FOR CONTRACT NO: 04-013524
PROJECT ID: 04-12000608

INFORMATION HANDOUT

WATER QUALITY

WQ1 California Regional Water Quality Control Board Order 01-120
(Issued October 17, 2001)

WQ2 California Regional Water Quality Control Board Order R2-2002-0011
(Issued January 23, 2002)

PERMITS, LICENSE, AGREEMENT & CERTIFICATION

P1 California Department of Fish and Game (CDFG) Incidental Take
Permit No. 2081-2001-021-03
(Issued November 19, 2001)

P2 CDFG Incidental Take Permit No. 2081-2001-021-03 Minor Amendment #1
(Issued October 14, 2009)

P3 CDFG Incidental Take Permit No. 2081-2001-021-03 Major Amendment #2
(Issued February 23, 2012)

P4 CDFG Incidental Take Permit No. 2081-2001-021-03 Minor Amendment #3
(Issued September 6, 2012)

P5 U.S. Army Corps of Engineers (ACOE) Permit No. 023013S
(Issued December 04, 2001)

P6 U.S Army Corps of Engineers (ACOE) Permit No. 023013S Letter of Modification
(Issued April 2, 2002)

P7 U.S Army Corps of Engineers (ACOE) Permit No. 023013S Letter of Modification
(Issued November 12, 2002)

P8 U.S Army Corps of Engineers (ACOE) Permit No. 023013S Letter of Modification
(Issued April 11, 2005)

P9 U.S Army Corps of Engineers (ACOE) Permit No. 023013S Letter of Modification
(Issued August 15, 2005)

P10 U.S Army Corps of Engineers (ACOE) Permit No. 023013S Letter of Modification
(Issued September 23, 2005)

P11 U.S. Army Corp of Engineers (ACOE) Permit No. 023013S Letter of Modification
(Issued May 20, 2008)

P12 U.S. Army Corp of Engineers (ACOE) Permit No. 023013S Time Extension
(Issued November 16, 2011)

P13 U.S. Army Corp of Engineers (ACOE) Permit No. 023013S Letter of Modification
(Issued July 6, 2012)

P14 San Francisco Bay Conservation and Development Commission (BCDC)
Permit No. 2001.008.34, Issued November 20, 2001
Last Amended January 23, 2014, Reflects Amendments 1-34

P15 National Marine Fisheries Service (NMFS) Biological Opinion and Incidental Take Statement
(Issued October 30, 2001)

P16 NMFS Supplemental Biological Opinion and Conference Opinion
(Issued April 10, 2009)

P17 NMFS Supplemental Biological Opinion and Conference Opinion
(Issued August 21, 2009)

P18 NMFS Supplemental Biological Opinion and Conference Opinion
(Issued February 6, 2012)

P19 NMFS Incidental Harassment Authorization
(Issued December 18, 2013)

P20 U.S. Fish and Wildlife Service (USFWS) Biological Opinion
(Issued October 29, 2001)

P21 U.S. Coast Guard (USCG) New Bridge Permit 3-01-11
(Issued December 11, 2001)

P22 U.S. Coast Guard (USCG) New Bridge Permit Amendment 3a-01-11
(Issued November 18, 2011)

MATERIALS INFORMATION

M1 SFOBB 504' & 288' Spans Inspection Reports

M2 SFOBB 504' & 288' Spans Original Construction Sequence

M3 SFOBB East Span Design Specifications – Superstructure Circa 1933

M4 Existing Bridge Modification Contract 4011 Resident Engineers Report on Deck Paving –East Bay July 19 1963 (Testing Reports and Contract Specifications)

M5 Existing Bridge Modification Contract 4030 Resident Engineers Report on Steel Work – East Bay Sept 18 1963 (Testing Reports and Contract Specifications)

M6 Original Bridge Contract 7 Superstructure East Bay Crossing Final Report March 24 1937 (Material Specifications and Testing Reports)

M7 Original Bridge Contract 7 Superstructure East Bay Crossing Specifications March 8 1933 (Contract Specifications and Cantilever Erection Procedure)

M8 Original Bridge Tests of Heavy Riveted Joints – Second Progress Report (1936)

M9 Original Bridge Tests of Heavy Riveted Joints – Special Report on Manganese Steel Specimens (1936)

M10 Original Bridge Tests on Riveted Tension Members and Their Connections (1934)

M11 SFOBB East Span Floor System Original Design Calculations (1933)

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M13 Pile Installation Demonstration Project (PIDP) Geotechnical Report: Main Text and Appendices

M14 Ground Motion Report: Main Text and Appendices

M15 Final Marine Geophysical Survey Report:
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M16 Final Marine Geotechnical Site Characterization Report:
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M17 Phase I Subcontractor Reports - Preliminary Geotechnical Site Characterization
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M19 Analysis and Design Procedures for Pile Foundations Supporting Temporary Towers Skyway Structures: Main Text and Appendices dated March 2001

M20 Revised Final Oakland Shore Approach Geotechnical Site Characterization Report, dated March 2001: Volumes 1, 2A, 2B, 3, and 4

M21 1920 Geology Reports

M22 1930 Boring Logs for Original Bay Bridge

M23 Final Geotechnical Foundation Report for Oakland Shore Approach Structures

M24 Caltrans Bathymetric Survey Report No. 23.00007024 R1 (2103)

M25 San Francisco-Oakland Bay Bridge East Span Underwater Debris Diagram, dated May 2001

M26 SFOBB East Span Survey Information, Control Diagram dated December 30, 2002

M27 USCG Private Aid to Navigation Sample Application Form

M28 Geotechnical & Material Report for YBI

M29 Ground Penetration Report No. 6488-01, GEO Vision, November 2006

M30 Historical Maps (1917, 1932, 1933)

M31 Construction Vibration Monitoring Field Data Form

M32 Water Quality Information Handout (Contract No. 04-01352) dated December 2012

M33 Correspondence with United States Custom Service regarding Jones Act and use of crane/barge, 2002 and 2005

M34 Phase 1 Archaeological Survey Report- Maritime Archaeology, September 1999

M35 Addendum to Archaeological Survey Report-Maritime Archeology, December 6, 1999

M36 Addendum to Archaeological Survey Report-Maritime Archeology, March 2000

M37 Addendum to Archaeological Survey Report-Maritime Archeology, August 17, 2000

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	M2	1.2	504' & 288' Spans Original Construction Sequence
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	M6	1.6	Original Bridge Contract 7 Superstructure East Bay Crossing Final Report March 24, 1937 (Material Specifications and Testing Reports)
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	M8	1.8	Original Bridge Tests of Heavy Riveted Joints - Second Progress Report (1936)
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	M19	2.7	Analysis and Design Procedures for Pile Foundations Supporting Temporary Towers Skyway Structures: Main Text and Appendices dated March 2001
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	M24	2.12	Caltrans Bathymetric Survey Report No. 23.00007024 R1 (2013)

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	P2	3.1.2	CDFG Incidental Take Permit No. 2081-2001-021-03 Minor Amendment #1. Issued October 14, 2009
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	P4	3.1.4	CDFG Incidental Take Permit No. 2081-2001-021-03 Minor Amendment #3. Issued September 6, 2012
	P5	3.1.5	U.S. Army Corps of Engineers (ACOE) Permit No. 023013S. Issued December 04, 2001
	P6	3.1.6	U.S. Army Corps of Engineers (ACOE) Permit No. 023013S Letter of Modification. Issued April 2, 2002
	P7	3.1.7	U.S. Army Corps of Engineers (ACOE) Permit No. 023013S Letter of Modification. Issued November 12, 2002
	P8	3.1.8	U.S. Army Corps of Engineers (ACOE) Permit No. 023013S Letter of Modification. Issued April 11, 2005
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TESTS ON HEAVY RIVETED JOINTS

Special Report
to
Department of Public Works
State of California

on

MANGANESE-STEEL SPECIMENS

by

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June 1936

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TESTS ON HEAVY RIVETED JOINTS

SPECIAL REPORT ON MANGANESE-STEEL SPECIMENS

June 1936

The tests reported herein were undertaken in order to obtain information regarding the behavior, in large joints and tension members, of a manganese steel which has been proposed for uses where nickel steel is now employed. The test series is a part -- designated as series M -- of an investigation of heavy riveted joints, conducted in the Engineering Materials Laboratory of the University of California in cooperation with the California Department of Public Works.* The specimens were furnished by the American Bridge Company. This report gives the results of those tests which have to do with the properties of the manganese steel as a material.

Description of Specimens and Coupons

Two types of specimen were tested, as follows:

Type M1: Butt joint; manganese-steel plates, manganese-steel rivets.

Type M2: Two stitch-riveted manganese-steel plates; carbon-steel rivets.

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* The chemical analyses and some of the coupon tests were made by the Carnegie-Illinois Steel Corporation.

The details of the specimens are shown in Fig. 1. Three specimens of each type were tested.

The allowable working stresses for plate and rivet steel were as follows:

	Working Stress, kips
Tension in manganese plate steel	34
Shear in manganese rivet steel	20
Shear in carbon rivet steel	15

The properties of plate and rivet steel were determined by tests on standard coupons, as follows:

Steel	Type of Coupon	Gage Length, in.	Cross-section Within Gage Length
Plate	I	8	Thickness x 1 1/2 in.
Rivet	III	2	1/2 in. diam.
	Rivet stock	8	1 in. diam. (nominal)

The location and marking of coupons of plate steel is shown in Fig. 2. Dimensions of Type I and Type III coupons are given in Tables 1 and 2 respectively.

Method of Testing Specimens

The specimens were tested in a 4,000,000-lb. Southwark-Emery precision testing machine. At each of four increments of load, listed in the following tabulation, longitudinal strains were observed at selected locations on the specimen.

Specimen		Nominal Stress at Net Section of Plate, k.s.i.
Type	No.	
Butt joint	M1-1, M1-2, M1-3	10, 20, 30, 40
Stitch-riveted plates	M2-3	
Stitch-riveted plates	M2-1, M2-2	20, 30, 40, 50

During each of these periods of observation, the load was held constant by means of an automatic load-maintainer. Strains were observed by means of 2 1/2-in. and 10-in. fulcrum-plate strain gages.

During the application of load, for the butt-joint specimens the relative slip at various points along both edges of adjacent plates was observed by means of dial gages.

When the observations of strain and slip at the various loads had been completed, the specimen was tested to failure in tension; during this period of the test, visual observations were made of localized yielding as indicated by the flaking of an inelastic white paint which had been applied to the member prior to test.

The elongation of each stitch-riveted specimen to failure was determined by means of measurements with divider and scales on a series of 5-in. gage lines located end-to-end along the center line of the face of the specimen.

Method of Testing Coupons

For all coupon tests made by the Carnegie-Illinois Steel Corporation, the idling speed of the testing head of the machine was reported to be 0.5 in. per min. For the coupons tested at the University of California, various loading rates were employed, as follows:

Steel	Coupon	Range	Idling Speed of Testing Head, in. per min.	Approximate Rate of Loading, p.s.i. per min.
Plate	Type I	Elastic	0.02	1,500
		Above elastic	Variable (0.18 to 0.86)	5,000
Rivet	Type III	Elastic	0.05	15,000
		Above elastic	0.33	---

Results of Tests on Coupons

Plate Steel. -- The detailed results of tests on coupons of plate steel are shown in Table 1, and the average values for all plate coupons are given in the following tabulation:

Location of Test	Yield Strength, lb.per sq.in.	Tensile Strength, lb.per sq.in.	Modulus of Elasticity, million lb. per sq. in.	Elongation in 8 In., percent	Reduction of Area, percent
C-I.S.C.	60,640	101,700	-	20.1	53.2
U.C.	58,200	98,500	29.7	19.9	52.2

It is seen that the average yield strength and tensile strength determined by the Carnegie-Illinois Steel Corporation are 3 to 4 percent higher than those determined by the University of California; the difference is due in large part to the difference in rate of testing employed by the two organizations. Although on the average the elongation and the reduction of area are somewhat smaller for the University of California tests than for the Carnegie-Illinois Steel Corporation tests, the difference is not large and is within the range of testing error.

The average deviations in test results for individual coupons of plate steel tested at the University of California are shown in the following tabulation:

	Average Deviation, percent
Yield strength	2.5
Tensile strength	1.0
Modulus of elasticity	1.4
Elongation in 8 in.	6.0
Reduction of area	2.8

Rivet Steel. -- The detailed results of tests on coupons of rivet steel are shown in Table 2, and the average values are given in the following tabulation:

Steel	Heat No.	Location of Test	Yield Strength, lb.per sq.in.	Tensile Strength, lb.per sq.in.	Elongation in 2 In., percent	Reduction of Area, percent
Carbon	129947	C-I.S.C.[a]	40,750	59,600	35.0	65.7
		U.C.[b]	40,590	58,650	36.5	65.9
Manganese	123885	C-I.S.C.[a]	56,980	88,800	26.0	58.7
		U.C.[b]	51,670	80,290	30.9	67.3
Annealed Manganese	123885	C-I.S.C.[a]	49,920	80,490	29.0	64.0
		U.C.[c]	52,560	76,180	32.9	65.1

a - Tests on 1 coupon.
b - Average for tests on 20 coupons.
c - Average for tests on 5 coupons.

It is seen that with one exception, the yield strengths and tensile strengths determined by the Carnegie-Illinois Steel Corporation are higher than those determined by the University of California. The elongations and the reductions of area are consistently higher for the University of California tests than for the Carnegie-Illinois Steel Corporation tests. The differences are due in large part to the difference in rate of testing employed by the two organizations.

The yield strength of the annealed manganese steel, as indicated by the University of California tests, is about 1000 p.s.i. higher than that of the untreated manganese steel, but the tensile strength of the annealed steel is about 4000 p.s.i. lower than that of the untreated steel.

In Table 2a are shown the results of tests to date on coupons of 1-in. rivet stock, together with the test results for corresponding machined coupons (Type III).

Stress-strain Relations. -- In Fig. 3 are shown typical stress-strain diagrams for coupons of plate steel. For three of the coupons the yield strength was determined by the "drop of beam" method; for the other coupon no drop of beam was observed and the yield strength was determined by the "offset" method, at an offset of 0.10 percent.

Figure 4 shows two representative types of stress-strain relation observed in the tests on coupons of plate steel over the entire range of load to failure. Nearly all of the coupons exhibited a definite yield point (see curve for coupon M1-2AB), and the yield strength was determined by the drop-of-beam method. For seven of the coupons, no definite yield point was observed (see curve for coupon M2-1AAA), and the yield strength was determined by the offset method, at an offset of 0.10 percent. At loads above the yield strength (Fig.4) the stress-strain curves gradually converge, and the ultimate loads are approximately the same for the coupons representing the two types of behavior.

