3 to 5 feet may occur at almost any time in the season, and are liable to come with little or no warning, the source being so far distant that they do not correspond to the local weather indications in the least. The declivity of the river from Fort Mohave to the Needles Cañon, and for a mile or two into the cañon, is about $1\frac{4}{10}$ feet per mile, though probably greater below that point, as the river is quite narrow where it cuts through the Needles Range.

The volume of the river varies from a minimum of 5 000 cubic feet per second to probably 500 000 in extreme high water (elevation 469.6 to 500.5). While the danger from this was not unforeseen by the locating engineer, Mr. Lewis Kingman, its gravity was not fully appreciated. The line finally adopted was surveyed by him in 1880, and the cost was estimated at \$666 220, while the line then built was estimated at \$586 554, making a difference of \$79 666 in favor of the latter. The line *via* Red Rock, then designated as the lower crossing "C," was identical with the point of crossing selected by the Kansas Pacific engineers in 1867, and also by the Atlantic and Pacific engineers in 1871.

The experience of the six years since the completion of the original line was such as to again force the attention of the management to the necessity of some effective remedy, and a joint letter from William B. Strong, President of the Atchison, Topeka and Santa Fé Railroad Company, and E. F. Winslow, President of the St. Louis and San Francisco Railroad Company, was issued January 30th, 1888, directing A. A. Robinson and James Dun, Chief Engineers of the respective companies, to examine with regard to what improvement was necessary to put the line in proper condition.

Leaving out many minor matters relative to the improvement of bridges, buildings, track, equipment, etc., we quote from the report made by these two chief engineers representing the joint ownership of the road, so much as relates to the question in hand.

COLORADO RIVER CROSSING.

"One of the most serious questions which we have to report upon is the crossing of the Colorado River. We find upon examination, that the present line is unsafe; that a portion of it is below recent high water mark, and all of it is subject to the encroachment of the Colorado River, so that it will be impossible upon the present line to give you any reliable figures as to the present or future cost of maintaining the present line and bridge, except to say that we know it will be very great.

"The estimate for the change of line and the maintenance of the present crossing, as shown on Exhibit 'C,' is based on the highest water known, but it is possible that the data are insufficient to establish the true high water mark: in which case there would be a constant element of danger from this source, which is entirely eliminated by adopting the Red Rock Crossing line. During the last six months the river has encroached upon the line about midway between Powell and the present bridge, threatening the line for more than a mile. This action of the river is undoubtedly only the beginning of the working over of the bottom into a new channel, as is customary with rivers of this class.

"While the expenditure of forty or fifty thousand dollars at this time might protect the road during the year 1888, it is more than likely that the same expense would have to be incurred during 1889, and indefinitely thereafter, with the more than probable danger of having our line cut in two entirely, and traffic suspended several weeks or months. Under this condition of affairs we see only one remedy, that is, to place the crossing of the Colorado River upon a safe and permanent basis.

"Two plans suggest themselves; one of which is to build the line directly across the valley, instead of following up the middle of the valley as by the present line, and building your track upon this bank from the present bridge to the bluff on the east side of the valley; thence along the foot of the bluffs and connecting with the present line near Powell. This plan will enable us to use the present bridge for some time to come, by lengthening it 500 or 600 feet. The road could be built upon this new location for about $160 000. This, however, would leave us with the river to fight, to maintain the channel under the present bridge. This expense of maintaining the channel from year to year will continue, and would undoubtedly amount to several thousand dollars each year. In addition to this, the character of the Colorado River is such that it is almost impossible to maintain a channel at any fixed point. The river is a navigable one, and the bridge is built upon a low grade line. The draw span is not serviceble, because the main channel of the river passes under the bridge several hundred feet from the draw. As a result of this you are paying a steamboat company now plying the river, $500 per month, because of the obstruction of the river by our bridge, and are unable to let boats pass. This is a dangerous situation, and leaves the gate open for any enterprising individual to buy an old rotten tub, and dispose of it to advantage by blackmailing the railroad company. The amount which we are now paying this steamboat company, namely, $6 000 a year, represents the interest on $100 000 at 6 per cent. The chances are, as we have intimated, the day is not far distant when more will be demanded.

"These considerations have led us to the conclusion that we can only say that the best course to pursue is to reconstruct the line for about 13 miles, crossing the river on a high grade line at the Red Rock crossing, about 9 miles below the Needles Station. This would put the line forever upon a safe basis and stop the further expenditures for protecting your road-bed and bridges against the river and for damages to navigation, and, in our judgment, is the only safe and wise course to pursue.

"We could not, of course, construct this bridge in time for the freshet of 1888; consequently, the expense of maintaining your present line during this season would have to be incurred. What this will be no person can tell until the freshet comes. The work which has already been done, seems to us to have been judiciously done. The money has been well expended, and is all that can be done until the high water season develops what further expenditures are necessary.

"Exhibit 'C' herewith gives you an estimate of the cost of reconstructing this 13 miles of road and the permanent bridge, and also the cost of rebuilding and putting in a permanent structure on the present bridge site and changing the line from Powell as above indicated.

"We would recommend that in doing this work, the grading be contracted for completion by the 1st of August; that the contract for the bridge be made for delivery on the 1st day of November, and that the track be laid to the bridge by the middle of September; that the work upon the masonry for receiving the superstructure be completed on November 1st, and that the bridge be erected and ready for traffic by January 1st, 1889. It is possible that the expenditure might be delayed, and the interest on the investment saved for three months more, but considering the difficulties liable to be encountered, the distance of the undertaking from market, and the extreme heat* which prevails in that climate, we think the plan should be laid as above indicated, to make sure of having the structure completed in ample time for the freshets of 1889. Thirteen miles of new steel will be required on this work.

* Heat; maximum atmospheric 124 degrees Fahr.; of sand, 135 to 145 degrees, and metal 165 degrees; minimum atmospheric, + 26 degrees Fahr.—*Rowe.*

NOTE.—During the summer of 1888 the river encroached both above and below the bridge, and with 3 feet more water, the line would have been lost and the river channel would have crossed the line about 3 miles east of the bridge. Luckily the summer flood was less than usual; notwithstanding this, the track was saved only by an expense of over $500 per day for over a month.—*Rowe.*

"We are sorry, indeed, to have to recommend to you the expenditure of so large a sum of money. We are certain, however, that a great mistake has been made in locating the line upon its present road-bed, and so we believe that the only course now open for this company is to rectify this mistake; that to continue to maintain the road-bed in the present position will only result in loss and disaster, which will be many times greater than the work of placing the line upon the proper location. There is no question whatever in our minds, but that this is the proper course to pursue."

The river bed had been examined systematically by Louis Trainor, Engineer of the Southern Pacific Railroad Company, in 1881, at which time that company was engaged in building eastward from Mojave. The maximum depth at midstream to reach rock was made about 30 feet, and it was assumed that by using a 400-foot span at midstream, the depth of foundation would not exceed 24 feet.

COMMENCEMENT OF SURVEY.—On July 2d, 1888, the writer received orders to make a survey and estimate of the proposed line crossing at Red Rock, and on the 4th walked over a portion of the line, making 15 miles, and on return to Needles Station at 6 P.M., found the thermometer standing at 122 degrees Fahr. This is simply mentioned so that the conditions may be to some degree appreciated by those unacquainted with the climate of that locality. The surveys were prosecuted vigorously, and only the river soundings remained to be done; these only awaiting arrival of appliances ordered and the subsidence of the summer flood, now about passed. On September 14th, in response to urgent request from the management, the following report was transmitted through the General Superintendent, A. A. Gaddis:

PRELIMINARY REPORT OF SURVEY OF RED ROCK LINE.

"ALBUQUERQUE, N. M., September 13th, 1866.

A. A. GADDIS,

General Superintendent.

I submit, in accordance with your directions, contained in your letter of July 2d, a report of survey, estimate and map (Plate CXI) of the proposed change of line, and of crossing of the Colorado River at Red Rock, as recommended by Messrs. Robinson and Bond, in their report submitted to Presidents William B. Strong and Edward F. Winslow, in February of the present year.

The Line.—Commencing at Station 14 571 + 41, a point 3 050 feet west of mile-post 562, or mile 562.6 of the main line of the Atlantic and Pacific Railroad; we run immediately across the Sacramento wash, and supporting on the side hill we reach the river immediately opposite to what is known as Red Rock. Crossing the river, we are obliged to curve at the earliest practicable point, to avoid precipitous hills, using 9 degrees curvature, being the lightest practicable. Thence we run up the edge of the river valley, keeping at all points above extreme high water marks, and avoiding possible attack from the river, and, at the same time, keeping the grade line sufficiently above the beds of the washes from the hills west to insure the passage of water under the track. We connect again with the present main track just west of the present bridge, at Station 312 + 81.5, at a distance by present line from the point of starting of 54 156.9 feet, having run by the new line 70 184.6 feet, making an increase in distance of 3.036 miles. A preliminary profile is herewith submitted, showing curvature and grades, hastily laid, from which to deduce approximate quantities.

Before proceeding with work the line should be slightly shifted in several places, and the grades revised. The approximate quantities given I feel quite sure will be somewhat reduced in construction, but will serve as a basis of estimate. The desire to save any unnecessary expense and not to delay the transmission of this report impels us to submit the matter in a less perfect state than is desirable. Most, if not all the items are intended to be above, rather than below what the actual cost should be.

Grading.—In estimating the cost of grading, I assume that 20 cents per cubic yard for waste and borrow; 26 cents for excavation hauled; 64 cents for loose, and $1 for solid rock excavation, and 1½ cents per cubic yard hauled 100 feet, will be a fair estimate for this work. The quantity of solid and loose rock will be small.* In view of the approach of the favorable season, these figures can probably be shaded somewhat. Water is convenient and supplies in easy reach. A detailed statement of quantities is appended.

Pile and Trestle Bridges.—Owing to the numerous washes making into the river, particularly on the west side of the river, the amount of pile bridging will be large. I think there is no place (case) where piles cannot be driven. It will require about eighty pile bridges, varying from 30 to 345 feet in length, with a mean height of 10 feet in the clear. These I would estimate at $6 per linear foot.

Iron Bridge at Red Rock.—It was intended to make full and careful soundings of the river bed at the line of crossing, but as it required at the present stage of water, expensive equipment and considerable time, it was deemed best to rely for preliminary estimate on the soundings made by Louis Trainor in 1881. These soundings were made under very favorable circumstances, the river being, at that time, nearly 6 feet lower than at present.

As the rock in question, on which it is proposed to build, is a volcanic "breccia," forming a dyke across the river at this particular place, the

* Most of the material to be moved is sand and loamy clay, and in no case marshy.

depth is liable to great variation, even in the length of the pier (about 60 feet); and I would advise careful examination by sounding before the line is fully established across the river. A slight shifting may be very advantageous and save much expense. The river is gradually falling, and where a great volume of rapid flowing water was passing two months ago, to the depth of 20 feet, is now a mass of sand and mud with not over 8 feet of water at the deepest point.

Plan of Bridge.—I submit plans for piers for the channel span, which may prove too light. I will examine them later with reference to this. They will be exposed to the force of water and drift only, as there is no ice in the Colorado River; but at extreme high water this will be considerable, as the water has at some time—years ago—attained a depth of from 50 to 60 feet, and a very high velocity.

Stone for Masonry.—I think the Chino stone should be used and the masonry should be first-class, laid with the best cement. The English Portland can be bought, I understand, at San Francisco, for \$3.50 per barrel; adding freight, 50 cents, would deliver it at the Needles for \$4, being about as cheap as domestic cement could be laid down at that point, and it will, I think, be most economical and give the best results for the cost.

After October 1st, on and until the May following, the river will be low, and I think there will be no serious obstacles to prevent the sinking of cribs for the two channel piers and the erection of the falsework for raising the bridge. The work cannot be delayed after the 1st of October or possibly a month later. From May 1st until about the present time it is impracticable to undertake such a work.

Relating to Erection of the Bridge.—I would advise the building of the line from the Needles south to the bridge site, as material can be delivered on west side of the river more conveniently.

In relation to the 396-foot channel span there might be a saving by using a shorter span, but the manner in which the channel shifts would seem to indicate it as being safer than a shorter span. From my observation of the river during high water, I think the span, as located, will always cover the main channel.

Superstructure.—By courtesy of the Keystone Bridge Company I am able to give their maximum figures for the erection of the superstructure of the bridge and the iron trestle approaches (Plate CXII). The quantities given for the masonry are the contents of the piers as shown by plan. The price assumed at \$12 per cubic yard seems high, but I doubt whether Chino stone can be put in any cheaper, as it is as hard and nearly as heavy as granite.