To study the effect of repeated loading and to determine approximately the stress at which considerable set begins to occur, coupon M2-2AA of plate steel was subjected to alternate tensile loadings and releases of load. For each loading, the maximum stress was 5,000 lb. per sq. in. greater than that for the preceding load. The test results are shown in Fig. 5. It is seen that for all loadings lower than that corresponding approximately to the elastic strength, no permanent set could be observed by the extensometer employed. However, a slight hysteresis effect was apparent, as indicated by the width of line of the stress-strain curves of Fig. 5. At a stress of about 0.93 yield strength, appreciable set began to occur.

Comparison of Test Results on Coupons of Manganese and Nickel Steel. -- Inasmuch as the manganese steel has been proposed for uses where nickel steel is now employed, it is of interest to compare the properties of these two steels as indicated by the test results on coupons. The following tabulation gives the average values of yield strength, tensile strength, and elongation for the coupons of plate steel tested to date:

Location of Test	No. of Specimens for Average		Yield Strength, lb.per sq.in.		Tensile Strength, lb. per sq. in.		Elongation in 8 In., percent	
	Nickel	Manganese	Nickel	Manganese	Nickel	Manganese	Nickel	Manganese
C-I.S.C.	12	10	65,870	60,640	105,700	101,700	18.1	20.1
U.C.	2	20	63,150	58,200	102,400	98,500	19.0	19.9

It is seen that on the average the manganese steel exhibits a yield strength 8 percent lower, a tensile strength 4 percent lower, and an elongation somewhat higher than the nickel steel.

Results of Tests on Specimens

The tests reported herein include those to determine the elasticity, slip, strength, and olongation of specimens. Observations were also made to determine the distribution of stress; these will be included in the general report on all specimens.

Elasticity. -- The modulus of elasticity at the gross section of the plates used in the specimens is shown in the following tabulation:

Specimen		Modulus of Elasticity, million p.s.i.	Measurement
Type	No.		
Butt joint	M1-1	30.6	In main plate outside of butt joint; 2 1/2-in. gage lines.
	M1-2	31.6	
	M1-3	31.1	
	Avg.	31.1	
Stitch-riveted plates	M2-1	29.7	Across gross section; 2 1/2-in. gage lines.
	M2-2	30.0	
	M2-3	30.2*	Five 10-in. gage lines, end to end, along center of face of specimen; gross section of plate used in computation of modulus.
	Avg.	29.9	-

* Excluded from average.

The average modulus of the butt-joint specimens is 31.1 million lb. per sq. in.; that of the corresponding coupons (Table 1) is 29.5. The average modulus of the stitch-riveted specimens is 29.9 million lb. per sq. in.; that of the corresponding coupons is 30.0.

The average unit elongation within the length of the joint at the allowable working load (34 k.s.i. at net section) is as follows:

Specimen		Avg. Unit Elongation, in. per in.	Measurement
Type	No.		
Butt joint	M1-1	0.0012	Within length of butt joint; 2 1/2-in. gage lines along edges of plate and spanning opening between ends of main plates.
	M1-2	0.0011	
	M1-3	0.0011	
Stitch-riveted plates	M2-3	0.0010	Average over length of 50 in. along center of face of plate; 10-in. gage lines.

For the gross section of the plates at the same load, the computed average elongations are of the same order of magnitude as those for the specimens.

Slip. -- The results of observations to determine the amount of slip between main and splice plates in the butt joint of Type Ml specimens are shown in Table 3 and Fig. 6. The locations of the gages employed to measure slip are shown in Fig. 6. Gages 9, 10, 11, and 12 were so mounted as to average the slip between the main plate and both splice plates.

In Table 3 is shown, for each gage, the slip (1) at the end of the first increment of load at which observations were taken (0.30 working load) and (2) at the working load corresponding to the working stress (34 k.s.i.) in the net section. It is seen that local variations in slip are considerable, probably because of differences in the contact pressures between plates and because of the fact that the rivets as driven did not bear equally against the sides of the holes. However, each average value for the several gages at similar locations should be representative of the slip of the joint as a whole.

The diagrams of Fig. 6 show the general load-slip relation near one end of the joint and near the butt of one main plate. Each curve represents the average slip for four gages at the same transverse section. The curves (not shown) for individual gages are consistently of the same general shape although as indicated in Table 3 they show some variations in the amounts of slip.

It is seen (Fig.6) that slippage begins at very low loads and that in general the rate of slip does not increase suddenly as the load is increased. Although the testing machine was operated in such a manner as normally to increase the load on the specimens at a constant rate, in many cases it was observed that when sudden slip occurred within a specimen there was a corresponding lag in the rate of loading.

In Fig. 6, it is seen that the average slip near the end of the joint is greater than that near the center -- at the working load roughly twice as great -- probably because (1) the average stress in the splice plates at the center of the joint is smaller than the stress in the main plate at the end of the joint; (2) at the center the rivet spacing is closer and hence the plates are held more tightly together than at the ends; and (3) at the center the gages are located 7/8 in. inside the end transverse row of rivets whereas at the end the gages are located only 1/8 in. inside the end transverse row of rivets.

Measurements were made of the differential movement between the stitch-riveted plates of specimen M2-1. The observed slips were very small and were localized and erratic. As a result of these observations, no slip measurements were made on the other two specimens of this type.

Strength. -- The ultimate strength of the specimens is shown in Table 4. It is seen that in each group one specimen is considerably weaker than the other two. The low strength of stitch-riveted specimen M2-2 as a whole was due to the failure of one plate at a relatively low load; the strength of the remaining plate was comparable with that for a single plate of the other specimens.

The ultimate stress at net section of the plates (Table 4) is generally less than that for corresponding coupons (Table 1), as shown in the following tabulation:

Specimen Type	Specimen No.	Avg. Stress at Net Section of Specimen at Ultimate Load, k.s.i.	Tensile Strength of Corresponding Coupons Tested at U.C., k.s.i.	Difference, percent
Butt joint	M1-1	90.3	98.7[a]	-8
	M1-2	70.6	98.8[a]	-28
	M1-3	91.8	100.0[a]	-8
Stitch-riveted plates	M2-1	91.3	99.2[b]	-8
	M2-2	63.7	97.4[b]	-35
	M2-3	97.9	97.7[b]	0

a - Average for 2 coupons.
b - Average for 4 coupons -- two from each plate.

The efficiency of the specimens (Table 4) reflects roughly the variations in strength of the joints. For the two butt-joint specimens which failed at nearly the same strength, the efficiency is 81 percent, whereas the ratio of net to gross section is 72 percent; the difference is due in part to the fact that "efficiency" as defined herein is based on the strength of coupons and not on the strength of a large plate of solid section. For the two stitch-riveted specimens which failed at comparable loads, the efficiencies are respectively 82 and 89 percent, averaging 86 percent; the corresponding ratio of net to gross section is 88 percent.

Elongation to Failure. -- In Fig. 7 is shown the elongation to failure of the stitch-riveted specimens M2-1, M2-2, and M2-3, measured on the center line of face of plate at gage lengths of 5 in. In general, the elongation near the center of the specimen is greater than that near the ends of the reduced section. For specimen M2-1, the unit elongation near the point of failure is about twice that at other points near the center of the reduced section. One plate of specimen M2-2 elongated about 9 times as much as the other plate. The average elongation within the central 50 in. of the specimens is shown by the following tabulation of values from Table 4.

Specimen (stitch-riveted)	Plate	Elongation, percent
M2-1	A	5.2
	B	5.7
M2-2	A	0.5
	B	4.5
M2-3	A	4.4
	B	4.5

Character of Failure. -- The general character of failure of the specimens is shown by the remarks in Table 4 and by the photographs, Figs. 8 to 15. The locations of failure in the stitch-riveted specimens are also shown in Fig.7. Detailed notes regarding failure are given in the Appendix.

Except for stitch-riveted specimen M2-1, the fractures are square with granular texture, and there are no silky textures such as occur in the carbon-steel specimens.

Figs. 8 to 10 show the appearance of the butt joints after failure. In general, just before failure of the specimen the splice plates exhibited some yielding at a section near the butt of the main plates. Fig. 11 shows typical yielding of the main plate just outside the joint, at a stress in net section of 62,500 lb. per sq. in.

Figs. 12 to 15 show the appearance of the stitch-riveted specimens after failure. Prior to failure, the stress patterns were generally as shown in Fig.15; but at the time of failure the yielding appeared to be fairly well distributed over the entire area of the specimen.

Concluding Remarks

The results of coupon tests to date show that although the strength of the manganese steel is lower than that of the nickel steel, the difference is small. Further, although the ductility of the manganese steel is greater than that of the nickel steel, the difference is small.

Two out of each group of three large specimens exhibited tensile strengths at the net section of plate greater than 90 percent of the strengths of corresponding coupons; these strengths are considered to be satisfactory. However, one butt-joint specimen exhibited a tensile strength only 72 percent, and one stitch-riveted specimen only 65 percent, of that of corresponding coupons. The reason for this marked lack of uniformity has not been disclosed by the physical tests which have been made.

Appendix

DETAILED NOTES ON FAILURE OF SPECIMENS*

Specimen M1-1

Load, kips	Remarks
261	Lag in load rate and loss in load of 500 lb.
324	" " " " " " " " " 200 "
472,481,486,537	Slight lags in load rate.
704	Lag in load rate and scaling of paint noted in main plates.
719	Marked lag in load rate, and rapid scaling of paint across main plates.
749,869,989	Lags in load rate.
1089	Maximum load and sudden failure by parting of main plate M1-1A, along section through rivets 1 and 2. Scaling of paint started in splice plates along butt of main plates just prior to failure. No scaling of paint from rivets up to maximum load. Square break, coarsely granular texture.

Specimen M1-2

Load, kips	Remarks
511	Slight lag in load rate.
659	Scaling of paint started near center line of main plate M1-2A.
672	Lag in load rate and loss in load of 800 lb.
690	Lag in load rate.
699	Lag in load rate; scaling of paint started near center line of main plate M1-2B.
713	Lag in load rate, areas of scaling of paint expanding.
739	Distinct lines of scaling, making about 45° with longitudinal axis of joint, proceeding from rivets 1, 2 and 37, 38.
769, 807, 845	Lags in load rate.
857	Maximum load; partial fracture of main plate M1-2B along line from edge to rivet 37 to rivet 38; section from rivet 38 to edge not ruptured at this load; load dropped off to 129 kips, built up to 231 kips, then gradually dropped off to final failure at 119 kips by fracture between rivet 38 and edge. Between edge and rivet 38: shear break with slight reduction of area, finely granular texture. Remainder of section: square break, coarsely granular texture.

Specimen M1-3

Load, kips	Remarks
263	Slight lag in load rate.
700	Lag in load rate, scaling of paint started in both main plates.
710	Lag in load rate and loss in load of 200 lb.
724	Scaling of paint noted in main plate near rivets 1 and 2.
727	Marked lag in load rate, with constant load for several seconds. Scaling of paint progressing across main plates.
979	Marked lag in load rate.
1109	Maximum load; partial fracture in main plate M1-3A, starting along line from edge to rivet 2; load fell off to 1089 kips, then increased to 1096 kips when final failure took place along broken line from rivet 2 to rivet 1 to rivet 3 to edge. Scaling of paint in splice plates along butt of main plates prior to failure. For 1 1/2 in. on a diagonal line from rivet 3 toward rivet 1: failure in shear (on a plane normal to face), silky texture; from ends of this break to both edges: square break, coarsely granular texture.

* - Numbering of rivets shown in Fig. 8 for butt-joint specimens and Fig. 7 for stitch-riveted specimens.

Specimen M2-1

Load, kips	Remarks
1040, 1105, 1124) 1168, 1200, 1231)	Slight lags in load rate.
1458	Marked lag and constant load for short period.
1730	Lag in load rate.
2150	Marked lag and loss in load of 20,000 lb.; sharp snap in joint.
2230	Maximum load and partial failure; plate M2-1A parted between edge and rivet 15; load fell off to 1510 kips and gradually built up to 1810 kips; tearing of plate progressed from rivet 15 toward rivet 14 to about center line of plate; remainder of plate failed at 1810 kips; plate M2-1B began to tear just prior to reaching load of 1810 kips; load fell off to 510 kips when section of plate between rivet 14 and edge parted, and failure was complete. Fracture was of V (or cup-cone) type with finely granular texture except for section between rivet 15 and edge of plate M2-1A which showed a square break with coarsely granular texture. Noticeable necking down in region of plate near rivets having 2-in. edge distance.

Specimen M2-2

Load, kips	Remarks
1280	Slight lag in load rate.
1320	Lag in load rate.
1450	Marked lag and loss in load of 1000 lb.
1552	Maximum load and partial failure; plate M2-2A parted suddenly between rivets 4 and 5 and opened up about 3/8 in.; load dropped off to 1360 kips.
1492	Plate M2-2A parted suddenly between rivet 5 and edge and opened up about 5/8 in.; load fell off to 1200 kips.
1405	Remainder of plate M2-2A parted suddenly between rivet 4 and edge and load fell off to 980 kips.
1060	Lag in load rate and loss in load of 20 kips; Plate M2-2B continued to elongate.
1065	Rivets 6 and 7 sheared and load fell off to 1050 kips.
1080	Rivets 8 and 9 sheared and load fell off to 1065 kips.
1098	Lag in load rate and loss in load of 5 kips.
1100	Rivets 10 and 11 sheared and load fell off to 1080 kips.
1120	Lag in load rate and loss in load of 5 kips.
1140	Lag in load rate and loss in load of 2 kips.
1148	Rivets 12 and 13 sheared and load fell off to 1138 kips.
1150	Rivets 14 and 15 sheared and load fell off to 1130 kips.
1165	Lag and loss in load of 2 kips.
1180	Maximum load on plate M2-2B and partial failure of plate by tearing between edge and rivet 10; load fell off to 1100 kips.
1115	Final sudden failure of plate M2-2B by parting of plate along line from rivet 10 to rivet 11 to edge. Both plates: square break, coarsely granular texture.

Specimen M2-3

Load, kips	Remarks
273, 304, 474, 526,613	Slight lags in load rate.
1220	Lag in load rate.
1410	Scaling of paint noted near center of plate M2-3A in region between rivets 6, 7, 8, and 9.
1430	Scaling of paint around rivets 8 and 9, both faces.
1448, 1490, 1515, 1920, 1962, 2090	Lags in load rate; some necking down of plate material in region of rivets with 2-in. edge distance.
2190	Lag in load rate and constant load for several seconds.
2395	Maximum load and partial failure; plate M2-3B parted suddenly between rivet 10 and edge and between rivet 11 and edge; load snaps occurred in quick succession at 2395, 2370, and 2330 kips.
2110	Final failure by parting of plates along line through rivets 10 and 11. Both plates: Square break, coarsely granular texture except (1) for about 1 1/4 in. from rivet 11 on plate M2-3B a V (cup-cone) break with finely granular texture, and (2) for about 2 in. from rivet 11 on plate M2-3A a sheared-cone break with finely granular texture.