A sketch for a caisson is submitted (Plate CXIII), showing a section across a pier and manner of weighting it down (Plate CXIV). My estimate for 886 cubic yards of beton is for this purpose and to fill the inner space when the pier is completed. As you will perceive, this will increase the base of the pier at least 3 feet on all sides, and obviate largely the necessity of riprap. I think the weighting in this manner is the best, as it strengthens, and at the same time renders the wall of the caisson watertight.

GRADING 13$\frac{1}{10}$ MILES:				
Embankment	261 316.8 cubic yards, at	20 cts.,	$52 269 36	
Excavation hauled	72 968.6 " "	" 26 "	18 971 84	
Loose rock excavation	2 332.7 " "	" 64 "	1 492 93	
Solid rock excavation	6 529.4 " "	" $1	6 529 40	
Excavation hauled 100 feet	534 778.9 " "	" 1½ "	8 021 69	
Total				$87 285 22
Pile bridges (78) aggregating 7 185 linear feet, at $6 per linear foot				43 110 00
MASONRY:				
Bridge masonry	4 212.73 cubic yards, at	$12,	$50 552 76	
Pedestal masonry	115.22 " "	" 15,	1 728 30	
Cement, E. P.	2 165. barrels,	" 4,	8 660 00	
Total				60 941 06
FOUNDATIONS:				
Cost of two caissons			$5 826 00	
Labor and machinery sinking foundation			10 500 00	
Labor on other piers and abutments			3 000 00	
False work for bridge			9 500 00	
Total				28 826 00
Beton for filling cribs, 886 cubic yards, at $8				7 088 00
SUPERSTRUCTURE:				
One span, 396 feet, at $160 per linear foot			$63 360 00	
Two spans, 195 feet 8½ inches, at $89 per linear foot			34 818 58	
281 linear feet iron trestle, at $33.60			9 441 60	
Total				107 620 18
Engineering and exigencies				15 000 00
Freight on iron, Albuquerque to Needles, 975 tons at $5.76				5 616 00
Freight on Chino stone, 9 100 tons at $1.42				12 922 00
Then add as per report of Messrs. Robinson and Bond—				
3 miles new steel rails, 60 pounds			$16 060 00	
9 500 new ties, at 72c.			6 840 00	
Laying and surfacing 13 miles track			10 000 00	
Total				32 900 00
Grand total				$401 308 46

(Signed) SAML. M. ROWE, Resident Engineer.

Following the transmission of the foregoing report, the location of the line was completed except in the immediate vicinity of the crossing of the river, and requisitions were made for machinery, boat and cable necessary to do the sounding; but in view of the considerable cost of the appliances and in the absence of any knowledge whether the work was likely to proceed, the local management hesitated to incur the expense, hence this part of the work was delayed until orders were received to let the work. The only thing then practicable was to presume on the correctness of the Trainor soundings, and so let the work, providing for such changes in the bridge structure as circumstances would make necessary. Facing the necessity of prompt action, to be able to finish the bridge before next season's high water (it now being the 20th of November), it was decided to employ Waddell and Jenkins, professional men at that kind of work, and possessing the necessary appliances, to do the sounding. Mr. Jenkins of this firm was promptly on the ground and proceeded to vigorously prosecute the boring. At the first test boring at station 193 + 75, where it had been planned to locate the west channel pier, it was found that instead of 22 feet to bed rock, the drill passed with but little interruption, to a depth of 64 feet. Meantime, the grading was let and well under way and the superstructure and substructure, both let provisionally; the former to the Phœnix Bridge Company, the latter to Sooysmith & Co. On making this discovery, all proceedings under these contracts were stopped and a thorough examination of the river bed was arranged for with the contractors for the soundings. Orders were issued to make a sounding every 50 feet so as to develop a complete section of the river on the line fixed upon. These soundings were completed January 1st, 1889.

When it became apparent that the Trainor soundings were entirely unreliable, and while the new conditions were being developed by the progress of the soundings, various combinations, using various lengths and numbers of spans, were carefully compared and the cost estimated approximately. While the plan seemingly best adapted to all the conditions of the case—that of two through spans of 405 feet each—did not largely exceed the cost of the various combinations of shorter spans, yet two considerations following were regarded as formidable in the opinion of the writer hereof, who at that time filled a subordinate position with relation to this work. In the first place, spans of such unusual length would be heavy and require a much larger amount of metal, and necessitate the maximum amount of masonry, as all the piers would have to be built to the grade line nearly 80 feet above low water, and to proportionately increased dimensions. This for the reason that the depth from grade to high water was insufficient to allow either span to be used as a deck span. In the second place, taking the known history of the river and the depths to bed rock at the point where the pier at midstream would be, it would be subjected to unusual stress from the great depth of water flowing at the excessive speed of 12 to 14 miles per hour and to a depth of nearly 100 feet. There is good reason to believe that the scour at that point has reached almost to the surface of the rock and that this probably occurred in the nowise extreme flood of 1884. The records of the Trainor sounding of 1881 certainly indicated that a stratum of boulders similar to that found in sinking the caisson at Station 189 + 25, did at that time extend entirely across the whole bed of the stream. By reference to Plate CXVI, it will be seen that the Trainor soundings and those of Jenkins conform very nearly, from the east bank to a point nearly one-third of the distance across the river (Station 190 + 50). The Jenkins soundings, however, found nothing of the kind beyond that point, giving plausibility to the conjecture that the flood of 1884 had removed all beyond the point mentioned. There is nothing above the line of the Jenkins soundings, except sand and gravel and a very few small boulders. Hence, while these objections were not deemed insuperable, yet it was considered best to survey the whole field before deciding. At the time that the chief engineers of the two companies visited the bridge site in February, 1888, the writer being present, suggested that, in view of the formidable character of the stream and the uncertainty as to foundation for piers in the river, the cantilever might be adopted. It was answered, however, that the cantilever was an expensive type of bridge, and if a foundation could be found at moderate depth, the truss would be cheaper.

When the Jenkins soundings had progressed so as to not only demonstrate the utter unreliability of those formerly made, but also to indicate that the foundation for at least one pier toward the east shore could be had at a very moderate depth, the question of the cantilever immediately recurred, and singularly enough, Mr. Waddell, agent of the Phœnix Bridge Company, came in response to a telegram, with a hasty but quite well digested plan for such a bridge (Plate CXVI). The span lengths were fixed and orders telegraphed to Mr. Jenkins to thoroughly sound a pier site at Station 189 + 25. While this was being done, the plan of the superstructure was made and checked over simultaneously at Albuquerque and at Phœnixville, by aid of the telegraph, and on December 29th, 1889, a proposition was received from the Phœnix Bridge Company of a pound price as had been provided in the provisional contract, just four days after the matter was taken up.

Numerous soundings were made at and about the proposed site, and by the order of the writer, one center boring was pushed down so as to determine, if possible, the character of the rock. This was done and the depth of the boring into the rock below the surface reported at 5 feet. The rock increased in hardness to such an extent as to prevent further progress with the drill. The depth below low water did not exceed 14 feet in the borings on the outskirt of the site, or a mean depth of 12 feet for the foundation.

The plans for the substructure were prepared immediately and work was at once commenced by Sooysmith & Co., under an amended contract. The specifications were prepared by Consulting Engineer Prof. S. W. Robinson, of the Ohio State University, with the assistance of Prof. J. A. L. Waddell, on the part of the Phœnix Company, and by him accepted on the part of that company. The presumption being that it would be very difficult and expensive, if not impossible, to maintain the old line through the coming summer of 1889, everything was done with a purpose to complete the bridge by May, or, at furthest, June, of that year.

In this connection it may be said that the adoption of the cantilever was justified, even if more costly than the two spans of through trusses (which it was not, there being nearly $60 000 in its favor), the bed of the stream being such that no prudent builder would take the risk of maintaining falsework during the season of high water, into which the work must, from the lateness of the time of commencement and the dimensions of the work, probably extend. Although, for causes hereafter stated, this danger was escaped in 1889, yet in the following year the wisdom of the plan was fully vindicated, as will be shown hereinafter. Then again, when the constantly shifting channel with reference to navigation, rendered it uncertain where the channel would be during the season of low water, one of the two plans became necessary to avoid the heavy demurrage by boat owners; that is, either the two through spans or the cantilever; and the former is still open to complaint during high water as a dangerous obstruction in the rapid river. Indeed, complaint was made to the Secretary of War in April, 1890, about the time the bridge was being completed, that the present structure would obstruct the navigation of the river; and Major W. H. H. Benyaurd, of the United States Engineers, was detailed to investigate. While the report has not yet been received, Major Benyaurd expressed his conviction to be, "that a plan better adapted to provide for unobstructed navigation could hardly be devised." To still further show the wisdom of the course taken, it may be here noted that the June rise of 1890, did carry away the falsework used for erection of the east anchor arm, although very heavy and strongly built; happily, however, after the erection had progressed beyond the point of danger therefrom.

In January, 1889, a contract was made with Sooysmith & Co., whose pneumatic plant was arriving at the site, to build the masonry and the concrete anchor piers, and to sink one caisson at Station 189 + 25. For the masonry and concrete work the prices were not changed, as, while the amount of masonry as contemplated in the original contract was very much reduced, on the other hand, the amount of concrete work was considerably increased. The caisson, 28 x 57½ feet, was built in place by the aid of the protection of an artificial breakwater, and sinking commenced. At the same time the contract for the cantilever and the viaduct approach was closed with the Phœnix Bridge Company, and arrangements made to prosecute the manufacture of the metal with the utmost speed.

The cantilever, as planned, was proportioned to conform to the grounds, the position and character of which in a great measure governed the economic location of the piers. Dividing the structure into two anchor arms of 165 feet each, and making the cantilever arms of the same length and the suspended span of even 330 feet, allowed the east anchor pier to be placed at low water level on solid rock at the east water edge; the west main pier, the same at the west water edge; the west anchor pier at the proper distance back and on a rocky ledge; and brought the east main pier on what was then deemed the best and most westerly location practicable without largely increased expense. It was generally conceded that the excessive length of 330 feet for the suspended span was not exactly the most economic; this was especially so claimed by Professor William H. Burr, Engineer of Construction for the Phœnix Bridge Company. After consideration, it was decided, for reasons above given, to adhere, however, to this arrangement, in which action Professor Burr readily concurred.

The following is given from the computations by Consulting Engineer Professor S. W. Robinson, showing that the objection to the span length as being uneconomical, had but little weight as compared to the cost of sinking to a foundation at greater depth both in and at each bank of the river.

"For the case that the center suspended truss is 330 feet or 275 feet, respectively; otherwise the same, except to be equally well proportioned for carrying the loads; we find that with the center span 275 feet, the whole bridge will weigh less than if it be 330 feet by 18.29 tons of metal, or there will be a less cost of \$2 194.80 at 6 cents per pound. The principal figures run about thus:

	330 feet.	275 feet.
Weight center trusses without track or floor—tons	271.42	180.81
Difference—tons		90.62
Weight cantilever arms, not including track or floor or details common to both—tons,	402.04	447.00
Difference—tons	44.96	
Maximum moment at one main pier—foot tons	591 175	82 498.8
Per cent. of excess in anchor arms for 275 feet center		5.72
For center span of 330 or 275 feet:		
Weight of supporting members of anchor arms—tons	478.5	505.87
Difference—tons	27.37	
Total advantage for 275 feet center—tons...		90.62
Total disadvantage—tons	44.96	
Difference in favor of 275 feet center = (90.62 — 72.33 = 18.29) 27.37	27.37	
	72.33	90.62."

Then again the question was raised as to the proper distance between the trusses. While at the time of making the design the same conclusion had been arrived at independently both at Abuquerque and Phœnixville, viz.: to fix this at 25 feet, center to center; and work had reached such a state of progress as to render it very expensive if not impracticable, to change the design; yet in view of the great interest in the work represented by the party raising the question, it was determined to submit the matter to some undoubted authority. This was done with no purpose on the part of the writer (at this time Chief Engineer) to change the design, but with the hope of settling the question to the satisfaction of all concerned, as to the correctness of the conclusions arrived at by the designers, originally. Indeed, with the large amount of work already done on the superstructure, and the substructure also, as well as the question of time of completion of the bridge and the danger threatening the traffic over the line, by which the loss, direct and indirect, would amount monthly to a very large sum, the question of change could not be entertained. The question was, however, settled to the general satisfaction of all, after full consideration. It is not claimed that the design is the very best possible, but taking into consideration the haste with which it had to be prepared, and the many points to be considered, the immense amount of computation and the amount of draughting and office work, it will do credit to all engaged. The simple, yet effective manner in which the suspended span is connected to the two cantilever arms, the nicety with which all expansion and contraction is provided for, the amplitude offered for lateral and transverse bracing, and the simplicity and effectiveness of the self-sustaining arrangements during erection, are some of the points that could be cited.

The following from William H. Burr, which is pertinent to this question, may be given here with propriety, as, while the Professor is connected in a business way with the Phœnix Bridge Company, still his standing as an authority on this subject will hardly be disputed.