Table 1. — Results of Tests on Coupons of Plate Steel

Specimen No.	Plate	Slab No.	Location of Test	Coupon No.	Yield Strength, lb. per sq. in.[a]	Tensile Strength, lb. per sq. in.	Mod. of Elasticity, million lb. per sq. in.	Elongation in 8 In., %	Reduction of Area, %	Type of Fracture
M1-1	A, B	109776	C-I.S.C.	M1-1A	61,040	103,800	-	19.5	48.4	Angular
			U.C.	M1-1B	57,600[b]	98,790	29.5	18.5	51.8	3/4 cup
			U.C.	M1-1AB	59,380	98,620	29.6	18.6	51.6	Full cup
			Avg. U.C.		58,490	98,710	29.6	18.6	51.7	-
M1-2	A, B	109776	C-I.S.C.	M1-2A	60,550	103,500	-	20.2	54.0	3/4 cup
			U.C.	M1-2B	58,280	99,730	28.9	20.0	51.8	Full cup
			U.C.	M1-2AB	59,970	97,830	30.3	18.9	52.0	Angular
			Avg. U.C.		59,130	98,780	29.6	19.5	51.9	-
M1-3	A, B	109776	C-I.S.C.	M1-3A	60,610	101,500	-	20.0	54.1	1/2 cup
			U.C.	M1-3B	58,930	99,510	29.0	18.2	50.9	Full cup
			U.C.	M1-3AB	58,260	100,570	29.4	20.2	52.0	Full cup
			Avg. U.C.		58,600	100,040	29.2	19.2	51.5	-
Avg. for all M1 coupons			C-I.S.C.	-	60,730	102,270	-	19.9	52.2	-
			U.C.	-	58,740	99,180	29.5	19.1	51.7	-
Splice plates for M1-1, M1-2, M1-3	C, D	109455	C-I.S.C.	C-130-A	64,890	102,400	-	17.5	53.7	Irregular
			U.C.	C-130-B	59,650[b]	100,270	29.5	16.6	44.5	Angular
			U.C.	C-130-C	60,200	97,220	29.1	19.9	49.8	3/4 cup
			Avg. U.C.		59,930	98,750	29.3	18.3	47.2	-
M2-1	A	109771	C-I.S.C.	M2-1A	58,660	102,600	-	19.2	50.3	Angular
			U.C.	M2-1AA	55,200[b]	99,140	30.6	20.3	51.9	Angular
			U.C.	M2-1AAA	64,300[b]	100,960	30.6	16.3	50.9	3/4 cup
			Avg. U.C.		59,750	100,050	30.6	18.3	51.4	-
	B	109771	C-I.S.C.	M2-1B	57,910	100,300	-	21.7	54.4	-
			U.C.	M2-1BB	55,000[b]	97,960	29.6	21.0	53.5	Angular
			U.C.	M2-1BBB	55,700[b]	98,850	29.9	21.0	53.8	Full cup
			Avg. U.C.		55,350	98,410	29.8	21.0	53.7	-
M2-2	A	109768	C-I.S.C.	M2-2A	61,440	102,000	-	20.0	54.7	3/4 cup
			U.C.	M2-2AA	56,900[b]	97,380	29.7	21.6	52.2	Full cup
			U.C.	M2-2AAA	57,930	97,860	29.7	20.8	55.2	Angular
			Avg. U.C.		57,420	97,620	29.7	21.2	53.7	-
	B	109768	C-I.S.C.	M2-2B	59,960	100,700	-	21.2	53.8	Irregular
			U.C.	M2-2BB	56,400	97,000	30.3	21.3	52.5	Angular
			U.C.	M2-2BBB	57,690	97,390	29.3	21.6	53.2	3/4 cup
			Avg. U.C.		57,050	97,200	29.8	21.5	52.9	-
M2-3	A	109768	C-I.S.C.	M2-3A	60,330	101,600	-	21.5	53.0	Angular
			U.C.	M2-3AA	57,290	97,800	30.9	20.7	54.2	Angular
			U.C.	M2-3AAA	57,850	97,940	29.6	21.5	52.8	Irregular
			Avg. U.C.		57,570	97,870	30.3	21.1	53.5	-
	B	109768	C-I.S.C.	M2-3B	61,000	100,600	-	20.0	55.2	3/4 cup
			U.C.	M2-3BB	58,830	97,850	29.5	20.0	54.8	Angular
			U.C.	M2-3BBB	58,630	97,360	29.5	20.7	54.1	3/4 cup
			Avg. U.C.		58,730	97,610	29.5	20.4	54.5	-
Avg. for all M2 coupons			C-I.S.C.	-	59,880	101,300	-	20.6	53.6	-
			U.C.	-	57,640	98,120	30.0	20.5	53.3	-
Avg. for all M coupons (including coupons for cover plates)			C-I.S.C.	-	60,640	101,700	-	20.1	53.2	-
			U.C.	-	58,200	98,500	29.7	19.9	52.2	-

GENERAL NOTES:

1. American Bridge Co. Contract No; G4850-X4.
2. Type I coupons; for location, see Fig. 2; for details, see Dwg.T6, Contract 6, San Francisco-Oakland Bay Bridge; overall length = 18", length of reduced (parallel) section = 9", gage length = 8"; thickness = thickness of plate; width of end sections = 2", width of reduced section = 1 1/2".
3. Heat No. W31212.
4. Slab temperatures:

Slab No.	Temperature, °F. Furnace	1st Pass	Last Pass	No. of Passes
109455	2428	2032	1566	15
109768	2450	2257	1820	17
109771	2450	2060	1833	17
109776	2428	2032	1566	15

5. Chemical analysis (by Carnegie-Illinois Steel Corp.) of samples from slab 109768:

Analysis	Carbon	Manganese	Phosphorous	Sulphur	Silicon
Ladle	0.33	1.43	0.028	0.027	0.196
Check	0.34	1.40	0.023	0.033	0.192

6. Rate of loading for coupon tests:

   Carnegie-Illinois Steel Corp.: Idling speed of testing head 0.5 in. per min.

   Univ. of Calif.: Idling speed of testing head 0.02 in. per min.

FOOTNOTES TO MAIN TABLE:

a - Determined by "drop-of-beam" method, except as noted.
b - Determined by offset method (offset = 0.10 percent).

Table 2. — Results of Tests on Coupons of Rivet Steel

Steel	Heat No.	Location of Test	Coupon No.	Yield Strength, lb. per sq. in.[a]	Tensile Strength, lb. per sq. in.	Elongation in 2 In., %	Reduction of Area, %	Type of Fracture
Carbon	129947	C-I.S.C.	-	40,750	59,600	35.0	65.7	-
		U.C.	C1	38,040	52,920	40.0	71.5	1/2 cup
			C2	38,710	60,150	36.5	65.3	1/2 cup
			C3	38,090	61,170	35.5	59.9	Full cup
			C4	41,860	60,710	33.0	64.8	3/4 cup
			C5	38,150	58,280	38.0	67.0	3/4 cup
			C6	39,470	53,420	38.0	72.5	3/4 cup
			C7	36,270	52,600	41.0	73.6	3/4 cup
			C8	41,090	58,280	36.5	68.0	3/4 cup
			C9	39,880	60,610	35.0	63.3	3/4 cup
			C10	40,180	62,180	33.5	59.2	3/4 cup
			C11	42,360	60,570	32.5	60.4	1/2 cup
			C12	41,300	57,040	39.0	69.9	1/2 cup
			C13	44,790	60,410	36.5	63.0	1/2 cup
			C14	45,860	61,120	37.5	64.0	1/2 cup
			C15	40,860	61,160	32.5	63.8	1/2 cup
			C16	43,920	60,950	36.5	64.8	1/2 cup
			C17	44,030	61,680	34.5	60.0	1/2 cup
			C18	38,500	60,160	36.5	64.5	Full cup
			C19	38,500	56,560	37.5	70.6	1/2 cup
			C20	39,910	53,000	40.0	71.3	1/2 cup
		U.C. Average		40,690	58,650	36.6	65.9	---
Manganese	123885	C-I.S.C.	-	56,980	88,800	26.0	58.7	---
		U.C.	M1	52,760	79,630	29.5	66.2	3/4 cup
			M2	52,250	78,730	30.6	69.0	1/2 cup
			M3	49,260	78,160	33.0	68.7	Full cup
			M4	50,170	81,920	32.0	66.0	1/2 cup
			M5	53,920	82,990	29.5	66.5	1/2 cup
		U.C. Average		51,670	80,290	30.9	67.3	---
Annealed Manganese[b]	123885	C-I.S.C.	-	49,920	80,490	29.0	64.0	---
		U.C.	MA1	52,950	77,350	33.0	64.2	3/4 cup
			MA2	51,590	73,300	34.0	66.0	3/4 cup
			MA3	53,260	77,000	31.5	64.0	1/2 cup
			MA4	52,850	77,150	33.5	66.2	Full cup
			MA5	52,150	76,090	32.5	65.0	1/2 cup
		U.C. Average		52,560	76,180	32.9	65.1	---

GENERAL NOTES:

1. American Bridge Co. Contract No. G4850-X4.

2. Type III coupons; for details, see Dwg. T8, Contract 6, San Francisco-Oakland Bay Bridge; overall length = 9", length of reduced (parallel) section = 2 1/2", gage length = 2"; nominal diameter of end sections = 1" (rivet stock), diameter of reduced section = 1/2". For results of tests on rivet stock, see Table 2a.

3. Ladle analysis (by Carnegie-Illinois Steel Corp.):

Heat No.	Carbon	Manganese	Phosphorous	Sulphur	Copper
129947	0.13	0.45	0.020	0.033	0.26
123885	0.22	1.35	0.026	0.021	0.30

4. Rate of loading for coupon tests:

Carnegie-Illinois Steel Corp.: Idling speed of testing head 0.5 in. per min.

Univ. of Calif.: Idling speed of testing head 0.05 in. per min.

5. Driving temperature of rivets:

Specimen	Rivet Steel	Driving Temp., °F.
M1-1, M1-2, M1-3	Manganese	1650
M2-1, M2-2, M2-3	Carbon	1795

All rivets driven with pressure tool.

FOOTNOTES TO MAIN TABLE:

a - Determined by "drop of beam" method.
b - Annealed at 1450°F.

Table 2a. — Results of Tests on Coupons of Rivet Stock

Steel	Heat No.	Yield Strength, p.s.i.		Tensile Str., p.s.i.		Elongation, percent		Reduction of Area, percent	
		Rivet Stock	Type III Coupon	Rivet Stock	Type III Coupon	Rivet Stock[a]	Type III Coupon[b]	Rivet Stock	Type III Coupon
Carbon	129447	39,750 39,360	40,750	57,550 56,770	59,600	33.5 32.5	35.0	54.2 63.3	65.7
Manganese	123885	54,860 54,330	56,980	81,360 80,710	88,800	22.0 26.2	26.0	55.1 55.8	58.7
Annealed Manganese	123885	50,080 48,890 48,620	49,920	75,110 74,720 74,190	80,490	27.2 28.0 27.7	29.0	62.7 62.7 62.7	64.0

a - In 8 in.

b - In 2 in.

NOTE: All tests made by Carnegie-Illinois Steel Corporation.

Rivet stock 63/64 in. diam.

For description of Type III coupons, see Table 2.

Table 3. -- Slip in Joint of Type M1 Specimens at 0.30 Working Load and at Working Load

Gage No.[a]	Slip, Inches					
	0.30 Working Load			Working Load[b]		
	M1-1	M1-2	M1-3	M1-1	M1-2	M1-3
1	0.0028	0.0023	0.0018	0.0135	0.0115	0.0124
2	0.0009	0.0021	0.0016	0.0109	0.0101	0.0115
3	0.0022	0.0030	0.0013	0.0122	0.0141	0.0112
4	0.0012	0.0030	0.0019	0.0106	0.0132	0.0121
Avg.	0.0018	0.0026	0.0017	0.0118	0.0122	0.0118
5	0.0010	0.0002	0.0008	0.0078	0.0048	0.0067
6	0.0008	0.0002	0.0008	0.0078	0.0051	0.0068
7	0.0003	0.0005	0.0003	0.0051	0.0062	0.0063
8	0.0003	0.0006	0.0006	0.0053	0.0068	0.0075
Avg.	0.0006	0.0004	0.0006	0.0065	0.0057	0.0068
9	0.0013	0.0010	0.0004	0.0074	0.0073	0.0068
10	0.0014	0.0002	0.0002	0.0072	0.0038	0.0039
Avg.	0.0013	0.0006	0.0003	0.0073	0.0056	0.0054
11	0.0030	0.0028	0.0026	0.0117	0.0119	0.0089
12	0.0027	0.0015	0.0019	0.0116	0.0092	0.0135
Avg.	0.0029	0.0022	0.0023	0.0117	0.0106	0.0112

a - For location of gages, see Fig. 7.

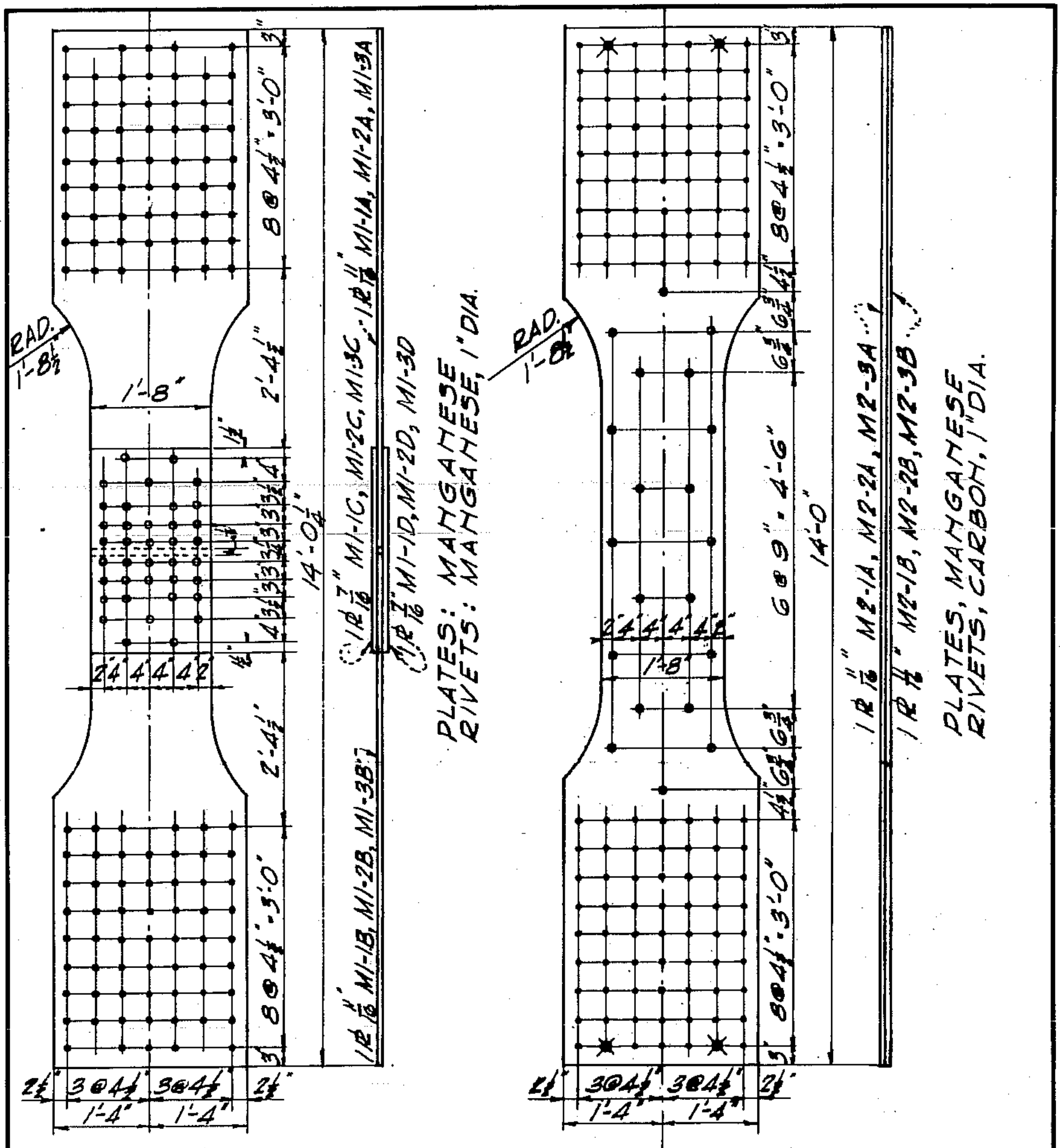
b - Average working load 410 kips.