"Abundant lateral stability is secured in an ordinary uncontinuous truss, if the width between centers of truss is taken at $\frac{1}{18}$ the span. In fact, engineers frequently make the extreme distance between truss centers for long spans $\frac{1}{20}$ the span length; but I think $\frac{1}{18}$ is a better limit, as giving greater lateral stability. Now, by a calculation, which is needless to give here, it can be shown that if the suspended span of a cantilever opening is $\frac{4}{10}$ of that opening, then a distance between the centers of a cantilever truss of $\frac{7}{180}$ of the total opening will give essentially the same stability (lateral) as that possessed by a simple uncontinuous truss of the same length as the total cantilever opening with its truss separated by a distance equal to $\frac{1}{18}$ the span. But $\frac{7}{180}$ x 660 equal 25.7 feet, and our suspended span is one-half of the total opening, thus permitting the trusses to be a little nearer together, *i. e.*, 25 feet, instead of 25.7. Again, the chord of the cantilever and anchor arms are about four feet inside measure, making the total width of structure 29 feet, and materially enhancing its stability. For all these reasons, I have no hesitancy in saying that the Red Rock cantilever trusses are amply far apart."

The Professor might have added the further fact of the peculiar form of the bridge giving less depth of truss than usual at center instead of greater, as is the case with ordinary truss. Wind stress being the agent feared, it is proper here to say that, while the design was being made, communication was opened with Lieutenant W. A. Glassford, then Superintendent of the United States Signal Service for the Pacific slope, who reported after examining the records of that department that—

"There is no record of wind so violent as to be characterized as a tornado, except in two cases, and in those the indications were that they were rather of the character of a sand gale."

At the bridge site, however, storms of this character are quite frequent, attaining a velocity of nearly 60 miles per hour, and frequently so strong as to stop work on the erection of the bridge. One occurring on the 27th of February, 1890, at which time the west half of the bridge was approaching completion, with the immense traveler on its long river arm, went very far to assure all observing the effect of the wind, that the bridge was stable. For the safety of the traveler it was lashed to the bridge, but the latter showed but a slight tremor. It had been proposed to stay the bridge with guy-lines to anchor cribs in the river, but it was found unnecessary to do so. Observation shows that the Arizona or Southern California wind storms, though severe, move with a steady flow, with scarcely a lull for hours at a time, and do not produce those sudden gusts that are found so destructive farther east. Indeed, what is known as the tornado or hurricane, is scarcely known west of the Continental Divide, or for several hundred miles eastward. While the usual provisions were made for wind stress, still there are less grounds for anxiety at that point than farther east.

Owing to the greater variation of temperature, unusual care had to be taken to provide for expansion and contraction of the metal. The lowest atmospheric temperature at that point is 26 degrees Fahr., and the highest, 125 degrees, making a range of about 100 degrees, causing a total difference in the length (660 feet) of the span between main piers of about 5¼ inches (using co-efficient .00000663 per degree Fahr.). The bridge resting entirely on the two main piers, with the suspended span supported from the cantilever arm by four large eye-bars at each end, and with the lower chord telescoping after erection wedges were removed, this expansion is provided for, half at each end. At no time under this range of temperature can any stress be exerted on the main piers. The expansion on the anchor arms is provided for by a slight rocking motion of the long anchor bars which turn on the anchor pin at the bottom of the anchor pier. The possible danger from a cold weld, should it occur on these piers, is provided for by slightly increasing the size of these eye-bars, beyond that necessary to bear the direct stress of the bridge.

While iron lying in or upon the sand, will absorb heat by exposure to the direct rays of the sun to 165 degrees Fahr., still in the bridge structure, it will not go over 135 to 140 degrees Fahr. This will not cut any figure, as there is an excess of some (over) 4 inches in the slotted chord, fully meeting such excess. Sand with the thermometer at 120 degrees in the shade, will absorb heat to 140 to 145 degrees, while water in the river rarely exceeds 60 degrees.

Resuming the history of the work: By the 16th day of March, the work having been steadily and uninterruptedly pushed, the grading had been completed to the bridge site at both banks of the river; the Chino Quarry had been opened and most of the stone cut and conveyed to the site; the west anchor and west main pier completed and the caisson built, and the sinking of the same had progressed to the depth of 8½ feet. The metal for the anchorage had been manufactured and received, and a large portion of the metal for the bridge had been rolled and was in process of manufacture; in short, there was every assurance that the bridge would be completed in June of 1889, when an unexpected difficulty was encountered.

The caisson, at the depth then reached, uncovered a portion of the supposed bed rock, which was found to consist of a compact boulder bed. Further investigation showed that there were portions of it that could be penetrated by the drill, showing gravel and sand underneath. Work on the caisson was immediately suspended and every appliance in reach was used to determine to what depth this extended. Several holes were drilled to a depth of 64 feet or thereabouts, below low water, all indicating a thickness of 3 to 4 feet in this bed of boulders, with nearly 20 feet of what seemed to be mainly sand and gravel, and with boulders frequently encountered, but of too unstable a character to depend upon for the foundation of the pier. Below this to 64 feet was found quite compact, yet of the same general character. After repeated trials with the drills (2-inch) then used, nothing beyond the 64 feet could be penetrated; even with 3-inch casing with tools of the same size, but a foot or two more could be made. Thus it became evident that a much stronger caisson, sunk to a much greater depth, would be necessary, involving an additional expenditure of at least $100 000. The question of change of design could hardly be entertained for a moment, yet, in view of such a large addition to the cost, it was deemed best to at once refer the matter to the management at New York and Boston.

The facts in relation to the soundings, on which the design was founded, will be given more at length hereafter, not to fix blame on any party connected with the work, but to serve as a lesson for the future. If any mistake was made beyond what might be due to the haste in which the work was done and to the unusual circumstances of the case or to the conditions there existing, the writer is not aware of it. Heavier and more perfect tools and appliances in the first place, would have gone very far to avoid the failure. These were afterwards used and the true bed rock was reached after penetrating 20 feet of large, smooth and very hard boulders, a result not often accomplished.

Meantime, work on the caisson and on the metal of the superstructure was immediately suspended, and by request of Presidents E. F. Winslow and William B. Strong, on behalf of the St. Louis and San Francisco, and Atchison, Topeka and Santa Fé Railroads, joint owners, it was arranged to have the matter investigated by A. A. Robinson, Second Vice-President, and James Dun, Chief Engineer. These gentlemen proceeded at once to examine the condition of the matter, reporting (a copy of which report is here inserted):

"ALBUQUERQUE, N. M., March 24th, 1889.

E. F. WINSLOW, President,

St. Louis and San Francisco Railroad Company.

WILLIAM B. STRONG, President,

Atchison, Topeka and Santa Fé Railroad Company.

"GENTLEMEN,—We have made a careful examination of the site of the proposed bridge across the Colorado River at the Needles, and of all the data in the office of the Chief Engineer of the Atlantic and Pacific Railroad Company, going over the estimate of cost of the various plans that have been proposed; with the result that we, without hesitation, agreed that the best and most economical course to pursue is to make no change in the plan of crossing, except to provide a larger and stronger caisson on which to found the east pier, and sink it to the depth of 70 feet, with a possibility of having to go to a maximum depth of 80 feet below low water. We are both of the opinion that it would not be safe to sink the caisson to a less depth.

"The soundings that have been made this season show that the boulders found above this depth are in nests of very limited dimensions and that

NOTE.—Confirmatory of this deep scour, it may be mentioned that about June 1st, 1890, shortly after the new bridge was opened to traffic, one pier of the old bridge went out, throwing two spans into the river. When it is considered that the pier in question had a pile foundation to a depth of 56 to 58 feet below water, it will be seen that the possibility of scour to great depth is fully demonstrated.—*Rowe.*

they are of comparatively small size, varying from 6 to 24 inches in diameter; neither do these collections of boulders appear to be stable. We have examined the records of soundings made at this same place (point) for the Southern Pacific Company by Mr. Trainor in 1881. He was engaged for a month in making the soundings and has left full records of the same, and evidently intended to make a thorough search for the bed rock and thought he had reached it. We can only account for the wide discrepancy between the soundings made by him and those recently made, on the supposition that the bed of boulders which Mr. Trainor found and reported to be bed rock, was scoured out by the exceptional flood of 1884, and that fine sand and gravel replaced them. The comparatively small size of the boulders found in the caisson of the east pier shows conclusively that they are shifted about from one point to another at the caprice of the current, and that the fine sand and gravel in which they are imbedded, affords no reliable foundation.

"We have made as close and reliable estimates as the information at hand justifies of the cost of the three plans, which seemed best to meet the new condition of affairs.

"*First.*—A cantilever span of 830 feet, the piers of which would rest on the rock, which is exposed on both sides of the river.

"*Second.*—Two spans of 415 feet each, resting on a pier midstream (and piers on rock on each shore).

"*Third.*—To adhere to the present plan of a cantilever span of 660 feet, with the exception of sinking a larger and stronger caisson 30 x 60 feet outside dimensions, to a depth of not less than 70 feet below low water.

"The comparative cost of the three plans resulted in favor of plan No. 3, aside from damage claimed by the bridge company owing to the change of plan of the structure. This damage, the bridge company estimate, would be about \$50 000, which renders the consideration of any other plan than No. 3 inadmissible. It is almost certain that the high water will occur by the 15th of May, and there is not sufficient time to procure the additional material and sink the caisson in the short interval remaining. We therefore recommend that the contract on the anchorage piers be allowed to proceed, as the stone is all quarried and nearly all cut, while the force and plant to do this part of the work are now on the ground and could not be brought back without an increase in expense. An extension of the time for completing the superstructure should be made until March 1st, 1890.

"The additional material for the caisson should be delivered in September, 1889, so that it could be framed in that month and the work of sinking be started by October 1st, 1889. We find that an agreement has been reached with Sooysmith & Co., for adjusting the value of the work performed by them to date, on the caisson which it is necessary to abandon. The sum agreed upon is \$24 000, which we believe to be fair and just. The grading for the new line is completed with the exception of one rock cut at the west approach of the bridge. About two-thirds of the pile bridging is completed, the track being carried over on temporary cribs on the remainder. The track is laid and surfaced for the entire distance, except at the site of the bridge and through the cut above mentioned. The masonry for the west pier is completed and the foundation for the anchorage piers ready for the concrete. Nearly all the stone is quarried and cut for the masonry. All the work which has been done is first-class in every respect, particularly so as regards the masonry.

"The following estimate of cost of the bridge and road when completed is submitted, which we believe will be found to be in excess of actual results, viz.:

Engineering, etc.	$25 000
Grading	84 000
Pile bridging	48 000
Steel rails	12 100
Cross-ties	13 100
Track fastenings	6 500
Track laying	12 000
Masonry and foundation of west pier completed	14 700
Loss on abandoned caisson, east pier	24 000
Cost of new caisson, east pier, and sinking same	108 000
Cost of east pier	15 600
Cost of anchorage piers	33 600
Cost of superstructure, including iron trestle approaches	219 000
Cost of bridge floor	6 500
Allowance for freight charges on Atlantic and Pacific line	15 000
Total	$637 100

"In the above estimate it is assumed that the 10 miles of steel rails and fastenings on the present line will be credited to the new line, but no allowance has been made for salvage on cross-ties and bridges on the present line between Powell and the Needles. Attention is called to the high estimate of cost of the caisson for the east pier, and we would not advise contracting it for this sum, believing that, if put down at cost and a percentage (the latter limited to $12 000), the actual cost would be at least 10 per cent. below the estimate for this item. But desiring to cover all possible contingencies, we have deemed it best to make an allowance sure to cover the same. All of which is respectfully submitted.

(Signed) James Dun,
Chief Engineer,
St. Louis and San Francisco Railroad.

(Signed) A. A. Robinson,
Chief Engineer,
Atchison, Topeka and Santa Fé Railroad."

Formal notice was sent by wire notifying the Phœnix Bridge Company to suspend work on the metal of the superstructure on the 16th of March, and on the 19th the writer received instructions, as indicated in this report, with further direction to determine the actual depth to rock at the caisson site. The contracts with the respective contracting firms having been modified to meet the changed conditions, and the first caisson broken up and removed to avoid its being buried and forming an obstacle to further progress of the work, the work was suspended so far as referred to the bridge.

It is proper to review the question of soundings here, as this experience by which the whole progress of the work was stopped and the completion of the bridge was delayed for nearly a year with the cost of maintaining the old line in the valley, impresses itself as one of the first importance. Going back to the time of making the design, while the soundings at the pier site were being made and about to be completed, the following instructions were telegraphed to Mr. Jenkins on the 25th day of December, 1888:

"Kindly arrange to have holes drilled to considerable depths, both on the site at Station 169 + 25 and the site at west edge of river 194 + 90 to see if any soft material interposes."