Table 4. -- Results of Tests on Specimens

Specimen Type	Specimen No.	Ult. Strength: Total Load, kips	Ult. Strength: Average Stress at Net Section, k.s.i.	Calculated Efficiency,[a] per-cent	Average Elongation to Rupture, percent[b]: Plate A	Average Elongation to Rupture, percent[b]: Plate B	Failure[c]
Butt joint	M1-1	1089	90.3	81	-	-	Sudden and complete failure by parting of main plate M1-1A along section through rivets 1 and 2. Square break, coarse granular texture.
	M1-2	857	70.6	63	-	-	Partial failure at maximum load by parting of main plate M1-2B from edge through rivet 37 to rivet 38; final failure at load of 119 kips by parting of plate between rivet 38 and edge. Major portion of break square with coarse granular texture.
	M1-3	1109	91.8	81	-	-	Partial failure at maximum load by parting of main plate M1-3A between edge and rivet 2; final failure at load of 1095 kips along line (rivet 2 to rivet 1 to rivet 3 to edge). Major portion of break square; coarse granular texture.
Stitch-riveted plates	M2-1	2230	91.3	82	5.2	5.7	Partial failure at maximum load by parting of plate M2-1A between edge and rivet 15; failure progressed slowly to final rupture at 510 kips; failure took place across irregular section through rivets 14 and 15, both plates. V or cup-cone fracture with fine granular texture except at section between rivet 15 and edge which showed a square break with coarse granular texture.
	M2-2	1552	63.7	58	0.5	4.5	Partial failure at maximum load in plate M2-2A between rivets 4 and 5; final failure of plate M2-2A at load of 1405 kips; square break, coarse granular texture. Several rivets sheared while plate M2-2B continued to elongate. Partial failure of plate M2-2B at load of 1180 kips (nominal stress in net section = 96.9 k.s.i.) by parting of plate between edge and rivet 10; final failure at load of 1115 kips by parting along section through rivets 10 and 11. Square break, coarse granular texture.
	M2-3	2395	97.9	89	4.4	4.5	Partial failure at maximum load by parting of plates between rivet 10 and edge and between rivet 11 and edge; final failure at load of 2110 kips along section through rivets 10 and 11. Major portion of break square with coarse granular texture.

a - Ratio of observed strength of specimen to computed strength at gross section of main plate based upon coupon tests at the University of California.
b - Average over length of 50 in. along center line of face of specimen.
c - Numbering of rivets shown in Fig. 8 for butt-joint specimens and Fig. 7 for stitch-riveted specimens.

Table 4



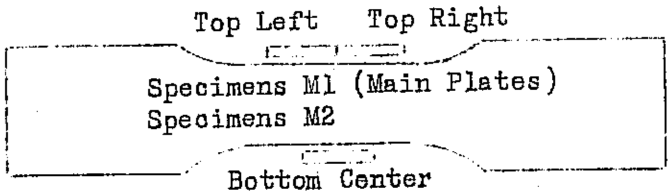
M1-1, M1-2, M1-3 M2-1, M2-2, M2-3

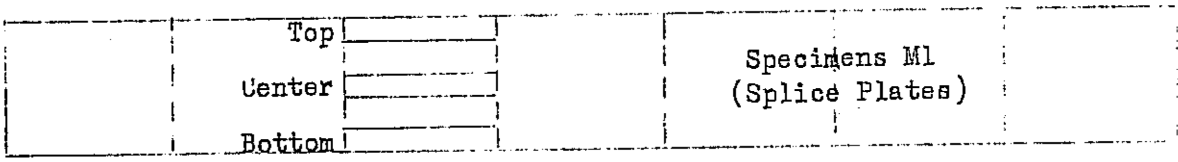
SCALE APPROX. ½" = 1'-0"

NOTE: DATA FROM:
AMERICAN BRIDGE CO. CONTRACT NO. G4850-X4, SHEETS T227 AND T228, REVISION OF APRIL 30, 1935.

DRAWN: JUNE 1936	UNIVERSITY OF CALIFORNIA ENGINEERING MATERIALS LABORATORY
	TESTS ON HEAVY RIVETED JOINTS
	SPECIMEN DETAILS-- SERIES M
	DRAWN BY E.J.G. / APPROVED: [signature] / DWG. NO. 36A-7

FIG. 1





Specimen	Coupon Marking		
	Top Left	Top Right	Bottom Center
M1-1 (main plates)	M1-1A	M1-1B	M1-1AB
M1-2 (main plates)	M1-2A	M1-2B	M1-2AB
M1-3 (main plates)	M1-3A	M1-3B	M1-3AB
M2-1	M2-1A	M2-1AA	M2-1AAA
	M2-1B	M2-1BB	M2-1BBB
M2-2	M2-2A	M2-2AA	M2-2AAA
	M2-2B	M2-2BB	M2-2BBB
M2-3	M2-3A	M2-3AA	M2-3AAA
	M2-3B	M2-3BB	M2-3BBB
M1-1,2,3 (splice plates)	Top	Center	Bottom
	C-130-A	C-130-B	C-130-C

University of California
Engineering Materials Laboratory
Tests on Heavy Riveted Joints

LOCATION AND MARKING
OF COUPONS

Series M

Drawn 6/6/36

Drawn by N.B. | Approved R. E. Davis | Dwg. No. 36A-8

FIG. 2

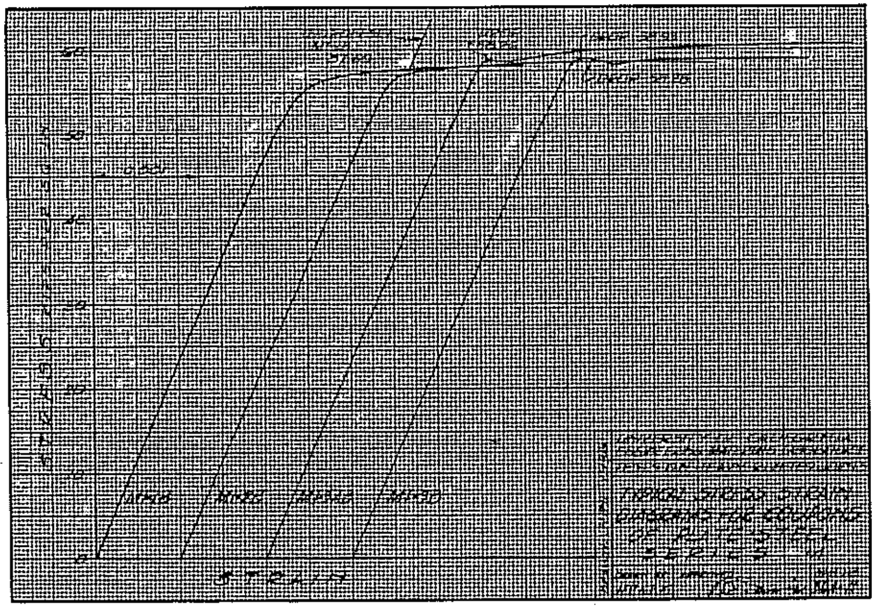


FIG. 3

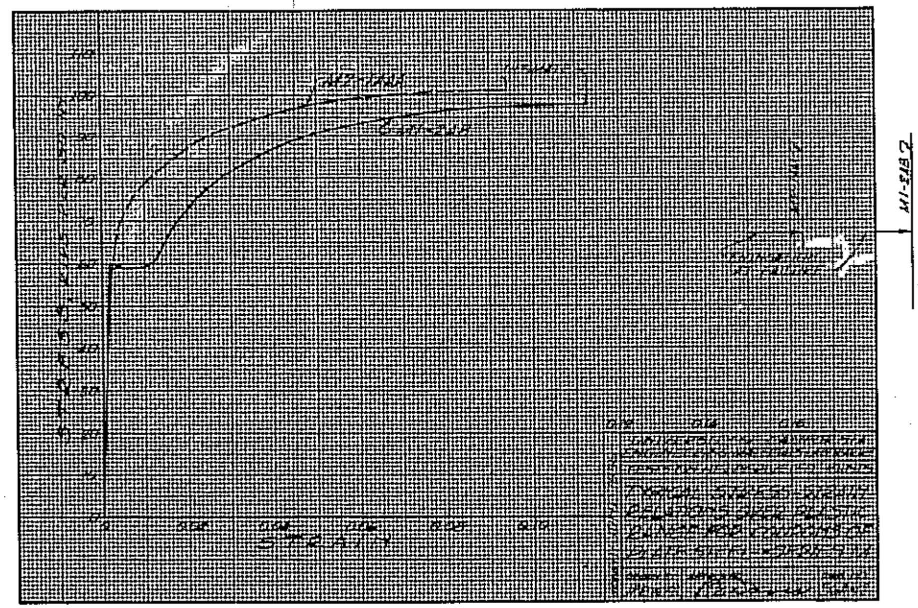


FIG. 4

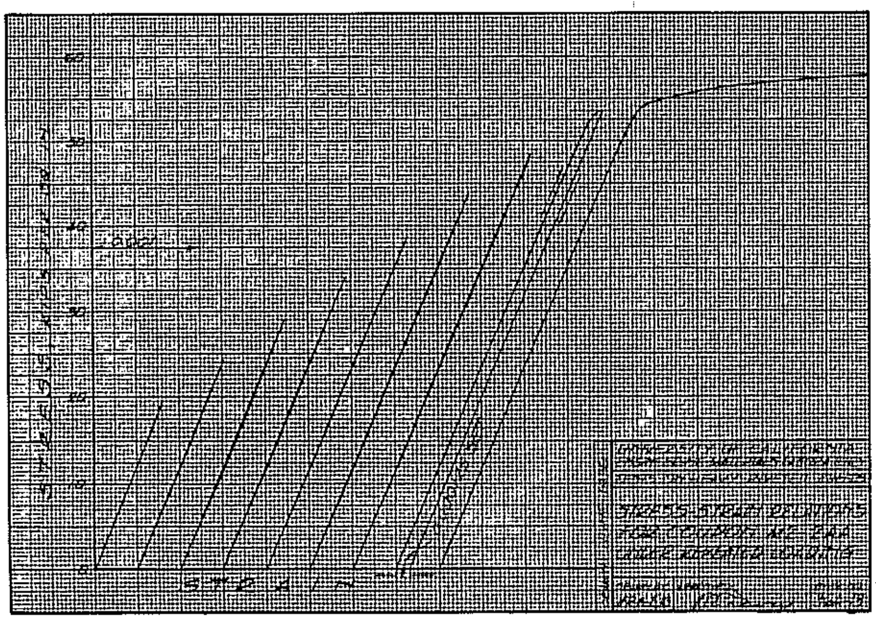


FIG. 5

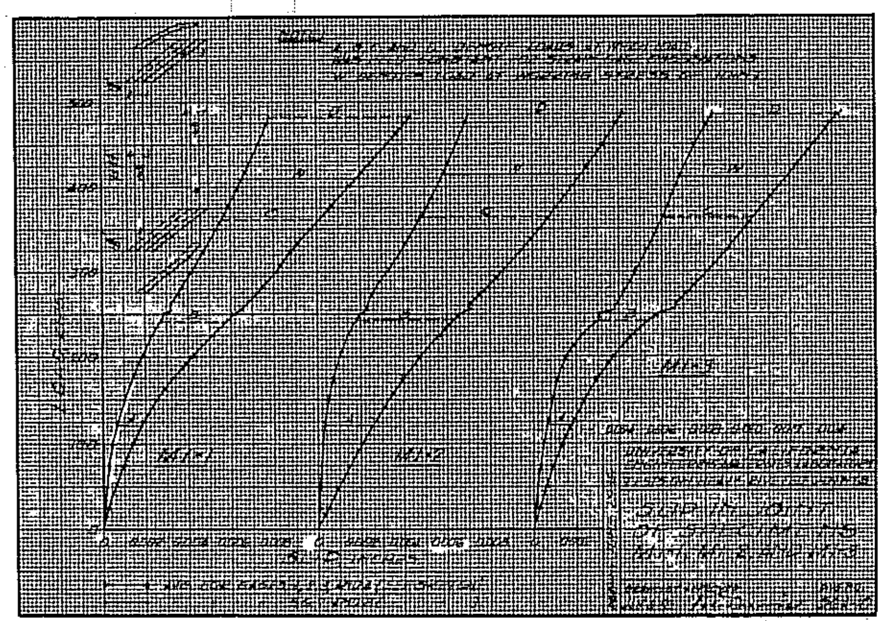
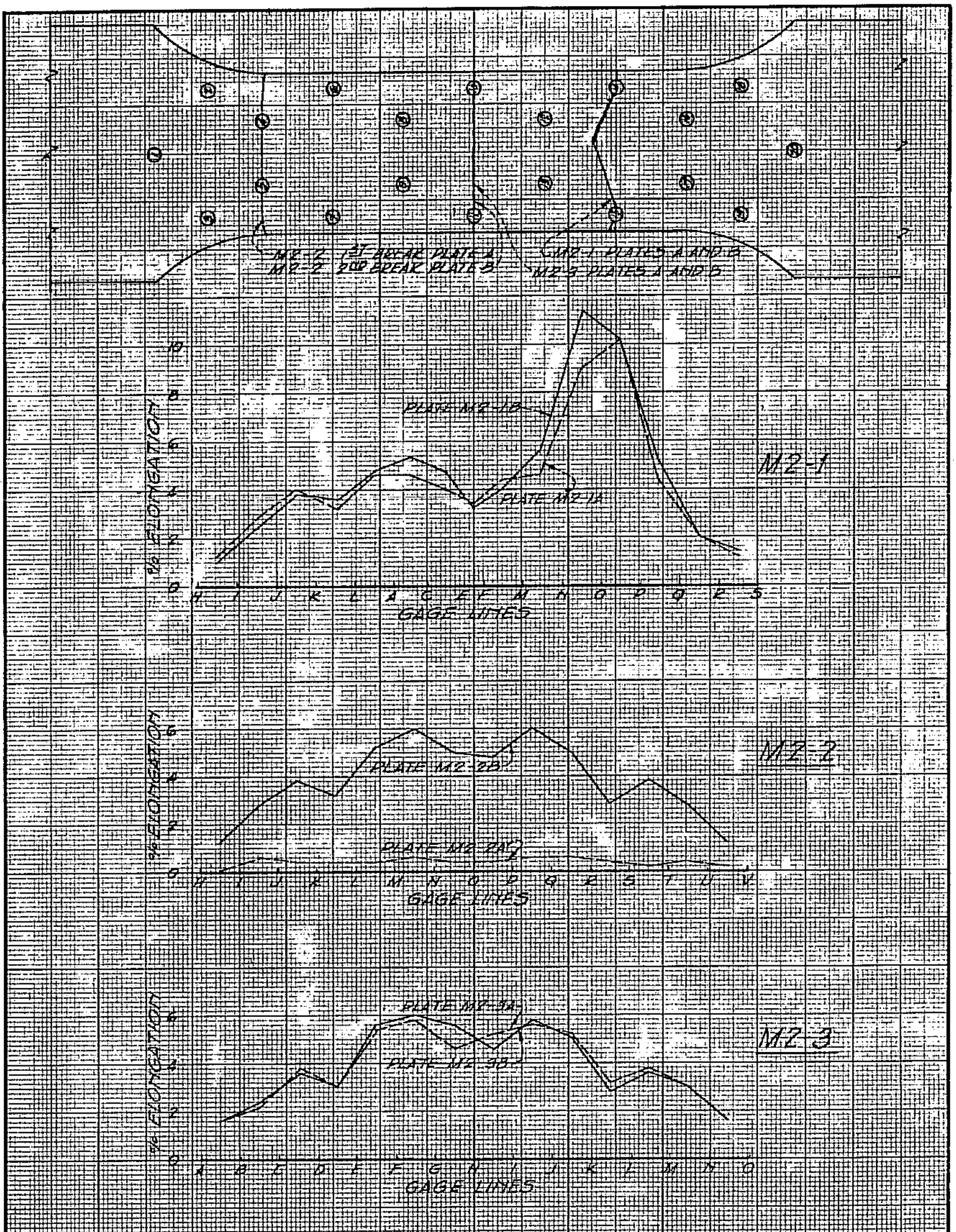


FIG. 6



NOTE:

ELONGATION TO FAILURE MEASURED ON CENTER LINE OF PLATE, AT GAGE LENGTHS OF 5 IN. (EXCEPT 2½ IN. FOR LINE EF ON SPECIMEN M2-1)

HEAT NO. W31212; SPECIMEN M2-1 FROM SLAB NO. 109771; SPECIMENS M2-2 AND M2-3 FROM 109768

UNIVERSITY OF CALIFORNIA ENGINEERING MATERIALS LABORATORY	
TESTS ON NAVY RIVETED JOINTS	
ELONGATION OF SPECIMENS M2-1, M2-2, AND M2-3	
DRAWN BY: E.J.B.	APPROVED: [signature]
DWG NO. 361-9	DRAWN - JUNE 1936