On December 29th, Mr. Jenkins reports as follows:

"Herewith we hand you records of soundings made at Red Rock crossing; also profile of soundings at Station 189 + 25. In making these soundings we have been careful to report only what experience has taught us is the true 'bed rock,' or the proper foundation upon which to build, but as you well know, there is always room for variation in reporting soundings where the material composing the bed of the river is so varied in character as in the present case. On the west side bottom we are positively sure that the bed rock is of the same character as that seen outcropping near the water's edge, viz.: red breccia, very compact and hard, on the east side (*i. e.*, east half of river bed—*Rowe*) the bed rock is more irregular and not so readily distinguished, but is no doubt composed of two varieties of the concrete, the softer overlaying the harder stratum. We would recommend, therefore, for a pier say, at Station 189 + 25, that the excavation be made through the upper stratum of concrete to the lower or harder material in order to obtain a proper or safe supporting power. Although but few boulders were encountered in sounding (and those small ones and principally on the east side), it is always advisable to provide a special clause in the specification for boulders, particularly if pneumatic caissons are to be used in the construction of the pier foundation."

The following is Mr. Jenkins' record of the test drill at the pier site in question, sounding No. 23 at Station 189 + 25 in accordance with the telegraphic orders just noted :

Boring No. 23 at center Station 189 + 25 :

470.64	Elevation of water surface.
3.00	Water.
467.64	Surface of sand.
6.19	
461.45	Gravel (or drift), boulders and sand.
0.61	
460.84	Surface of breccia, red in color, hard and compact,
5.63	but easily broken up with drill.
455.21	Hard stratum of solid substance, probably "breccia" of same character as eastern shore.
9.80	to bed rock—15.43 to harder stratum.

The tools used by Mr. Jenkins consisted of a $1\frac{1}{4}$-inch drill, or what is termed the "jet drill," working in a $1\frac{1}{2}$-inch casing, for which ordinary wrought-iron pipe is often used. Steel pipe, however, was provided as being stronger. The drill rod was made of three-quarter-inch pipe, and the jet was furnished by a double lever hand force pump. This outfit being light, was well adapted to use in the river by aid of a light flat-boat, anchored at the desired spot, and was found to penetrate compact gravel readily, even passing directly through boulders of $1\frac{1}{2}$ feet diameter. Usually, however, it would either shift or turn the rock aside, or, owing to the elasticity of the casing, deflect to the most yielding side and so pass on.

Immediately on the discovery of the difficulty at the caisson site, heavier tools were made, 2 and 3-inch, and pending the decision as to what course would be decided upon, several holes were pushed down in and about the site. It was found that, while difficult to penetrate the first bed of boulders which were laid bare in the caisson, yet some hours of persistent labor would accomplish this, and the drill would proceed with little further difficulty until the depth of 64 feet was reached (elevation 406.00), when in every case the work would stop, either from breakage of the tools by long and persistent pounding or by the collapse of the casing.

In June following, heavier tools of much the same character were procured and placed upon a flat-boat; a No. 6 steam force pump, and an engine to run the machinery, were provided. The 3-inch tools were first used to the depth of 64 feet, before reached. The casing used was strong 3-inch wrought iron pipe, armed with a steel shoe to strengthen the end coming in contact with the work. Beyond this, however, progress was very slow and difficult; boulders were encountered at every move, and it is presumed, were in most cases cut through or broken, as they were imbedded in compact gravel cemented into a mass by a silicious cement, preventing any movement to allow the casing to pass. When the casing could no longer be driven, the 3-inch tools would be laid aside and a 2-inch casing and drill would be introduced inside of the 3-inch casing. This would be driven forward a foot or two until either the tools or the 2-inch casing would collapse; then withdrawing the 2-inch casing and tools, the 3-inch would be again resorted to. Thus foot by foot would be gained. The 2-inch casing, when withdrawn, would somewhat resemble the letter "S," becoming so distorted as to prevent the movement of the drill rod in it. During the whole progress from the first sand bed to the boulder bed, the jet would throw out a constant stream of clear, river washed sand, from which the cuttings of the drill were difficult to distinguish.

When, however, the boulder bed was entered, the cuttings became more plentiful, and the character of each stone passed through was as well indicated, almost, as if the boulder could be seen. Pure quartz, gneiss, porphyry, trap and the various types of volcanic rock and some very fair specimens of natural concrete were among the exposures (note at the time that this formation was afterward reached in sinking the caisson, bits of partly siliciureted wood were found above, on or near the boulder bed, which would indicate somewhat the great length of time this formation has occupied its present position).

Finally, on reaching 80.7 feet in depth, the sand thrown by the jet changed, or rather became highly colored and reduced in quantity, and then finally ceased, and well identified cuttings of the red breccia were obtained, identical with that outcropping on either shore. Thus, the first test hole was located at the 189 + 08, and 18 feet south of the center line of the bridge. Another was put down at the 189 + 50, about the same distance from the center line on the opposite side, of which it is unnecessary to say anything except that the same formation was reached, at $\frac{8}{10}$ foot less depth; otherwise the history does not materially differ.

In each case the bed rock was penetrated about 1 foot. In both the casing was so contorted by its encounter with large boulders, as to prevent further progress without undue expense. Indeed, the formation was so thoroughly identified as to render it unnecessary, especially as the character of the material below the elevation 406, as developed by all the borings, forced the conviction that it would be very difficult, if not impossible, to sink a caisson below that point. There are the best of reasons for believing that a caisson sunk half the distance, or to the elevation of 436, would have been entirely secure, as from that elevation, the boulders were found so numerous and so compactly embedded in cemented gravel, that it was highly improbable that the river would ever, in the lifetime of the bridge, come to that depth at that point.

The lesson taught may be of value in the future and in this connection every hint should be heeded and every event scanned. The fact mentioned by Mr. Jenkins as to the change of character in what was supposed to be bed rock, from that well identified on the west half of river bed and that found on the eastward, it can be seen should have cast suspicion on the conclusion drawn, as well as the very moderate depth, at a point so distant from the east shore. Again, the conformation of the river, by close examination of the vicinity of the bridge, as well as the character of its drift, should have indicated the probable presence of the accumulation of drift; while the conformation for a mile or two above would have sufficiently indicated its ancient character. By examining the map of the bridge site, it will be readily understood that the tendency of the channel is westward at that point, while the rock bound bank on the west side of river for a mile or more above, with the further influence of a large cañon entering the river above the head of the Needles Cañon on the same side, with its frequent discharge of drift including boulders of considerable size, tend to crowd the river channel eastward. The deep scour of the river must occur at time of extreme flood, at which time its course is most in conformity with that indicated on the map, and it is hardly possible that it should attack the pier site.

The soundings in the Colorado River were unusually difficult, both in consequence of the great depth, and the heavy, coarse character of the drift, to which were to be added the evanescent character of its quicksands and the violence of its current. From all those combined with the haste in which the work was prosecuted, it is only surprising that more mistakes did not result. Had the suggestion made at the time of making the preliminary report been followed, time and money would have been saved, as well as much embarrassment. The engineer must know what the conditions are before he can either plan or proceed with the erection of a structure of this kind with any degree of safety or credit. In any similar case larger and heavier appliances still than those last used would be safer, particularly when boulder beds are apprehended, as "well men" all know the fact that a formation of that character is the most difficult of all to penetrate.

For the benefit of others in the future, it is here stated that it was found that a water pressure of 18 to 20 pounds on the jet was the best; a heavier pressure would raise gravel and fragments of rock to such extent as to impede the free stroke of the drill rod. With softer rock, perhaps a less pressure would be necessary. The sands as well as the rocks in the Colorado River are nearly 15 per cent. greater in specific gravity than those of other localities farther east. And further it may be said, that in work of this character, extreme care must be taken to not overstrain the tools, thus incurring breakage or disconnection of the drill rod coupling. It was found that by changing drills and reconnecting the rods every five hours, work could be safely and steadily prosecuted, while any disregard of this precaution would result in a job of fishing, the nature of which every experienced drill man will appreciate.

The result as above having been attained in July, 1889, the material for the caisson was ordered and received, so that in the latter half of September, the work was again resumed; the tramway (Plate CXVII) by which the caisson site was reached was partially rebuilt, about 200 feet having been swept out by the high water of June; 20 feet depth of the river bed having been swept out and again replaced, as the river subsided. On November 21st, air was put onto the caisson and kept on continuously until February 11th, when the filling of the caisson was completed, resting on the boulder bed at elevation of 409.00. The sinking progressed steadily from the first, and the corners did not get out of place to exceed 4 or 5 inches either longitudinally or laterally, during the whole progress of sinking. The material proved even harder and more firm in character than was inferred from the boring. Owing to the unyielding character of the material surrounding the caisson, comparatively a small

PLATE CXVII.
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PLATE CXVIII.
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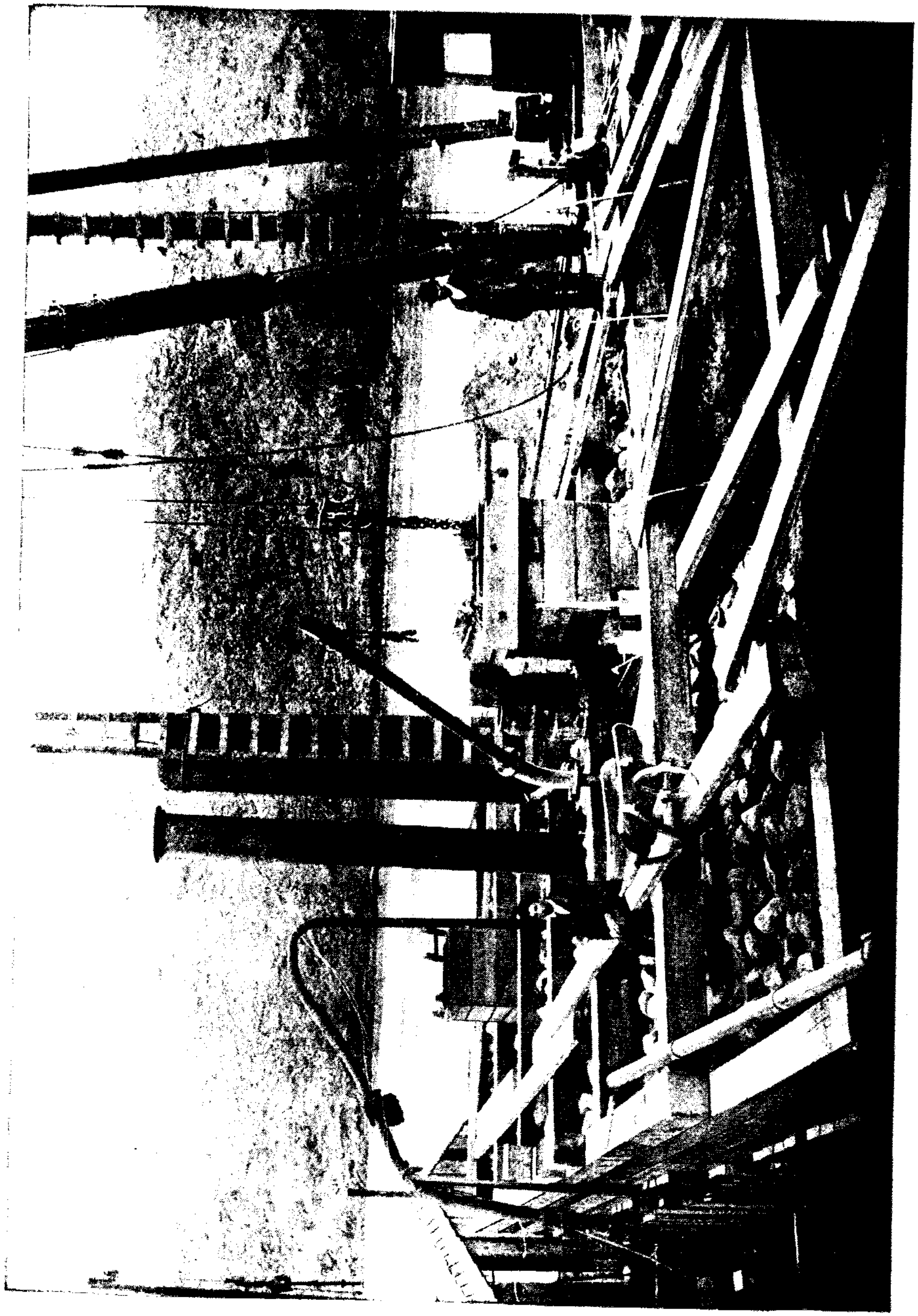
RED ROCK CANTILEVER BRIDGE.



amount of excavation was made beyond its area. The caisson, a plan of which is shown in the photograph (Plate CXVIII), was carefully and strongly built, and measurements made at the time of sealing, showed that it had borne the strain with scarcely any distortion. The table appended gives a history of the progress in sinking.

To determine in advance just when to stop the crib and commence the footing courses of the pier, was very difficult. In order to reach elevation 406 required that a portion of the pier should be built, as the great distance through which the caisson had already sunk through rough, unyielding material caused great friction on the sides of the crib, and made it necessary to withdraw almost or quite all the air pressure to move it. It was decided to stop the crib at a height that would put it about 4 feet below low water, so that the timber would not be exposed; but at the same time, to crowd the caisson down to 406 or possibly 2 feet more to 404. To do this, it was found necessary to put on all the footing courses and about one-half of the neat pier, and afterward lay temporarily two additional courses. Notwithstanding this, the caisson failed to settle beyond 409. After repeated trials to cause it to do so, and after making a thorough examination of the foundation, it was decided to excavate from 2 to 2½ feet all around under the cutting edge, which could readily be done, the wall standing perfectly firm, and follow with the beton in sacks until it reached the cutting edge at every point, which was done. The center was then excavated and sealed, followed by filling the working chamber. The caisson was already about 5 feet into the boulder formation at the northeast, 3 feet at the northwest, 2 feet on the southeast, and down to it on the southwest corner, indicating that its surface sloped to the southwest. The excavation made and replaced with "beton" fully reached the firm foundation at all points, and over the whole extent of the chamber. The boulders formed the greater mass of the underlying stratum and were bedded compactly, so that in excavating, each separate stone had to be picked or pried loose. While the chamber was being sealed there was a steady daily subsidence of the caisson of about .05 feet, but when the beton reached the cutting edge, this ceased and no further settling occurred up to the time of completion of the bridge. This movement was utilized to right a slight tilt of the pier to the west by sealing that side first. The slight remaining tilt was taken out in the subsequent courses of masonry and the pier finished systematically, although slightly larger than designed. It might have been possible to spend a larger sum of money in trying to force the caisson lower, but the author doubts if it was possible to do so, and no good end would have been subserved. The top of the crib is about at the level of extreme low water.

Of the material used, each part will be treated in its turn. A record of the progress of the work of sinking the caisson is given in Appendix "A." The timber used for the caisson and crib consisted mainly of what was termed Oregon pine (yellow fir), a most excellent timber, strong and firm, though somewhat coarse grained, which weighed 35 to 40 pounds per cubic foot when well dried. The amount used in the different parts was about as follows:

	Cubic Feet.		Feet, Board Measure.
Working chamber, including 3 inches inside casing	6 880	=	82 560
Roof, 8 feet thick	12 992	=	155 904
Crib, including 3 inches casing outside	20 071.5	=	240 855
Making total amount of timber (neat)	39 943.5	=	479 319

Iron bolts, stay and drift and steel spikes 29 tons = 58 000 pounds.

Concrete (beton) put into crib, 47.7 cubic yards per running foot	2 290	cubic yards.
Concrete (beton) put into working chamber	580	"
Total	2 870	"

weight at 4 050 pounds per cubic yard, saturated.

Timber at 35 pounds will absorb water to nearly 80 per cent., so that the timber at 35 pounds when dry, and absorbing 80 per cent. (= 8 x 35 = 28), will weigh 35 + 28 = 63 pounds per cubic foot, or have about the same weight as water. Then taking the caisson at the time it stopped we have, 10 800 square feet of surface on which the pressure of the material outside tended to produce friction; the excess of the weight of the concrete in the crib over the displacement of the water, which, being 101 203 cubic feet, at 62½ pounds per cubic foot, weighed 3 162 tons. At this time there were also 125 cubic yards of masonry on the crib, equal to about 800 tons. Therefore, we have—

2 290 cubic yards of beton in crib =	4 637.25	net tons.
125 cubic yards of masonry	804.00	"
Total	5 441.25	"
Resisting this is the uplift of the water	3 162.00	"
Leaving the downward pressure of	2 279.25	"

PLATE CXIX.
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RED ROCK CANTILEVER BRIDGE.

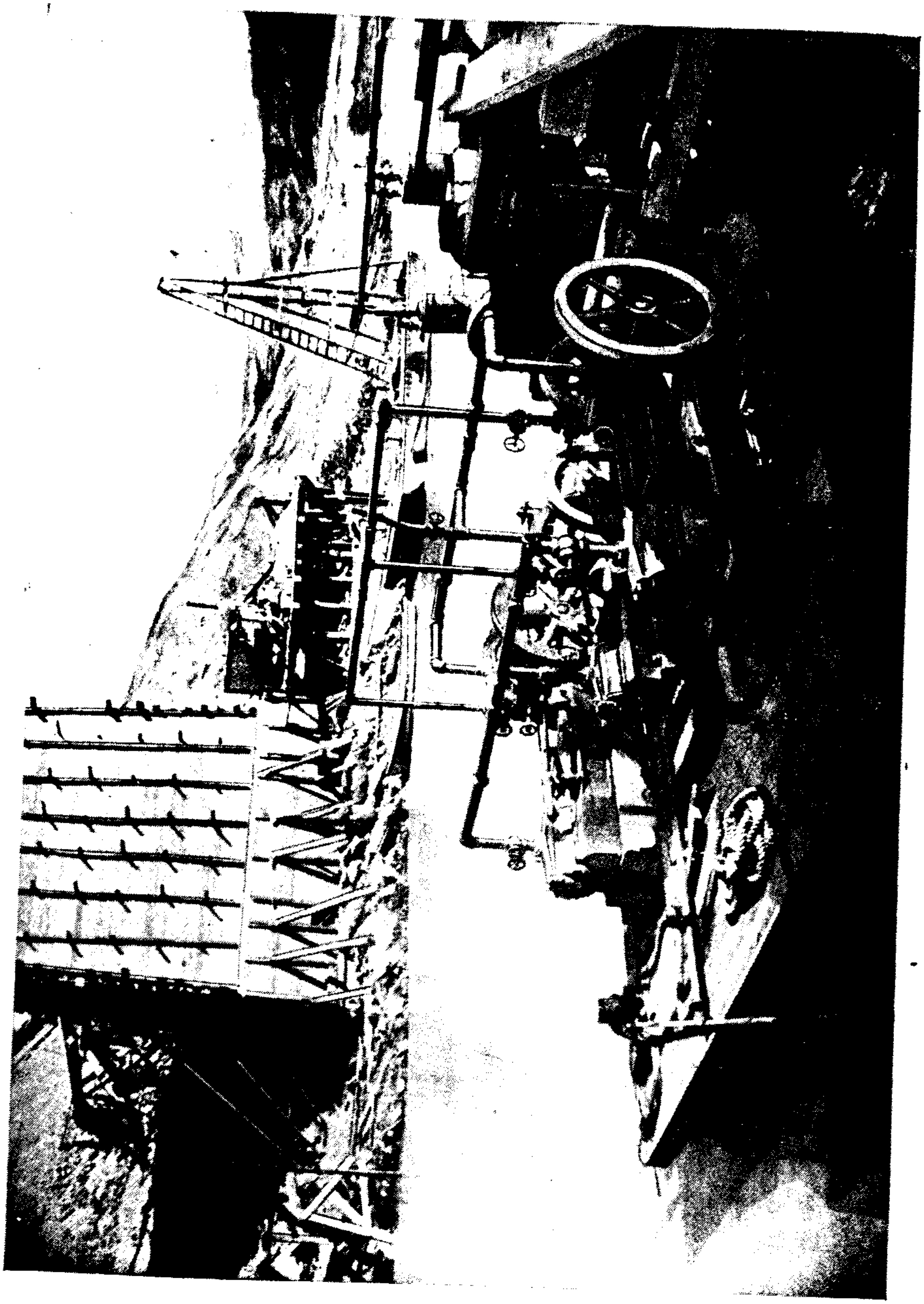

PLATE CXX.
TRANS. AM. SOC. C. E.
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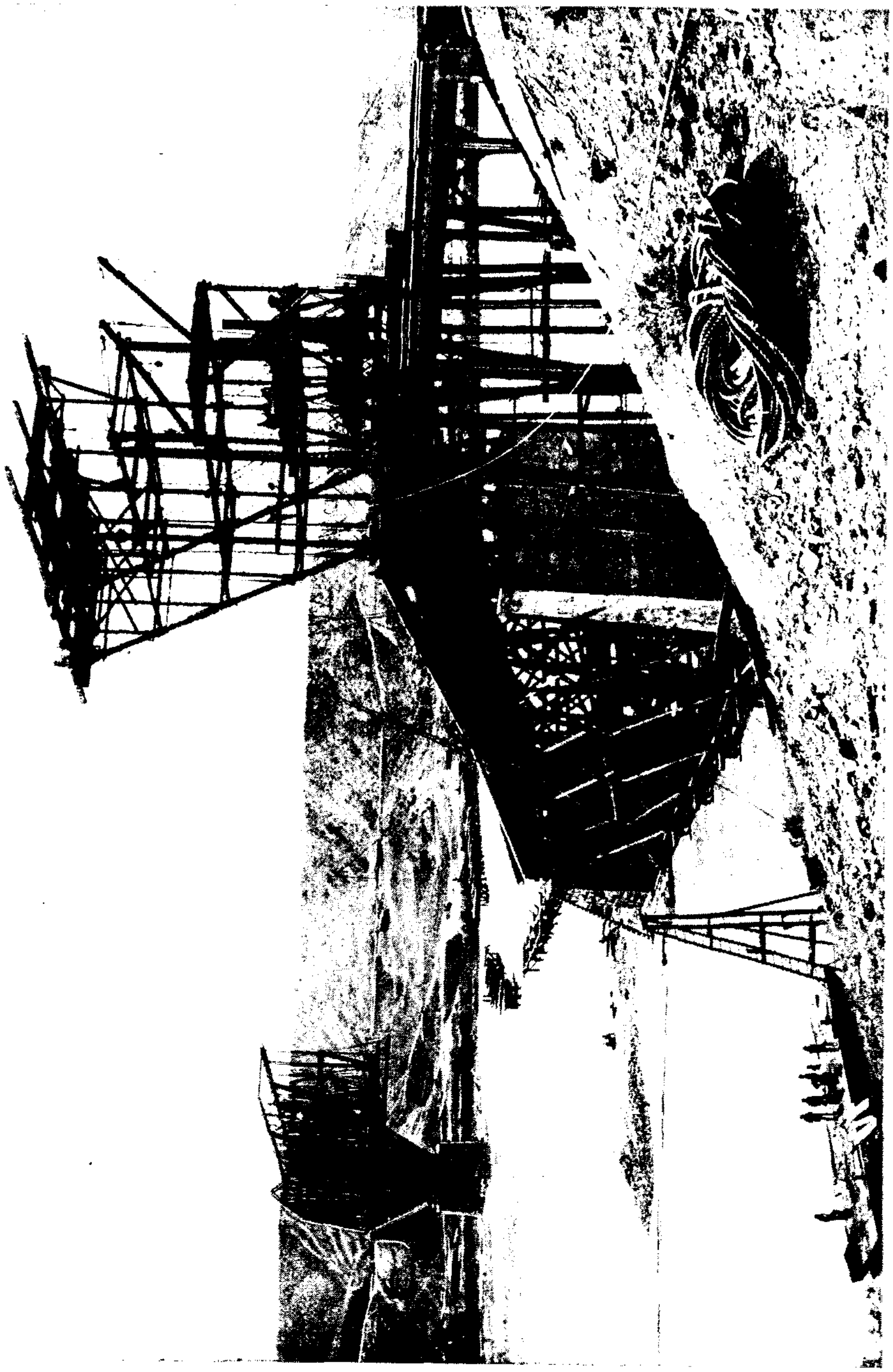
RED ROCK CANTILEVER BRIDGE.



equal to about 420 pounds per square foot when the air pressure is entirely off. When the air was on at 27 pounds per square inch, this tendency downward was entirely overcome. The air was entirely and repeatedly removed toward the close, and much of the surrounding material drawn. In ordinary sand and gravel the caisson could have been pushed to any depth desired. It is presumed that boulders were crowding between the pier walls of the excavation and the sides of the crib to such extent as to sustain it, notwithstanding the sudden release of the air, causing the sudden application of the 2 000 tons as before stated.