FIG. 7

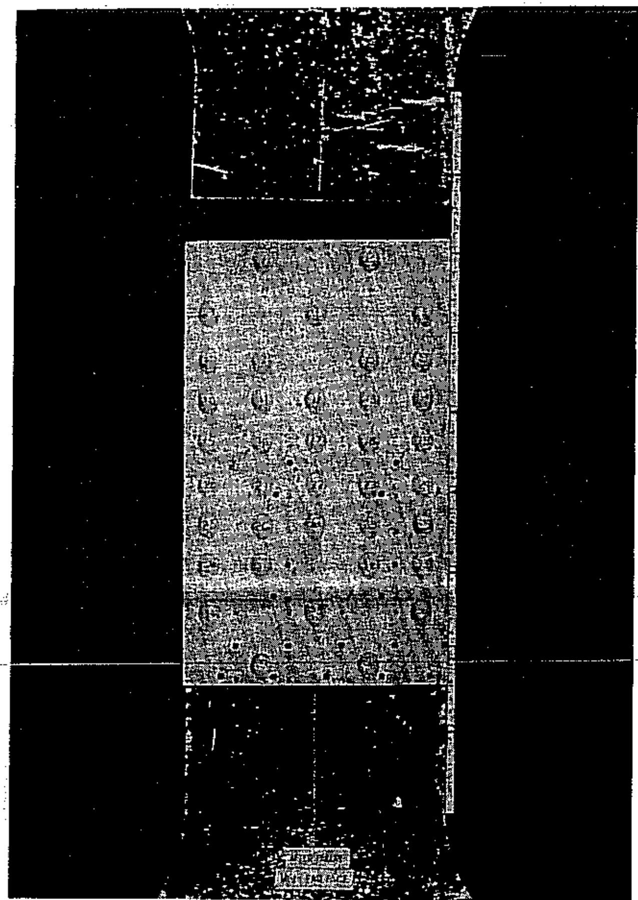


Fig. 8

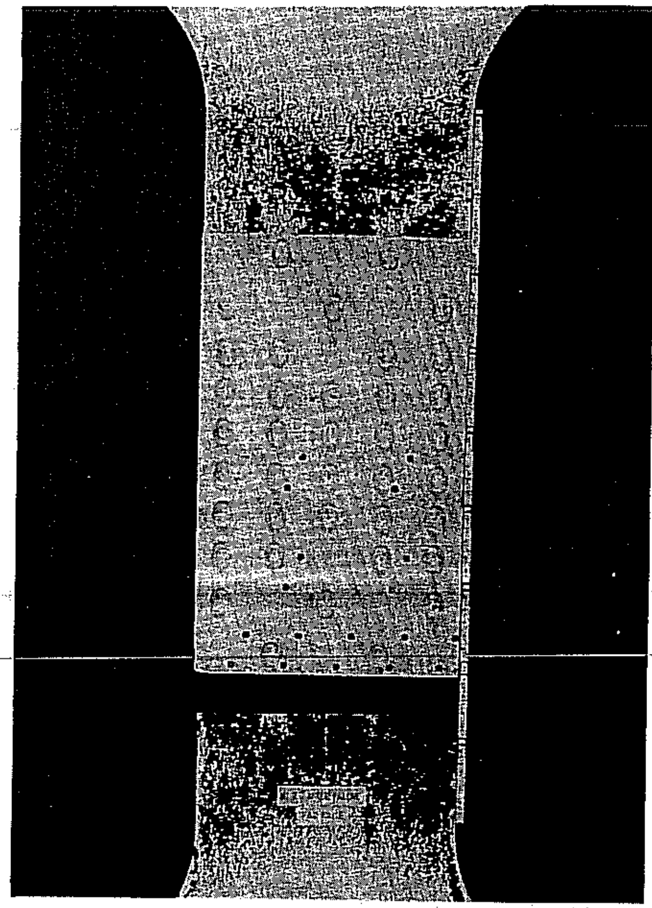


Fig. 9

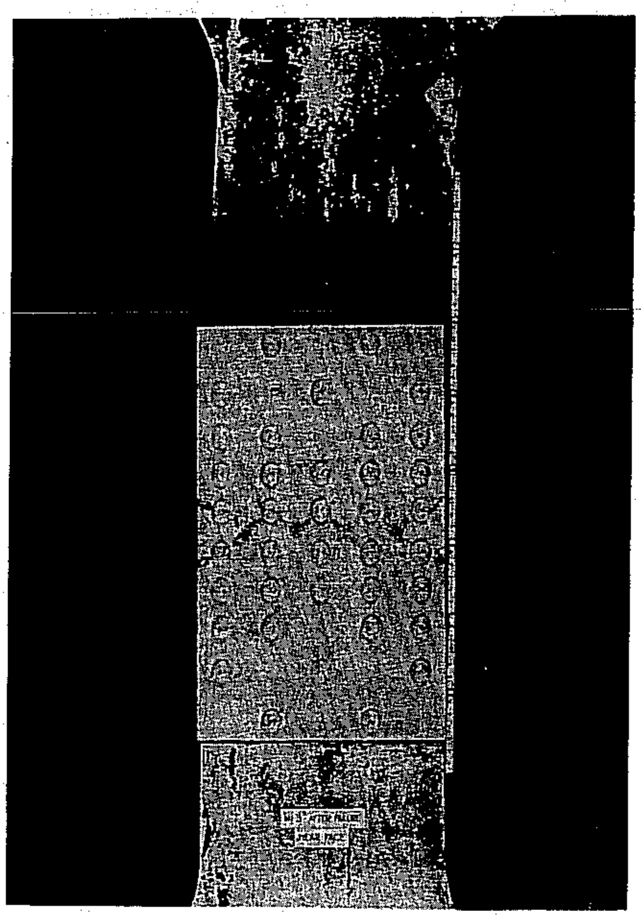


Fig. 10

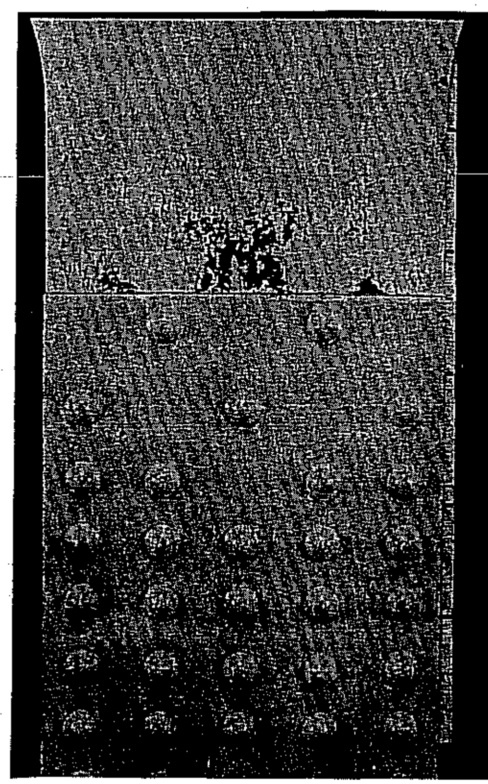


Fig. 11

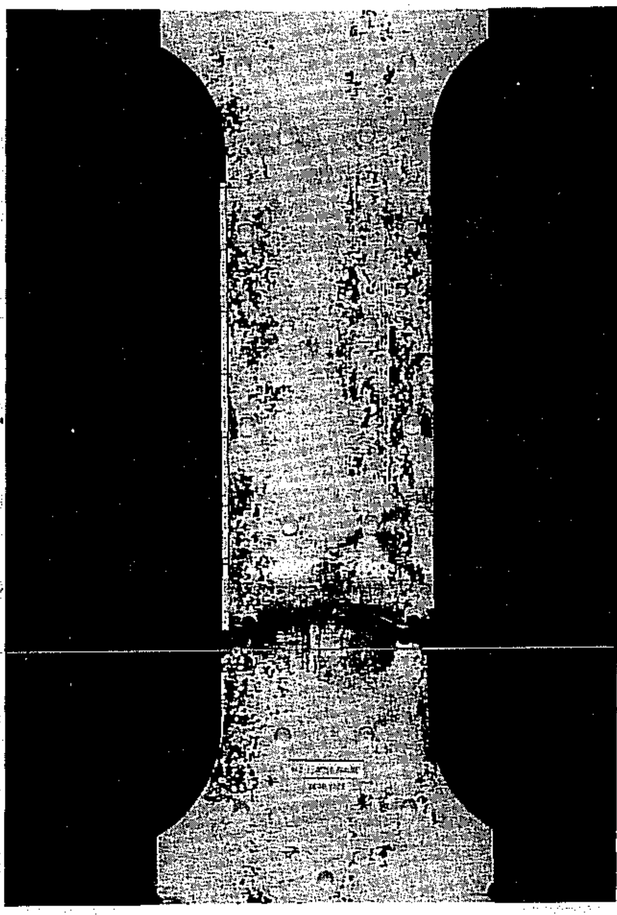


Fig. 12

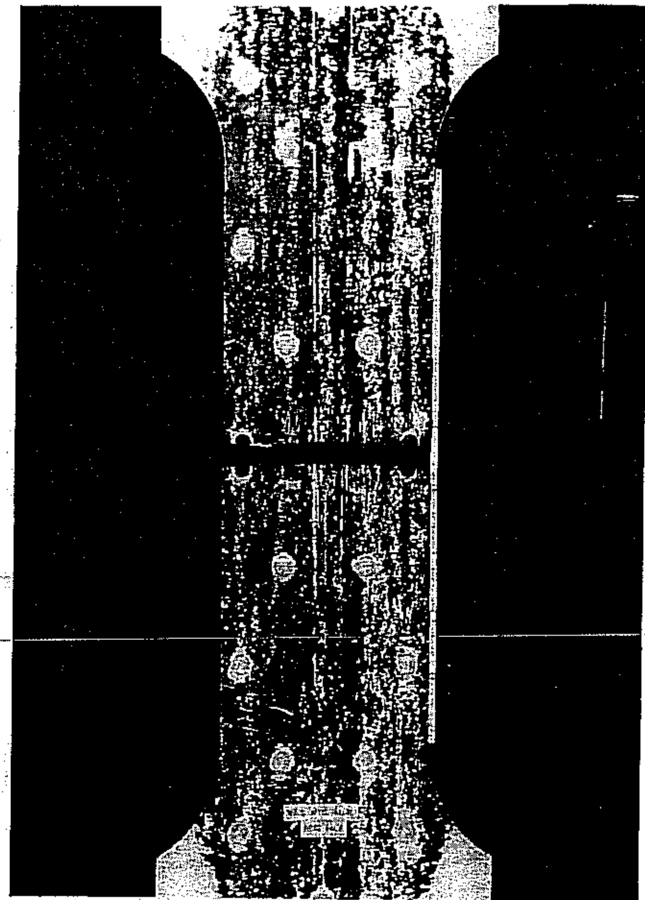


Fig. 13

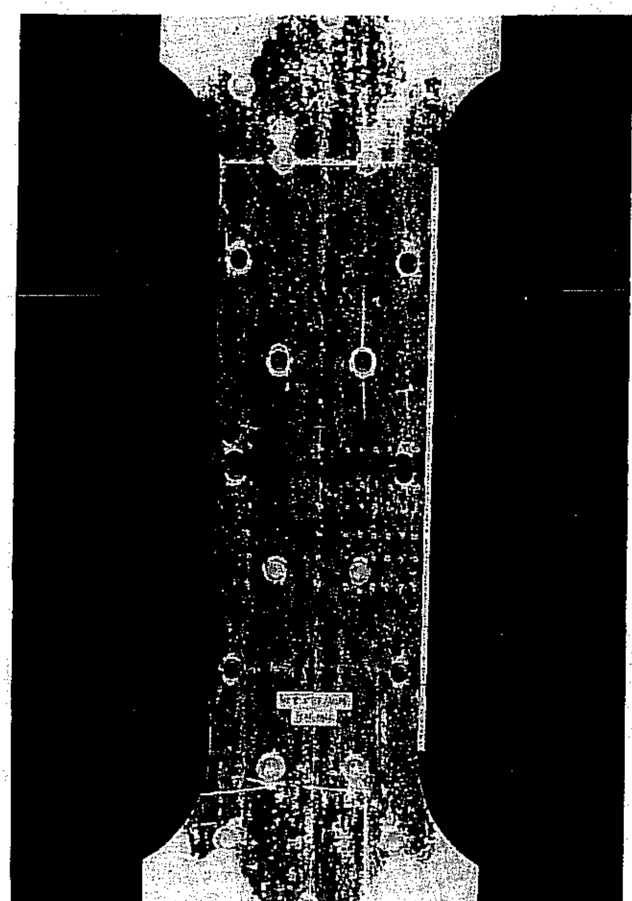


Fig. 14

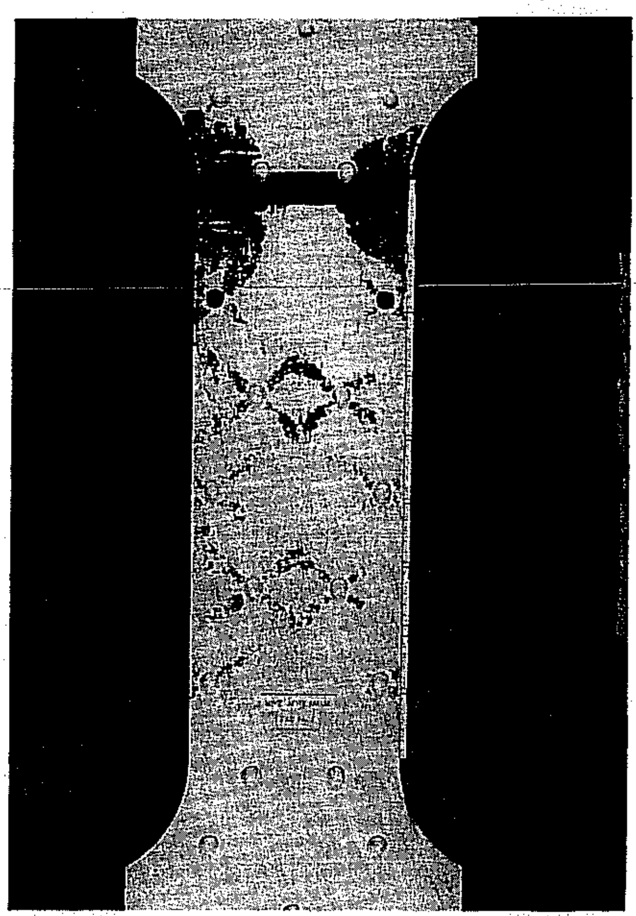


Fig. 15

STATE OF CALIFORNIA

DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

TESTS ON RIVETED TENSION MEMBERS AND THEIR CONNECTIONS

June 1934

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

TESTS ON RIVETED TENSION MEMBERS AND THEIR CONNECTIONS

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Appendices

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

TESTS ON RIVETED TENSION MEMBERS AND THEIR CONNECTIONS

A. INTRODUCTION

Structural steel is the most reliable and the most uniform in its characteristics of all materials with which the engineer has to deal. It is possible that this reliability explains the small amount, when compared to reinforced concrete, of experimental work that has been done on this material. Of the laboratory work on large steel members, the majority of tests have been on compression specimens, and very few investigations have been conducted on tension members of a corresponding size. There have been some very thorough investigations of riveted joints, but these have been mainly confined to the wide and short joints that obtain in tank and ship work rather than on the long joints that occur on heavy bridge work.

It is the purpose of this series of tests to secure experimental data that will justify or disprove certain assumptions, many of them tacit, that are now made in the design of heavy riveted steel structures.

B. PROBLEMS INVOLVED

Some of the uncertainties involved are noted below. An analysis of some would include a study of all processes connected with the manufacture of structural steel, which is, of course, beyond the scope of the present investigation. Others would involve the use of more elaborate testing equipment than is available. It will, however, be wise to keep all these questions in mind and to consider their bearing on past experiments and those now proposed.

(1) Elastic and Plastic Action of Structural Steel.

While structural steel is commonly considered an elastic material, its plastic action is of great importance in the even distribution of stress over the component parts of a tension member and even over the entire area of each component. This action is most important in a riveted joint. In the tests herein proposed every effort should be made to investigate this question.

(2) Information Furnished by Commercial Mill Tests and its Relation to the Strength of a Fabricated Tension Member.

Recent technical literature contains such expressions as "It is also evident that the yield point, as recorded by the ordinary tensile specimen tests, ... does not give the correct index of the strength of the material." Other indices such as the "Useful Limit Point" have been considered. All possible information along these lines should be secured during the investigation.

(3) Distribution of Stress over Wide Plates of Higher Strength Steels.

This question has been investigated in the case of ordinary structural steel, the results indicating a quite uniform distribution of stress. It is desirable to extend these investigations to include the case of high tensile steels and also to include a steel in which the yield point closely approaches the ultimate.

(4) Effect of Rivet Holes in Reducing the Strength of a Tension Member.

In an elastic material subjected to stress, high concentrations occur at the edges of a hole drilled through the material. In case the material also possesses plastic properties, readjustments of the material will take place so that, within certain stress limits, the condition is not serious. The effect of this stress readjustment is probably more favorable in the case of a member subjected to stress in one direction only than in one subjected to alternating stresses.

Assuming equal stress distribution over the widths between holes, formulae for stagger of holes to maintain net section may be established. These formulae are based on elastic theories and do not consider plastic action.

(5) Variations, including Reversal of Stress.

An immense amount of experimental work has been done in recent years on alternating stresses. Due to the difficulties of providing suitable equipment, these investigations have not included large size members under direct tension and compression, so that the rules for designing members subject to alternate stresses are largely "rule of thumb." In the present series, only a limited amount of stress reversal study is contemplated. Care should therefore be taken in applying any deductions from the test data to members subject to stress reversal.

(6) Modulus of Elasticity of a Fabricated Tension Member.

The stress-strain ratio of a standard tension test specimen closely follows a straight line below the yield point, with a modulus of between twenty-nine and thirty millions of pounds per square inch. In the case of a wide plate it is possible that the release of stresses from the rolling operation would result in a lesser apparent value. In a fabricated member there is probably considerable plastic flow resulting from stress adjustment over the component parts, and also the effect of the rivet holes must have some effect. There appear to be no published results of investigations of these points.

(7) Partition of Stress between the Different Rivets in a Riveted Joint.

Assuming elastic conditions, it is possible to determine the partition of stress between the various rows of rivets in a joint. These analyses indicate that most of the stress is taken by the end rivets. Tests of riveted joints indicate a stress redistribution so as to more nearly equalize the stress between the different rivets. The majority of these tests have been made on joints containing comparatively few rivets or on wide joints with comparatively few rows. It remains to be demonstrated that this redistribution will take place in a long joint and at a stress in which no permanent injury is done to any of the component parts.

(8) "Slip" in a Riveted Joint.

The cooling of a rivet after it has been driven results in a considerable tension in the rivet producing tension in the shank and a contraction in the diameter of the shank. The amount of friction probably varies over a wide range, depending on the extent to which the parts are held in contact by bolts, the "spring" in the components, the driving temperature of the rivets, the length of time the pressure is held, etc. When the load in the joint exceeds the friction, the parts will slip until the rivets come into full bearing against the hole. In case the term "slip" is held to include all distortions except those due to elasticity, the plastic deformations resulting from the overstresses at the edge of the hole may also play a small part.

Most investigators agree that this slip occurs within usual working stresses and that the rivet material has little, if any, effect on the stress at which slip will occur, and there seems to be a tendency to minimize the effect of friction. However, until the rivets loosen, this friction must play an important part in the action of the joint, and this effect should be considered in the proposed series of tests.

(8) Comparison of Rivet Materials.

Until recently the standard structural steel has been of the 55,000- to 65,000-pound grade and the corresponding rivet steel has been 46,000- to 56,000-pound. At present the use of 60,000-72,000-pound medium grade is gaining favor with 52,000 to 62,000 specified for rivets. For many years there has been a search for a higher strength rivet steel for use with nickel and other high strength alloy steels. Nickel steel rivets have been tried, but for many reasons have not proven satisfactory. In the past few years a carbon manganese rivet has been used in a number of large structures. In the present program it is proposed to compare the efficiency of these rivets with the higher grade structural rivet.

(9) Thickness of Material.

Many investigators have pointed out that, presumably due to the smaller amount of work the material receives during rolling, thick material has a lower yield point than the thinner. In ordinary practice the thickness is held to a maximum of 3/4" to 1", although in many cases the use of thicker material would have some advantages.

(10) Effect of Details on the Strength of Members

Examinations of overstressed bridges establish the fact that trouble almost invariably occurs due to faulty details. In spite of this fact very little experimental investigation has been done towards establishing the effect of these details. As subjects for experiment may be suggested the following:-

a. Butt vs. lap and shingle splices.
b. Eccentricity at gusset plates.
c. Effect of pantograph action of lacing bars.
d. Action of rivets passing through fillers.
e.

f.

(11) Effects of Shop Workmanship

a. Edge planing.
b. Full-size punching vs. reaming.
c. Variations in riveting conditions.
d.

e.

The effect of the first two can not be properly studied without apparatus for a great number of cycles of variable stress. The third is outside the scope of the present program, but is being covered by an independent study.

C. PREVIOUS INVESTIGATIONS

a. Riveted Joints

There has been a great deal of both theoretical and experimental work done in connection with riveted joints. The best statement of this work has been made by A. E. R. de Jonge (1) and (2).

Theoretical Analyses

Prof. Cyril Batho (3) treated the subject theoretically and compared his results with test data. His analysis and tests indicated that no gain in strength was obtained by using more than five lines of rivets in a joint, and even with five lines the majority of the stress was carried by the inner and outer rows.

- - - - - - - - -

Hrennikoff (1) presents similar conclusions. He admits, however, that, due to the ductility of the structural member, the rivets at the center of the joint come into play. He recommends in detailing:-

(1) Increasing the number of gauge lines so as to reduce the number of rivets on each gauge line.

(2) Reducing the longitudinal pitch to the minimum.

(3) Making the number of rivets on each gauge line proportional to the area of the material centering on that gauge line.

Experimental

While it is not practicable to describe in detail the many tests that have been made on riveted joints, there are a few outstanding series which should be mentioned. Most of the tests mentioned have been made in connection with tank and ship work, so that they do not cover the case of long connections or splices.

- - - - - - - -

The A.R.E.A. tests (4) are outstanding in that the results have formed the basis of American specifications on riveted joints for the past thirty years. The conclusions follow:-

(1) That the resistance of a riveted joint against deformation by shearing forces, up to the yield point, is due to the friction between the surfaces held in contact by the rivets.

(2) That the yield point of a riveted joint is reached when the shearing forces are equal to the friction of the surfaces held in contact by the rivets.

(3) That the deformation of a riveted joint at the yield point is caused by the slipping on each other of the surfaces held in contact by the rivets, and is due to the diametral contraction of the rivets in cooling after they are driven, which leaves a space between the body of the rivet and the edge of the rivet hole.

(4) That after the slip at the yield point has occurred and the rivet is brought to bear against the edge of the rivet hole, a deformation of the body of the rivet takes place with an accelerating increase in resistance, until the entire side of the rivet has been brought to bear against the edge of the rivet hole, and that the deformation continues beyond this point with a diminishing increase in the resistance, until the ultimate strength of the rivet in shear has been reached and the breakdown occurs.

(5) That lap joints, on account of the unsymmetrical distribution of the material, deflect sideways under strain, throwing the rivets in tension, and thereby reducing the shearing forces between the surfaces held in contact by the rivets.

(6) That fillers inserted between the main plates reduce the strength of a riveted joint, but that the full strength can be obtained by connecting the fillers to the main plates by additional rivets.

(7) That the number of rivets connecting the fillers to the main plates should, for each intervening plate, be about one-third of the number of rivets required in a similar joint without fillers, to obtain the same strength in both cases.

(8) That the strength of a riveted joint with rivets of larger grip than about four times their diameter is decreased, as the length of the grip is increased.

(9) That the number of rivets, in a riveted joint with larger grip of the rivets than four times their diameter, should be increased at least one percent for each one-sixteenth of an inch increase in the grip above this length, to obtain the same strength as a similar joint with the grip of the rivets shorter than four times their diameter.

(10) That a riveted joint, subject to forces always acting in the same direction, may safely be strained beyond the yield point up to a point where the rivets are brought to bear against the edges of the rivet holes.

(11) That a riveted joint, subject to forces alternating in opposite directions, may not safely be strained up to the yield point.

(12) That, to obtain a minimum slip at the yield point, it is necessary that the holes in the component pieces should thoroughly match, and that the driving tool should upset the rivet throughout its length, so that it will thoroughly fit the rivet hole.

\- - - - - - - -

The Illinois tests of 1906 (5) were largely a duplicate of the A.R.E.A. tests, except that nickel steel was used in place of carbon steel. The conclusions of these tests follow:-

(1) A total of 90 nickel-steel riveted joints and of 54 chrome-nickel-steel riveted joints were tested in tension. These riveted joints duplicated in dimensions the series of carbon-steel riveted joints reported by the American Railway Engineering and Maintenance of Way Association. Sixteen nickel-steel riveted joints and sixteen chrome-nickel steel riveted

joints were tested in tension, compression and alternate tension and compression. Stretch, slip and set of riveted joints were observed, and the bending of rivet was determined by means of holes drilled axially through the rivets.