The whole resistance was below the elevation of 440.00, where the material was all of hard, firm gravel and boulders. The following will give much information as to the relative cost of sinking, taking labor roll alone:

November, 10 days, total roll......	$2 611 72	Depth made 9.94 feet, mean cost per day $261.18, per vertical foot.....	$262 75
December, 31 days, total roll......	10 026 05	Depth made 23.38 feet, mean cost per day $323.42, per vertical foot....	428 83
January, 31 days, total roll.........	10 710 50	Depth made 26.80 feet, mean cost per day $346.83, per vertical foot.....	*400 00
February, 11 days, total roll.......	3,759 05	Filling chamber 11.5 feet, mean cost per day $341, per vertical foot...	326 00

The less amount of cost per foot for January was owing to the use of the air pressure for raising much of the material during that month. The pressure used reached 27 pounds, which was maintained during the time of filling the working chamber. The air plant consisted of three compressors, two of which were double cylinders 16 x 24 inches, and one 12 x 18 inches. Two were used while excavating and one held in reserve. These were driven by two 75 horse-power boilers and one of 50 horse-power. The whole air-plant was placed on a boat 24 x 60 feet, built for the purpose (Plate CXIX), and all housed in to protect it from the sand storms. Fuel (coal) was unloaded from the car in reach of the compressor. Water was drawn from the river, and settled in a submerged flat boat as far as possible, but was always bad, being destructive to the boiler flues and causing much trouble. The 25th day of February saw the substructure complete and the west half of the superstructure nearing the center point of the bridge (Plate CXX).

The stone used in the piers, coping and bridge seats was obtained at the Chino quarry, about 140 miles east of the bridge site, in Arizona,

*The cost of the last foot or two of sinking was nearly $2 500 per foot.

where there is an extensive ledge. The color of this stone is a light, clear, cherry color, free from stain, and, laying as it does in thick ledges, it can be quarried of almost any size and shape desired. It is a compact sandstone, very hard and strong, homogeneous in texture, weighing about 160 pounds per cubic foot (4 320 pounds per cubic yard), and cutting a little easier than granite. A block of the stone 3 x 3 x 6 inches was tried by Prof. Waddell, at Kansas City, and remained unbroken after being subjected to 12 000 pounds per square inch (the extent of the capacity of the press). In the quarry the courses run from 20 inches to 6 feet, but owing to its homogeneity the stone can be split into any dimension or shapes desired. In constructing the two main piers many of the headers overlapped at the center of the pier where the pier was 15 feet thick, and some of the stretchers show 9 feet in length on the face of the pier. The courses varied from 26 down to 18 inches in thickness, with coping 22 inches. The main seats for the four pedestals carrying the whole weight of the bridge are 9 feet square and 2½ feet thick, made up, however, of four sections each. It was first designed to use stones of full size, but in consideration of the excessive cost and difficulty of handling and placing, without much heavier appliances than were at hand, it was decided to use the latter.

	Pounds.
The anchor arm, including floor, weighs	593 900
The cantilever arm, including floor, weighs	613 100
The two bridge seats, pedestals and piers	79 850
The suspended span, one-half including reaction of anchor	656 700
Live load on all at 3 000 pounds per lineal foot	1 980 000
Making a total weight in pounds.	3 943 550

Then as there are two seats on each pier $\frac{3\,943\,550}{2}$ = 1 971 775 pounds on each seat. Each seat 7 x 7 feet = 7 056 square inches, and $\frac{1\,476\,775}{7\,056}$ pounds = 279.4 pounds per square inch, or a little over $\frac{1}{50}$ of the ultimate crushing load.

The two main piers (Plate CXXI) and the abutment and pedestals supporting the viaduct were built of this sandstone, as well as the coping of the two anchor piers.

The anchor piers (Plate CXXI) were built of beton, the specifications for which will be found in the Appendix E. The west anchor pier was built with hand mixed beton, as well as the foundation for the east anchor pier and the west main pier. At the resumption of work in October, 1889, however, a mixing machine run by steam and having a capacity of 150 cubic yards in ten hours, was used, not only economizing in labor, but giving better work. The Gillingham English Portland cement was used and the specifications varied somewhat. The concrete for the east anchor pier, caisson crib and working chamber were provided with a composition as follows: The mixer being arranged with carriers to measure each ingredient, was arranged thus: Four cups cement, thirteen cups sand, and sixteen cups broken stone, carried up and discharged into the trough of the machine. A minimum of water was discharged into the sand and cement so that they became mixed before receiving the broken stone. The water was so gauged that it should not appear when the concrete was placed in the work and well tamped. The concrete was discharged into wheelbarrows or one-third yard iron buckets and conveyed to the work. Meantime, a quantity of one-man stone was distributed over the work to an amount of perhaps one-half of the amount of the concrete, and the latter driven around, between and over the stone. It was required that the broken stone should be well wetted before feeding into the machine, as well as the stone used in the work, so that thorough contact with the mortar should be secured. It was also required that each course in the pier should be well wetted after the tampers had gone over each portion of the work, to the end that all crumbs of mortar or dust should be smoothed down, and a clean surface should be secured, to give more perfect bond to the subsequent course. To prevent possibility of the feed of cement being interrupted, an inspector was placed at the machine to guard against this as well as to govern the amount of water used.

So important is this, and the frequency that it will occur, that it would be well to so arrange the feeding hopper, especially of the cement, that it would feed itself from a hopper holding a considerable quantity. The importance of having the proper amount of water and no more, will be understood when it is considered that to the packing quality of the concrete, its superior strength as a beton is due, as well as its less tendency to shrink. It is well known that, if well packed, perfect adhesion to the stone with which it comes in contact will be secured. If imperfectly packed from having too much water, it will shrink and break its bond. In the main piers the same concrete mixture with a slightly larger allowance of cement, omitting the "one-man" stone, was used.

First laying the face stones of the course and filling and ramming the face seams with mortar; the backing was all so laid as to leave room for ramming between; then the proper quantity of concrete was mixed and it was so deposited as to secure thorough packing, in several courses, until the whole course was leveled up; not forgetting to first wet all the stone with a sprinkling pot. It is not doubted that the pier will have all the stability of a monolith; the course pursued is much preferable to the practice of using drowned mortar and spawls, and the concrete will be less likely to separate than even well jointed solid courses.

The cement, of which nearly six thousand barrels were used, was tested by taking numerous briquettes from the quantities mixed by hand, and by the machine, and were found so uniformly good that the only precaution used was to break the briquettes from several barrels together, thus avoiding the bad effect from an occasional barrel that might fall below the standard. At a time before commencing the work, enough tests of neat cement were made to indicate a surprising uniformity in this brand. The test was usually made on ten or twelve briquettes each day, taken from the machine and allowed to dry in a shaded place twenty-four hours; then immersed in water for the same period, and then immediately broken. The testing machine was the "Fairbanks," and the briquettes gave a tensile strength from 160 (exceptional) to 225 pounds per square inch, a mean of nearly 220 pounds. Samples kept thirty days gave over twice that amount (410 pounds mean); some gave over 500 pounds. It was early found that the strength was governed largely by the character of the sand. No drift (wind) sand was used, as it was found to give very low tensile strength, but a bed of clean, water-washed sand was found convenient, having quantities of fine gravel intermixed, and later, a large bed of coarse sand in the bluff east of the river, so well adapted to the work as to justify its shipment around nearly 30 miles, to use in the caisson. Particular attention is called to this sand as worthy of shipment a long distance, for public buildings and other important work. A comparison of tests shows that this sand gives 30 per cent. excess of strength over good river sand (525 pounds at thirty days).

The broken stone was at first supplied from the débris of the Chino Quarry and from the volcanic rock found in the vicinity of the bridge, but it was found that the broken volcanic rock with which the "mesas" were strewn, could be collected at less cost, and being of the same character, was substituted in the caisson work at a saving of nearly $1 per cubic yard. The process of gathering was to rake these fragments of stone into windrows and haul them by wagon to a pile where convenient to load into a car when needed. An inclined screen was erected to separate the dust from the stone while conveying it to the car. Indian labor was used very successfully for this as well as for labor about the caisson.

The criticism has been made that the anchor piers should have been made with masonry rather than concrete. In reply, it is answered that, while making the original design, the concrete was considered most suitable and cheapest. Masonry of the character required would have cost $20 per cubic yard, excluding cement, owing to the complicated structure, it having twelve angles instead of four as in an ordinary solid pier. The comparison would run thus:

Masonry, per cubic yard........	$20 00	
One-half barrel cement.........	2 00	
Freight on stone, per cubic yard.	3 00	
Making total.....................		$25 00 per cubic yard.
Concrete, contract price........	$12 00	
One and a quarter barrels cement	5 00	
Making total.....................		17 00 " "
Making a difference of............		$8 00 " " in favor

of the concrete, and (there being in the two anchor piers 1 770 cubic yards) a saving of $14 160. Taking into consideration its better adaptation to the purpose, the criticism is answered. These, at least, are the considerations which impelled its adoption.

The anchor piers have not less than 700 cubic yards of concrete over the anchorage, which at 4 050 pounds per cubic yard, will give a weight on the anchorage of 2 835 000 pounds.

The uplift will not exceed the following:

Reaction of excess of weight of cantilever over anchor arm..	19 200 pounds.	
" " half of dead load of suspended span...........	328 350 "	
" " live load on cantilever arm $\frac{165 \text{ feet} \times 3\,000 \text{ pounds}}{2}$	247 500 "	
" " live load on suspended span $\frac{330 \text{ feet} \times 3\,000 \text{ lbs.}}{2}$	495 000 "	
		1 090 050 pounds.

(The heaviest train obtainable so far, that made up of coal, does not exceed 2 000 pounds per linear foot.) This does not take into consideration the cohesion of the concrete, which is greatly in excess of the simple weight of the mass. It would not do, however, to rely upon this altogether in any case, as notwithstanding the utmost care, the strength at the joints between courses will be less strong than the body of each course. As the anchor metal is so interwoven with the mass of the base of the pier, the above weight must be ample.

Location of Piers.—As a supported tape measurement across the river was impracticable, the pier centers had to be located by triangulation. A base line 850 feet long on the west bank of the river was carefully measured, and from that two permanent monuments were fixed on the center line, one being on each bank sufficiently distant to remain undisturbed ("*A*" and "*C*," Plate I). This line was measured with two 10 feet iron poles furnished by the Phoenix Bridge Company, and correct at 70 degrees Fahr. temperature. Later a tape was drawn across, supported partly by the tramway and the balance by the suspended stretcher 100 feet long, confirming the triangulation within $\frac{1}{100}$ foot. Then again, during the suspension of work in the summer of 1889, a large sand bar formed on the west side of the river, rendering it practicable to secure a good base line perpendicular to the center line of the bridge from the west main pier, which was done. Much care was taken and repeated measurements made at different temperatures, and they were found after applying the correction (.00000663 per degree Fahr.) to agree within $\frac{1}{100}$ foot in 702 feet, the base being extended so as to use a parallel base 42 feet from the center line of the bridge. From this an angle of 45 degrees was carefully and repeatedly turned and reference points fixed at such a distance as allowed a clear sight over the east pier when finished. By these reference points the bridge pedestals were set on the east main pier, and the bridge erected. When the bridge erection met at the center of the river, the lower chord bars overlapped 5⅝ inches, and pins were inserted and quickly driven, as soon as the lower erection wedges were slightly slacked off.

Completion of Bridge.—The bridge was completed on the 25th of June, 1890, in a manner creditable to the Phoenix Bridge Company, the contractors, every part going together without a hitch and with commendable speed. It was, however, opened for the passage of trains on the 10th of May, by the removal of one engine and the floor traveler, this being necessitated by the long expected disaster to ne, in spite of strenuous efforts to maintain it by the Road ent. Within two weeks, too, the old bridge lost a pier and two spa.

The shop inspection was placed in the hands of Hildreth & Nettleton, and owing to the dissolution of that firm was carried through by R. W. Hildreth & Co. Later, the senior member, R. W. Hildreth, acted as Inspector of Erection. To avoid useless repetition, the report of R. W. Hildreth & Co. is given partially as follows:

(Copy.)

"INSPECTION OF RED ROCK BRIDGE.

"MATERIAL:

"The material used in the manufacture of the superstructure of the Red Rock Bridge was wrought-iron, with the exception of the working section of the main truss members, which was of open hearth steel. The viaduct approach was entirely of wrought-iron.

"The material purchased by the Phœnix Bridge Company of the following rolling mills: Phœnix Iron Company, Phœnixville, Pa.

"All angles, squares, rounds and flats not over 12 inches wide, Pottstown Iron Company, Pottstown, Pa.

"All wrought-iron plates over 12 inches wide, Charles Huston & Sons, Coatsville, Pa.

"Steel filled iron plates for anchorage girders, Pennsylvania Steel Company, Steelton, Pa.

"Open hearth steel blooms to be rolled by Phœnix Iron Company into shapes and flats under 12 inches wide, Midvale Steel Company, Nicetown, Philadelphia, Pa.

"Steel pins, Carbon Iron Company, Pittsburgh, Pa.

"Open hearth steel plates over 12 inches wide and steel flats for eye-bars.

"Rolling was started at Phœnixville and Pottstown in the latter part of January, 1889, and continued intermittingly at the various mills until March, 1890.

"The requirements for steel being for three-quarter round test specimens, rolled from special ingots cast with each heat, are for the purpose of insuring the proper quality of metal. A number of tests from finished steel were required by the specifications, to serve as a check of the heating and rolling. The requirements for both iron and steel, while necessitating good material, were easily met by the rolling mills; we were, therefore, obliged to make very few condemnations on the results of tests.

"At the Carbon Iron Company we were obliged to take all tests from the finished plates and bars, as these mills had no facilities for rolling rounds. This was preferable, however, as it not only gave the quality of the material as well as the three-quarter inch round would have done, but also showed whether or not the steel had been injured in the subsequent process, as of heating and rolling, more thoroughly than the specified number as taken on shapes, etc.

"For every specimen of steel taken for a tension test, a similar one was taken for bending. In all cases these specimens were successfully bent, cold, 180 degrees to close contact. Considerable material was condemned at every rolling mill; this was rarely, however, for poor quality, but on account of surface defects and flaws.

"Tests of full-sized eye-bars were all made on the 600-ton hydraulic testing machine at the Athens shop of the Union Bridge Company. Only two of this series of tests broke in the head, and, in each case, this was due to the flaws discovered during inspection, the bars being selected for tests on that account. The result of the test of the 5 x [illegible]-inch bar was good, considering that the fracture was in the neck and caused by a flaw, so no retest was ordered. The retest of the 8 x [illegible]-inch bar gave good results for a bar that had already been strained so much beyond its elastic limit. These tests not only showed that the proportions of the heads were sufficient to break the body of the bar in all cases unless weakened by flaws, but that the material of the bars had not been injured by the manufacturing process to which it had been subjected at the bridge shop." (See Appendix "F.")

There was no formal test of the bridge after its completion owing to the difficulty of securing engines enough to produce the typical strain. As a matter of interest to all engineers, this should still be done, if practicable. Two 91-ton engines and a train of coal cars fully loaded (Plate CXXII), sufficient to cover the bridge from one main pier to the other, estimated to be about 66 per cent. of a full test load, gave a total depression at the center of 3[illegible] inches.

In concluding this report the writer desires to give credit to all those connected with this important work. Mr. C. W. Smith, General Manager; A. A. Robinson, Chief Engineer on the part of the Atchison, Topeka and ta Fé Railroad Company, and James Dun, Chief Engineer on the part of the St. Louis and San Francisco Railroad Company, advisory engineers, throughout its construction; Prof. S. W. Robinson, Professor of Mechanical Engineering, Ohio State University, Consulting Engineer; Martin Rapp, and W. F. Behrens, Assistant Engineers; R. W. Hildreth, shop and field inspector; each and all have the thanks of the writer for their efficient aid. The designers, Prof. William H. Burr and Prof. J. A. L. Waddell, the Phœnix Bridge Company, and Sooysmith & Co., contractors, each should share the credit of a good job well done. The accompanying views were secured by the aid of F. E. Evans, of Oakland, California.

PLATE CXI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXV Nº 516
RED ROCK CANTILEVER BRIDGE.

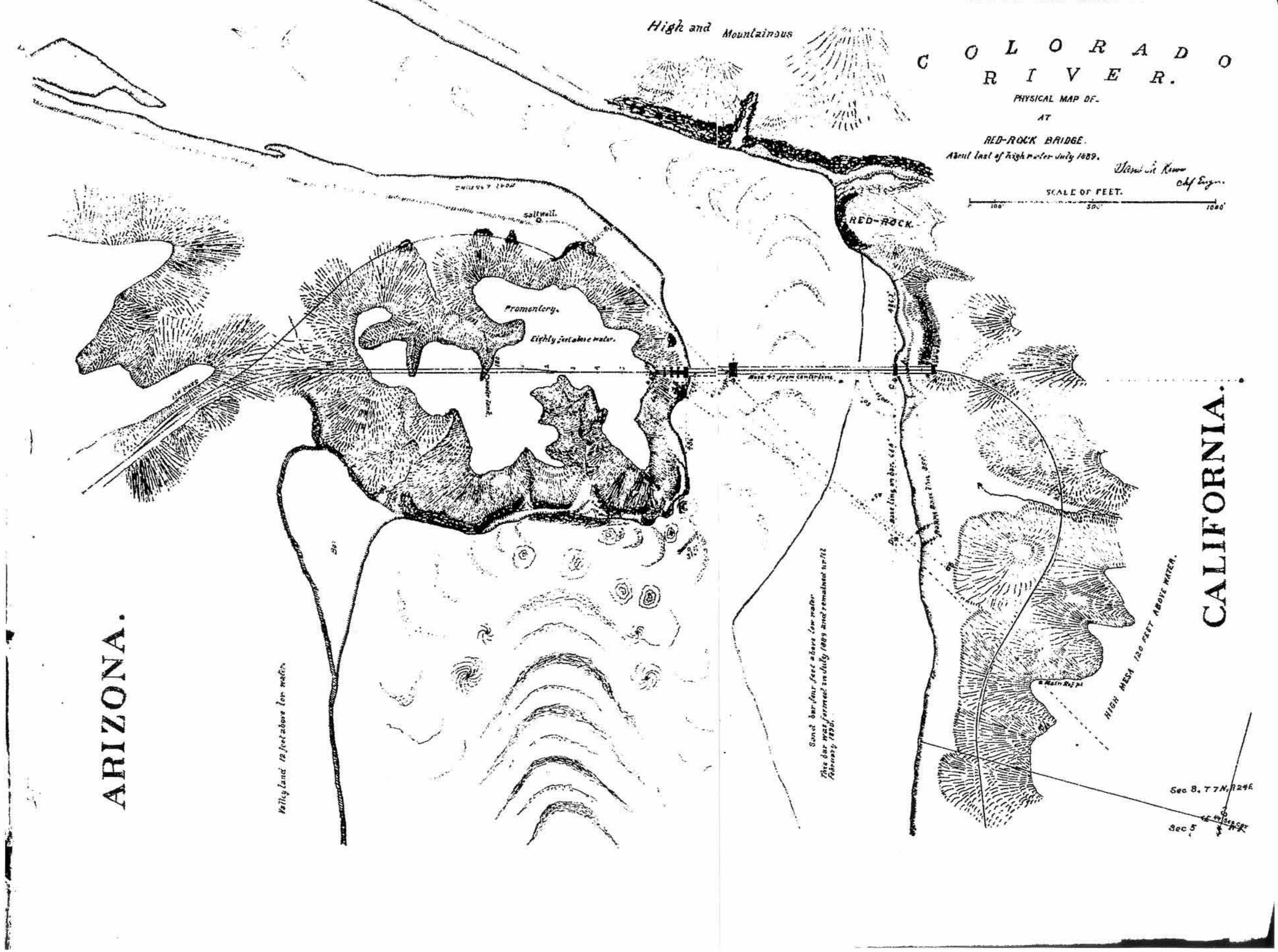
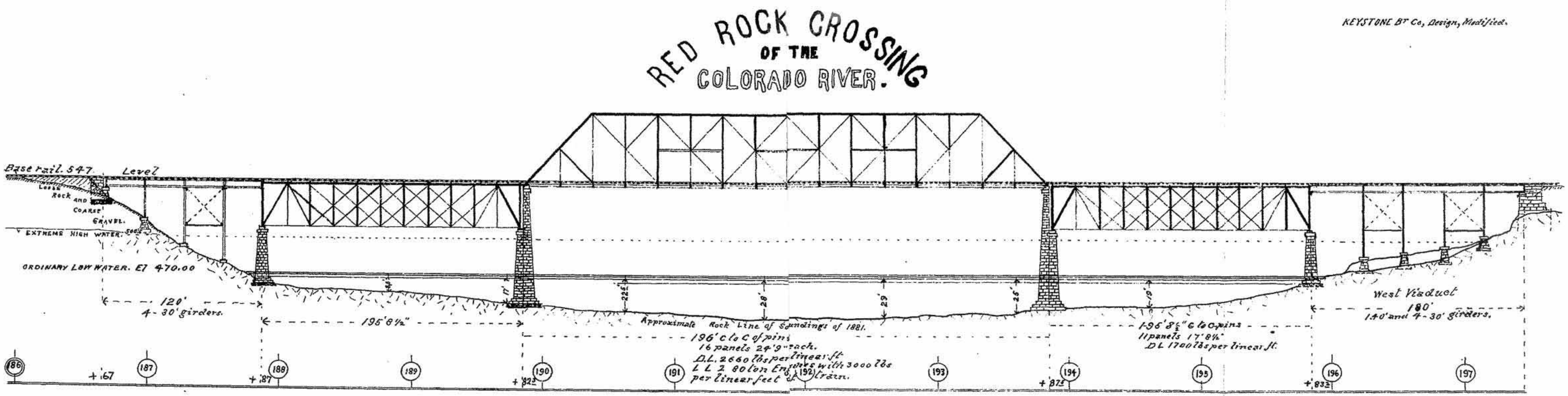
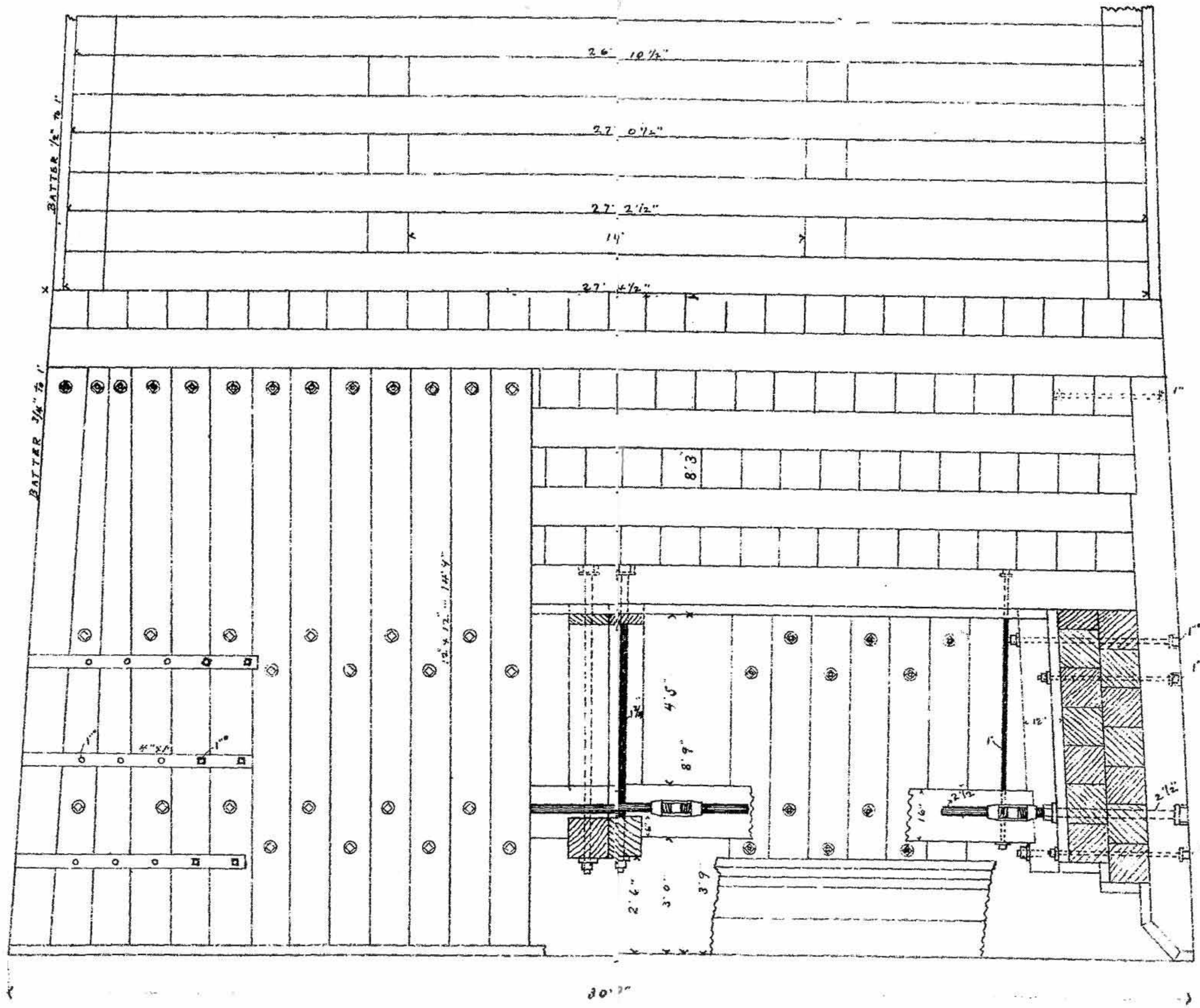