(2) In the tests there was a noticeable slip of joint generally at loads within ordinary working shearing stress of rivet. The movement of the joint increased fairly regularly to a load averaging about 35,000 pounds per square inch of rivet shear for the nickel-steel riveted joints, when a marked increase of movement was found. This increase was closely coincident with a marked set of the joint and with a marked bending of the rivet. All the riveted joints failed by shear of rivets, as was to be expected, at ultimate shearing stresses which ran fairly uniform in both the nickel-steel series and the chrome-nickel-steel series for all the types of joint tested.

(3) The experimental evidence indicates that the resistance of the joint to first noticeable slip of rivet depends more upon the workmanship of the riveting than upon the quality of the rivet material, though the contractile and gripping properties of the rivets have an influence.[Φ]

(4) The yield point of a riveted joint, taken as the load at which a marked increase of yield occurs, seemingly indicates a definite property of the riveted joint. This phenomenon is worthy of further investigation. The first marked bending of the rivets was found to be closely coincident with the yield point of the joint. It was found that the longer the rivet the greater the relative importance of the resistance to bending. In the alternate tension and compression tests the first appreci-

---

[Φ] To determine the effect of painting the contact surfaces of riveted joints upon the load to give first noticeable slip, a phase of the subject brought out in correspondence with Mr. Albert Kingsbury, of Pittsburgh, Pennsylvania, tests for this purpose have been made since this bulletin was put in type. Joints resembling TB5 were riveted up, one set being unpainted, one set painted with graphite paint, and one set painted with red lead. All the riveted joints showed evidence of slip at loads within ordinary working shearing stress of rivets. Those painted with graphite paint gave noticeable slip at loads somewhat lower than those painted with red lead, and the unpainted test joints slipped at loads still a little higher, the differences in the three types of test joints being not large.

able bending of the rivet seemed to be slightly lowered by a few applications of load.

(5) In the alternated load tests the most striking feature was the relatively large slip which took place at comparatively low loads. The amount of this slip was especially large when a riveted joint had been subjected to a single load considerably beyond the ordinary load.

(6) The ultimate shearing strength of riveted joints depends on the shearing strength of rivet material, and this is influenced by the relative hardness of rivets and plates.

(7) The ratio of the yield point of riveted joint to ultimate shearing strength of riveted joint in the tests was about the same as the ratio of the yield point of the plate material in tension to the ultimate tensile strength of the plate material.

(8) In riveted joints designed on the basis of ultimate strength, strength of rivet material and of plate material are of prime importance and the use of special steels of great strength may be of advantage.

(9) In riveted joints designed on the basis of frictional hold of rivets without reference to the bending of rivets there is little advantage in using rivets of special steels of great strength, since joints with such rivets show about the same resistance to first noticeable slip as do joints with ordinary carbon-steel rivets.

- - - - - - - -

Gayhart's tests (6) were made on high strength steels and rivets and were made with special reference to ship plating.

Certain of Gayhart's conclusions follow:-

"At low plate stress intensities the outer row of rivets of any joint carries a larger portion of the total load."

"On account of a probable 'quilting' action in the cover plates during the riveting of a multiple row joint, joints containing four or more rows of rivets show inferior slip resistance."

"Joints fabricated of high tensile steel show resistance to slip greatly inferior to that shown by medium steel and so low that it appears doubtful whether any great portion of the load could be considered as carried by frictional forces."

"In terms of single shear stress, the stress in the rivet at which the first slip occurs is so much lower than customary design shear stresses, and is so greatly affected by the number of rivets in the joint and the effects of eccentric loading and bending, that it does not appear desirable to design riveted joint construction on the basis of frictional resistance, but rather by the commonly used method of proportioning on shearing and bearing."

"Joints in which the alternate rivet was omitted in the outer row did not develop the efficiency that might be expected from their greater net section area. They showed an efficiency likewise of 80 per cent, from which it appears that a tighter joint with greater slip resistance may be obtained with full-row riveting without loss in joint efficiency."

"The frictional resistance of a joint fails at such low plate stress that for practical purposes the load partition among rows may be considered as dependent upon the bearing and shear resistance of the rivets."

"As plate stress intensity increases, the proportion of the load carried by the first rivet decreases. This action tends to cause equalization of load between rivet rows and suggests the desirability of having only ductile material around rivet holes if good distribution is to be obtained.

"The stress at which load equalization takes place increases with the number of rivets in the joint and may occur within commonly accepted design plate stresses, provided the joint does not have too great a number of rows. Practically, this means that for the more common type joints the usual assumption of uniform stress distribution is nearly true for the customary design plate stresses."

"The features of construction that give the best slip resistance are:-

1. The use of joints in which all rows of rivets are complete.

2. The use of two-ply material where the highest stresses occur.

3. The substitution of medium steel rivets for high tensile steel rivets in joining high tensile steel plates... This proposition is made for the following reasons:-

a. The test results indicate a marked superiority in slip resistance (absolute superiority, and not relative after taking the material strength into consideration) where medium steel rivets are used.

b. The superiority was indicated not only in the case when used with medium steel but was also apparent when used with special treatment steel.

c. The causes for the poor performance of the high tensile steel joints can be corrected at least in part by the substitution of medium steel as a rivet material."

- - - - - - - - -

The Illinois Tests of 1928 and 1930 (7) included tests on wide plates and on their joints. These tests are especially notable for the precise instruments used.

Certain of the conclusions follow:-

"Continuous wide plates without joints...may be expected to develop a unit stress equal to approximately 90 per cent of the unit strength of control specimens. Two of the fifteen plates tested developed a unit stress less than 86 per cent of the strength of the control specimens."

"Omitting rivets from the outside rows of a joint does not increase the actual efficiency as much as the theoretical."

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Tests made by Lyse at Lehigh University (9) show the partition of load between the various rivets of a joint.

\- - - - - - - - -

The Carnegie Steel Company, in 1927, made comparative tests of nickel and manganese steel rivets. These tests indicated that the manganese steel rivets were superior to nickel in their driving properties, and indicated an ultimate single shear value of over 70,000 pounds per square inch for the manganese rivets.

b. Tension Members

Compared to the amount of research on compression members, few tests have been made on riveted tension members.

\- - - - - - - - -

In 1895 and 1896, J. E. Greiner (8) made a number of tension tests on riveted tension members, the object of the tests being to ascertain "to what extent the individual pieces of built-up members will act together while under a tensile strain, the efficiency of different styles of webs or lacing, and whether the results, as compared with specimens, make a better or worse showing than those obtained from eyebars." The maximum section tested had an area of 6.68 square inches. The yield point of the member was determined by the drop of the gauge in the testing machine and also by the sealing of the member. No extensometer measurements were taken.

The yield point and ultimate strength of the fabricated member averaged respectively 111 and 88 per cent of the specimen tests.

The tests indicated that there was a considerable reduction in both yield point and ultimate due to bending caused by the "pantograph" action of double lacing.

- - - - - - - -

The most complete series of tests on tension members was that made by the engineers of the Quebec Bridge (10).

The tests included:-

a. 12 single plates carbon 36x5/8
b. 4 single plates nickel 36x5/8
c. 10 triple plates carbon 3 - 36x5/16
d. 6 fabricated sections carbon
e. 2 fabricated sections nickel.

The specifications for the steel were as follows:-

	Carbon	Nickel
Yield Point, Min.	35,000	50,000
Ultimate, Min.	62,000	85,000

The tests were made with a view to ascertaining:-

a. The efficiency of such members as compared with eyebars.

b. The relative efficiency of different types of pier plates.

c. The relative efficiency of different splices.

d. The relative efficiency of single plates and multiple plates, stitch riveted together in different ways.

The average of the test results are shown by Table I.

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· SAN · FRANCISCO - OAKLAND · BAY · BRIDGE ·
· TABLE · I – QUEBEC · TENSION · TESTS ·
· AVERAGE · OF · RESULTS ·

· 3 · 14 · 34 ·

	SPECIMEN TESTS		· FULL · SIZE · TESTS ·				· RATIOS · IN · PER · CENT ·			
	YIELD POINT	ULT.	ULT.	ELASTIC LIMIT	YIELD POINT	ELONGAT'N % IN 200"	ULT. / ULT.SPEC	ULT. / SPEC.ULT	Y.P. / Y.P.SPEC	Y.P. / SPEC.Y.P.
a. Single Pls. Carbon.			LBS.PER.SQ.IN.-NET SECT'N							
Maximum.	41420	68700	59722	35900	37400	4.60	87.0	96.0	90.0	107.0
Minimum.	40165	63120	46820	22000	22000	1.20	68.0	75.0	53.0	63.0
Average.	41210	67800	54820	28200	34000	2.86	81.0	88.5	76.7	91.4
b. Single Pls. Nickel.										
Maximum.	66520	93360	80000	48600	53000	2.08	89.0	94.0	80.0	94.0
Minimum.	62880	89360	79257	39800	45700	1.90	85.0	92.0	73.0	92.0
Average.	64200	91360	79175	43500	49000	2.00	87.0	93.0	75.8	93.0
c. Triple Pls. Carbon.										
Maximum.	44030	65620	57100	30400	39800	4.14	93.5	94.0	66.0	114.0
Minimum.	43430	62910	50810	22800	29300	3.81	77.5	82.0	92.0	81.0
Average.	43950	64560	55030	26500	34000	3.92	85.3	89.2	77.5	92.8
General Average a, b, c.							83.6	89.2	75.5	92.8
d. 6 Fabricated Carbon.										
Maximum.	46700	63770	58400	29000	33780	4.30	91.5	92.7	73.2	96.6
Minimum.	44660	63550	54980	26000	30640	2.70	86.5	88.6	68.6	87.5
Average.	45700	63650	57000	27300	32700	3.46	89.6	91.7	71.5	93.3
e. 2 Fabricated Nickel.										
Maximum.	61440	93260	78050	47400	53500	2.40	84.0	92.2	87.0	107.5
Minimum.	61440	93260	75580	43500	53500	1.91	81.0	89.2	87.0	107.5
Average.	61440	93260	76800	45500	53500	2.15	82.5	90.7	87.0	107.5

· NOTES ·

Specifications

	Carbon	Nickel
Y.P. Min.	35000	50000
Ult. Min.	62000	85000

$\frac{\text{Ult.}}{\text{Ult. Spec.}} = \frac{\text{Ultimate Strength Full Size Tests}}{\text{Ultimate Strength of Specimen}}$

$\frac{\text{Ult.}}{\text{Spec. Ult.}} = \frac{\text{Ultimate Strength Full Size Tests}}{\text{Specified Ultimate Strength}}$

$\frac{\text{Y.P.}}{\text{Y.P. Spec.}} = \frac{\text{Yield Point Full Size Tests}}{\text{Yield Point of Specimen}}$

$\frac{\text{Y.P.}}{\text{Spec. Y.P.}} = \frac{\text{Yield Point Full Size Tests}}{\text{Specified Yield Point}}$

Elastic Limit – Proportional Limit as determined by Extensometer measurements.
Yield Point – Stresses per sq. in. of net section of which Extensometers began to creep perceptibly under a steady load.

D.E.M.

From these tests it would appear that the ultimate strength and yield point of a riveted tension member may be assumed as about 80 per cent and 70 per cent respectively of the ultimate and yield point of the specimen. Since the mills, to avoid rejected material, ordinarily furnish material above the minimum figures, these values expressed in terms of the specifications may probably be safely raised to 85 per cent and 75 per cent respectively.

In connection with these and other tests, one point should be considered. The yield point, as determined, is probably a function of the member as a whole and may bear more relation to the gross than to the net area. Quite possibly there is some serious yielding at points of reduced section, which would not be apparent when measured over a gauge length of 200 inches.

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In 1904, the Pennsylvania Steel Company made an extensive series of tests on wide (24-inch and 32-inch) plates with pier plates riveted on the ends, as a comparison with eyebars. The yield point and ultimate strength of these members averages respectively 95 and 85 per cent of the specimen tests. In these tests the yield point was determined by the drop of the mercury gauge, rather than by use of extensometers.

Discussion of Tests

Upon comparing the data from tests with the large size tension members now commonly used in riveted structures of even moderate size, one can not but note the small amount of information on which the designs are based. To a certain extent, the structures now giving satisfactory service justify the assumptions underlying their design. In this connection, however, it should be observed that these structures, for the most part, are comparatively modern, and have not been subjected to the overload that they will probably receive during their lifetime.

In the tests of riveted joints never have there been more than four lines of rivets on either side of the joint. The largest area in any tension member has been 37 square inches gross.

Conclusions from Previous Tests

The previous tests make it possible to draw certain conclusions:-

(1) Within usual working stresses, the shear in a riveted joint is not evenly distributed between the several rivets, the greater proportion being taken by the end rivets. As the load increases, the distribution becomes more uniform, but is probably never equalized. The extent of this equalization may depend to a great extent on the plate or shape material, possibly being less for the high tensile steels.

(2) Within usual working stresses, the effect of the friction between the plates, caused by the tension due to the cooling of the rivets, becomes a minor factor and main dependence must be on the rivets' bearing on the sides of the rivet holes. The failure of the frictional effect occurs at lower unit stresses with high tensile steels than with softer ones.

(3) The efficiency of a butt splice is greater than that of a lap splice. This is due to the bending of the material, caused by the eccentricity of the line of stress.

This throws considerable doubt as to the usual details of connecting riveted members to gussets. Due to the outstanding flanges, there is a moment arm of considerable magnitude between the center of the gusset plate and the stress line of the member. In the case of members entering within gussets, the effect of this eccentricity may be reduced by tie plates between the two segments. When the members connect outside of gussets, diaphragms between the gussets located back of the flanges of the segments are probably desirable. The best detail is probably one that permits the member to "shingle" on the gusset with the member connected in double shear.

(4) The efficiency of a tension member is not increased as much as theory would indicate by omitting rivets at the end of the connection in order to increase the net section. It appears probable that the strength of a tension member is not reduced by holes to the extent usually assumed.

(5) The efficiency of a joint is increased by making the joint as compact as possible.

D. TEST PROGRAM

General

The following series of tests are proposed as those that, within the limit of available funds, will furnish the greatest amount of information towards an answer to some of the present uncertainties. Insofar as practicable in each of the tests the number of variables is reduced to the minimum. The steel should be as uniform as possible and, to this end should be furnished from as few heats as practicable. In many cases, the plate material is made heavier than required for strength in order to keep an uniform grip throughout a given series of tests.

In all cases, it is proposed to provide for control specimens so as to secure as definite knowledge of the properties of the material as possible and attempt to correlate these properties with the full-size test specimens. It is believed advisable, if necessary, to curtail the number of tests and to measure thoroughly distortions of all parts of the test members.

Series A and B. Stress Distribution over Wide Plates

In the Illinois Tests of 1928 and 1930 this question was thoroughly investigated for soft (50,000/60,000-pound) steel. It is proposed to extend these tests to include medium carbon, silicon and nickel steels. It is further proposed to include a carbon steel, so heat treated as to bring the yield point as closely as possible to the ultimate.

In Series B, it is proposed to determine the stress partition between the various rows of rivets. This series will also afford a comparison of the relative efficiencies of carbon and manganese rivets.