PLATE CXII.
TRANS. AM. SOC. CIV. ENGRS.
VOL XXV No 518
RED ROCK CANTILEVER BRIDGE



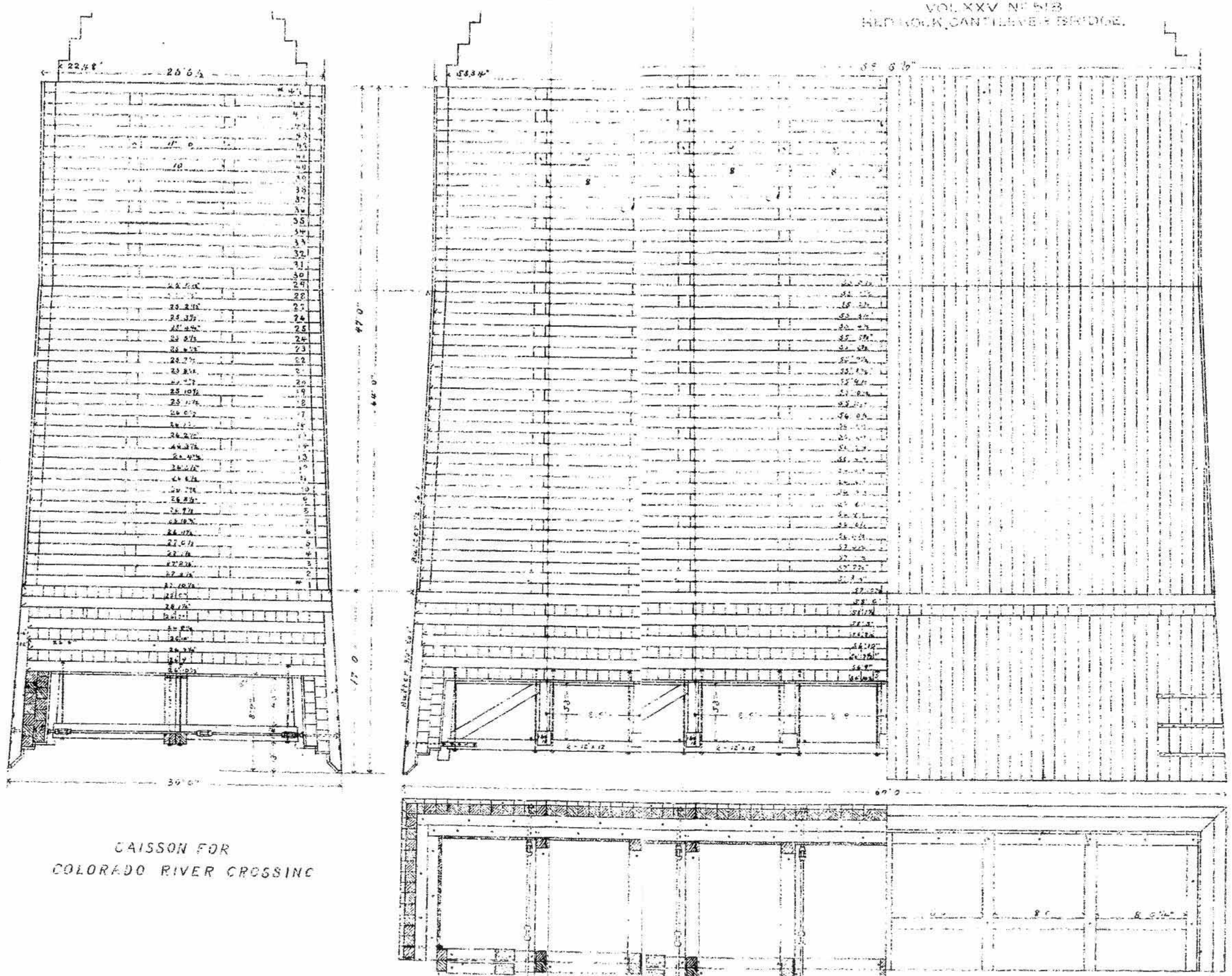
Sept 5th 1883 Saml. M. Rowe C.E.

PLATE CXIII.
TRANS AM. SOC. CIV. ENGRS.
VOL. XXV Nº 518
RED ROCK CANTILEVER BRIDGE.



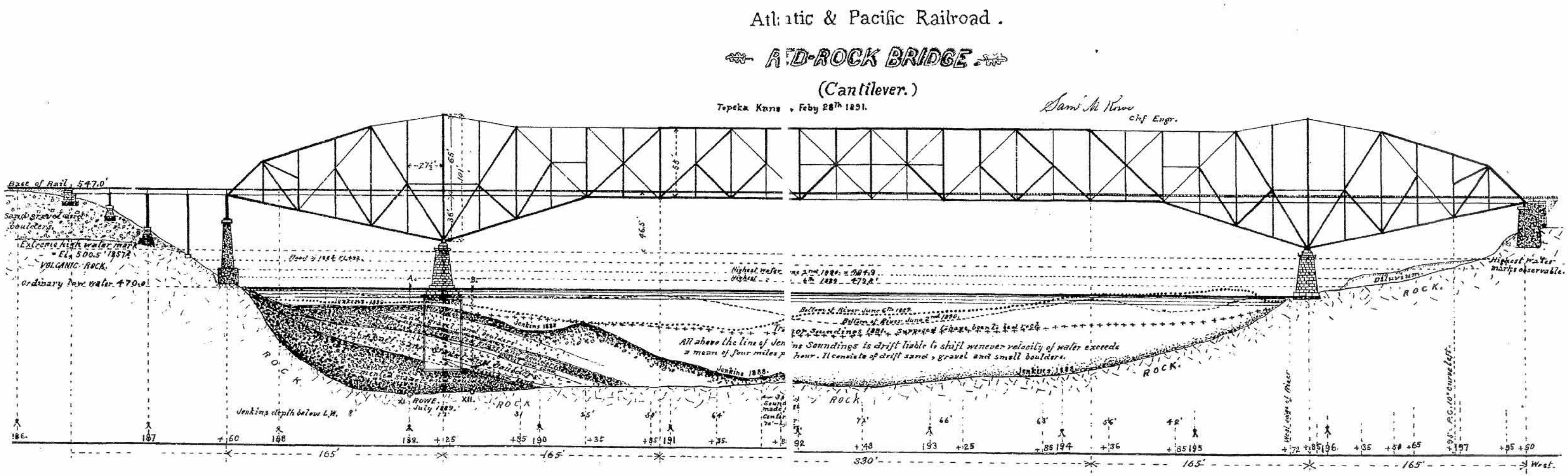
CAISSON FOR COLORADO RIVER CROSSING

PLATE CXIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXV. No. 518.
RED ROCK CANTILEVER BRIDGE.



CAISSON FOR
COLORADO RIVER CROSSING

PLATE CXVI.
TRANS AM SOC CIV ENG'RS
VOL XXV. Nº 518
RED ROCK CANTILEVER BRIDGE.

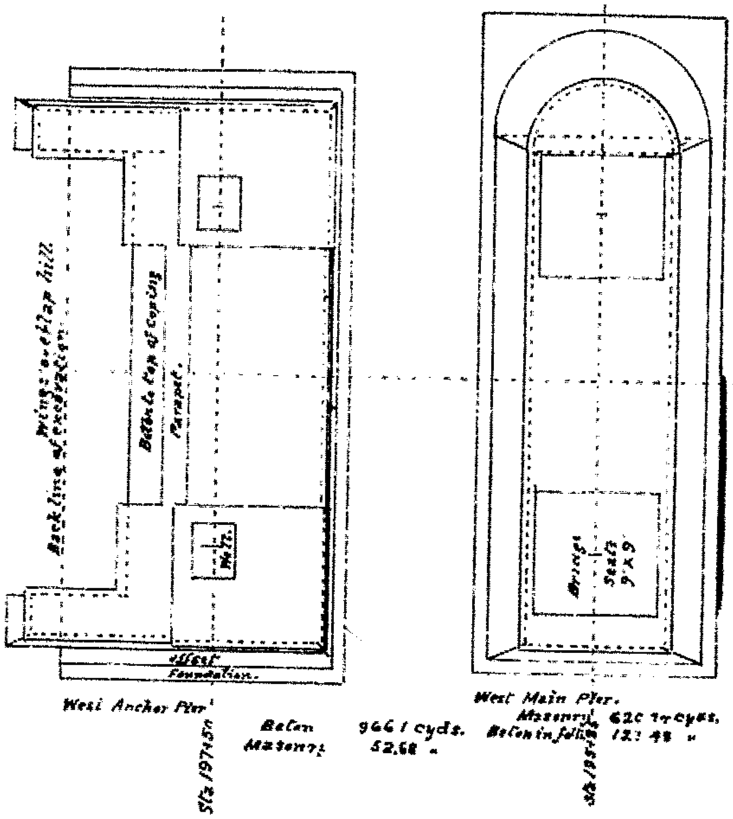


RED-ROCK BRIDGE.

PLAN AND DIMENSION OF PIERS. No. 2

Albq. Aug 5th 1889.

Scale 5' 10'



RED-ROCK BRIDGE.

PLAN AND DIMENSION OF PIERS. No. 1.

SCALE 10' TO 1".

Albq. Aug 5th 1889.

Saml. M. Rowe.
Chf. Eng.

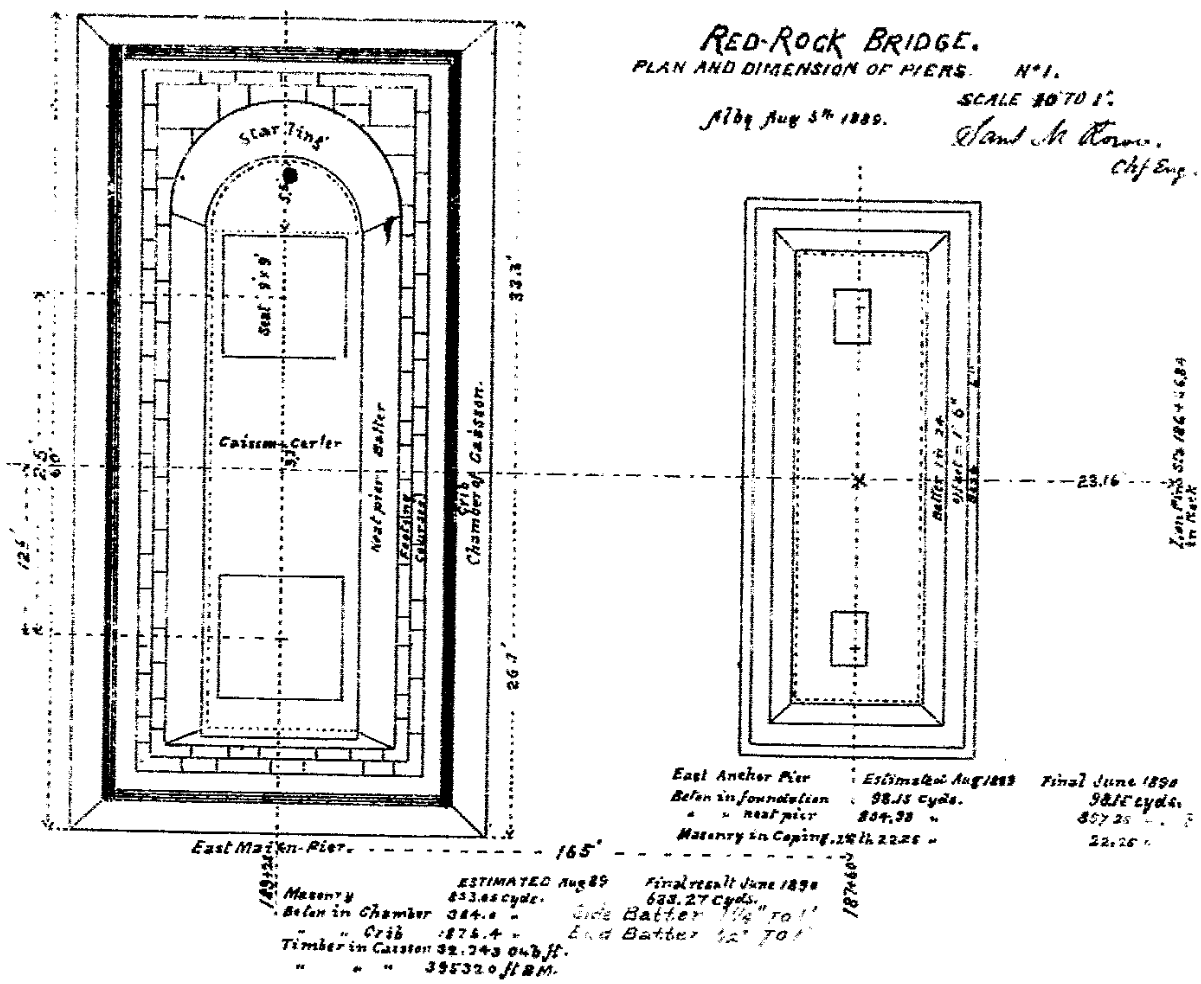


PLATE CXXII.
TRANS. AM. SOC. C. E.
VOL. XXV, No. 518.
RED ROCK CANTILEVER BRIDGE.