Series C. Comparison of Rivet Materials
Partition of Rivet Stresses

This series consists of a number of butt splices using both carbon and manganese rivets. The splices are longer than any that have heretofore been tested. We hope to establish the degree to which the stress is evenly distributed over a group of rivets and to the extent that this happens before the yield point of the joint is reached. It should also indicate the relative efficiency and economy of the two classes of joints. The comparison between C.S.M. 30 and 30a, and 36 and 36a should add information as to the advantages of a more compact rivet arrangement.

The C.C.C, series and C.N.M. series are proposed to study the effect of variations in plate material on the partition of rivet stresses.

Series D. Rivet Materials
Arrangement of Materials

In a built channel member composed of plates and angles, it is quite customary in detailing to put sufficient rivets in the angles to develop the proportion of stress carried by the angles and count on the rivets between the toes of the angles to develop the full width of the plate. As against this practice it is claimed that there should be sufficient rivets through the angles to develop both the angles and the portion of the plate below the angles. This series is designed to test this theory and also compare the efficiency of a long connection with carbon rivets as against a shorter connection using manganese rivets.

We also hope to secure data as to the effects of the bending due to the eccentricity of the line of stress.

Series E

There is still considerable doubt as to the extent to which the strength of a tension member is reduced by rivet holes. In most tests, the results are reported as comparing the properties of the net section of the specimen with the control specimen and neglecting the reduction in strength of a wide plate as compared to the specimen.

Several empirical formulae have been developed for the deductions to be made for various combinations of pitch and gauge. A formula based on the theory of elasticity has been developed by Young (11). The following page is a comparison for 1" rivets (1-1/8 holes) between Young's results and the A.A.S.H.O. specification.

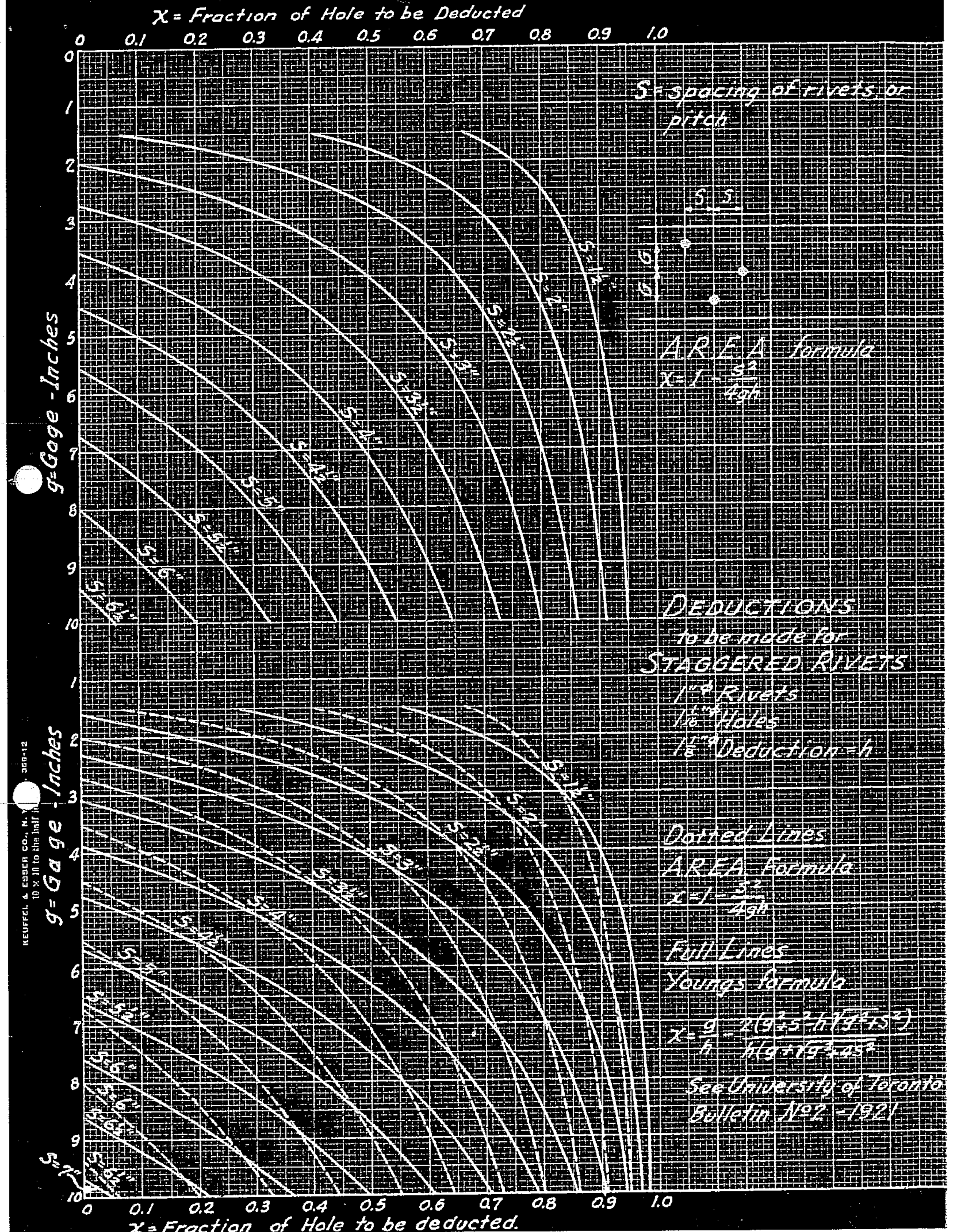
There is also a question as to whether the effects would be changed by the holes being filled by rivets, and certain of the tests are being duplicated to cover this condition.

In the general series of tests, silicon steel is used as being an average material for the structure under consideration. To check whether the deductions made for silicon steel may be considered general, certain of the specimens are duplicated in carbon and others in nickel steel.

Series F. Butt vs. Shingle Splices

In the case of heavy members, it is often more economical of material to use a "shingle" splice rather than to cut all of the material at one spot. The design of these splices is not covered by specifications although ordinarily the principle of moments is used to calculate the required splice material at the points where the various components are cut. Ordinarily the calculation is not carried to its logical conclusion to adequately preserve the net section of the member throughout the length of the splice.

In the series proposed, the specimens with the shingle splices are detailed on the basis of usual details rather than using special effort to be more theoretical.



X = Fraction of Hole to be Deducted
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
S = spacing of rivets or pitch
AREA formula
X = 1 - S²/4gh
g = Gage - Inches
S = 1½"
S = 2"
S = 2½"
S = 3"
S = 3½"
S = 4"
S = 4½"
S = 5"
S = 5½"
S = 6"
S = 6½"
DEDUCTIONS
to be made for
STAGGERED RIVETS
1" Rivets
1 1/16" Holes
1 1/8" Deduction = h
Dotted Lines
AREA Formula
Full Lines
Youngs formula
See University of Toronto
Bulletin No 2 - 1921
S = 7"
X = Fraction of Hole to be deducted.
KEUFFEL & ESSER CO., N.Y. 359-12
10 X 10 to the half inch

Series G. Deformations around Rivet Holes

By the elastic theory, the stress at the edge of a circular hole in a tension member is three times the average across the plate. The evidence from former tests is that at a comparatively early stage of loading, the overstressed material at the edge of the hole yields, causing a redistribution of stresses across the section.

With a rivet hole of 1-1/16 inches diameter, the surfaces are so small that it is impracticable to accurately measure distortions. It should be possible to obviate this difficulty by using a ten-inch hole in a thirty-inch plate. It is proposed to adopt this expedient in this series.

If possible, some of these specimens should be tested under reversing stress conditions.

The yielding effect, above noted, may have an appreciable effect in the diameter of the rivet hole and may contribute to the action of a riveted joint after the first slip of the rivet.

Series H. Alternate Stresses on Rivets

The usual testing machine is not designed to provide for reversal of stress. A limited amount of this work was done by Talbot and Moore (5). It is desirable to extend these tests to include a larger number of rivets.

The methods of testing should be carefully considered. In the Illinois Tests (5) each specimen was tested in cycles of gradually increasing intensity. Possibly more could be learned by many cycles (100-150) at the same intensity, followed by destruction in tension.

Series J. Tension Members and Details

In this series it is proposed to study the action of typical tension members and the effect of their details, such as gusset plate connections, lacing, etc.

STATE OF CALIFORNIA
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SAN FRANCISCO-OAKLAND BAY BRIDGE

TESTS ON RIVETED TENSION MEMBERS AND THEIR CONNECTIONS

APPENDIX I

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TESTS ON RIVETED TENSION MEMBERS AND THEIR CONNECTIONS

APPENDIX V

Specifications for Materials and Workmanship

(1) General. - The materials to be furnished under these specifications are for test purposes. It is desired that the materials of each grade shall be as uniform as possible. To achieve this result, the material of each grade shall preferably be furnished from a single heat.

It is further desired that the ultimate strength of the material shall fall as nearly as possible midway between the specified extremes.

(2) Process. - All structural steel shall be made by the open hearth process.

(3) Grades. - Three grades of structural steel will be used in the various parts of the test specimens and are designated on the Drawings as Nickel Steel, Silicon Steel and Carbon Steel. An additional grade, designated Heat Treated Steel will also be used.

Two grades of rivet steel will be used and are designated on the Drawings as Manganese Rivets and Carbon Rivets.

(4) Chemical Analysis. - An analysis to determine the quantity of the different elements in the steel shall be made by the manufacturer from a test ingot taken during the pouring of each ingot. The drillings for this purpose shall be taken at least one-half (1/2) inch below the surface of the test ingot. Each ingot shall be numbered and the steel rolled therefrom shall be subject to identification through all stages of the fabrication. A copy of this analysis, certified to by the manufacturer's chief chemist, shall be furnished to the Inspector immediately on the completion of such analysis. The various grades of steel shall not contain more than the following percentages of elements:

	Nickel Steel	Silicon Steel	Carbon Steel		Manganese Rivet Steel
			Medium	Rivet	
Carbon	0.40	0.40			0.30
Manganese		1.20			1.50⊕
Silicon		0.45⊕⊕			0.25
Nickel	⊕⊕⊕				
Phosphorus					
Acid Process	0.06	0.06	0.06	0.04	0.04
Basic Process	0.04	0.04	0.04	0.04	0.04
Sulphur	0.05	0.05	0.05	0.045	0.05

⊕ The percentage of manganese in manganese rivet steel shall not be less than 1.30.

⊕⊕ The percentage of silicon in silicon steel shall not be less than 0.20.

⊕⊕⊕ The percentage of nickel in nickel steel shall not be less than 3.00.

The percentage of copper in all the above steels shall not be less than 0.20.

(5) Check Analyses. - Check analyses of the finished product will be made by the Engineer. The results of such check analyses shall not exceed the requirements specified for phosphorus and sulphur in the test ingot analysis by more than twenty-five (25) per cent, and for other elements the variation from the limits specified shall not be more than five (5) per cent.

(6) Discard. - A sufficient discard shall be made from each ingot to secure freedom from piping and undue segregation.

(7) Physical Properties. - Specimens cut from the finished material shall show the following physical properties:

	Nickel Steel	Silicon Steel	Carbon Steel Medium	Carbon Steel Rivet	Manganese Rivet Steel
Tensile Strength Pounds per Square Inch	90,000 Minimum	80,000/ /95,000	62,000/ /70,000	52,000/ /60,000	75,000/ /90,000
Yield Point, Minimum Pounds per Square Inch	55,000	45,000	37,000	30,000	42,000
Elongation in 8 Inches Minimum Per Cent	1,600,000* / Tensile Str.	1,600,000* / Tensile Str,	1,500,000** / Tensile Str.	1,500,000 / Tensile Str.	1,500,000 / Tensile Str.
Reduction of Area Minimum	30%***	35%***	42%****	52%	45°
Bend Test, Material 3/4 Inch or Less	180° around D = 1-1/2 T	180° around D = 1 T	180° around D = 1 T	180° flat	180° around
Material over 3/4 Inch to 1-1/4 Inches	180° around D = 2 T	180° around D = 1-1/2 T	180° around D = 1-1/2 T		D = 1/2 T

D = Inside diameter of bend.
T = Thickness of material.

* For silicon and nickel steel material over 3/4 inch thick, deduct one from percentage of elongation for each increase in thickness of 1/4 inch or fraction thereof, above 3/4 inch, but in no case shall the elongation be less than 14% for silicon steel or 12% for nickel steel.

** For medium steel material over 3/4 inch thick, deduct one from percentage of elongation for each increase in thickness of 1/8 inch or fraction thereof, above 3/4 inch, but in no case shall the elongation be less than 18%.

*** For silicon and nickel steel material over 3/4 inch thick, deduct one from percentage of reduction of area for each increase in thickness of 1/8 inch, or fraction thereof, above 3/4 inch, but in no case shall the reduction of area be less than 24% for silicon steel or 20% for nickel steel.

**** For medium steel material over 3/4 inch thick, deduct one from percentage of reduction of area, for each increase in thickness of 1/8 inch, or fraction thereof, above 3/4 inch, but in no case shall the reduction of area be less than 35%.

(8) Manganese Rivets. - Manganese Rivets, in addition to the above requirements, shall further conform to the requirements of the "Proposed Specifications for High Strength Structural Rivet Steel", Revision of October, 1933, as prepared by Committee A-1-Sub-Sub-Committee of Sub-Committee II of the American Society for Testing Materials. A copy of this specification is on file at the office of the Engineer.

(9) Heat Treated Steel. - Heat Treated Steel shall have an ultimate strength of not less than 100,000 pounds per square inch with a desired yield point of 90,000 pounds per square inch. The Contractor shall submit for the approval of the Engineer a statement covering the proposed methods of manufacture.

(10) Identification. - All steel shall be made especially for this work and shall be subject to a system of identification approved by the Engineer and shall be handled by itself and isolated in such manner as to prevent the possibility of its becoming mixed with other kinds of steel. The Engineer may approve the use of stock material, for which certified copies of chemical and physical tests can be furnished by the manufacturer's chemist, for minor parts.

Every finished piece of steel shall be distinctly stamped with the melt number. Rivet steel may be shipped in bundles securely wired together, with the melt number on a metal tag attached. The mill marks designated on the "Bill of Material and Cutting Lists" shall be stamped with steel dies near the ends of the sections.

Universal plates and shapes shall be hot stamped. Sheared plates shall be stamped with steel dies after laying out. Painting heat numbers will not be allowed.

(11) Uniformity. - All steel shall be of uniform quality of each class. It shall be straight, without buckles or kinks, and free from injurious seams, flaws, cracks, excessive scale and pitting and other defects.

(12) Tolerances. - The cross-section or weight of each piece of steel shall not vary more than two and one-half (2-1/2) per cent from that specified, except in the case of plates wider than thirty-six (36) inches, for which allowance will be made in accordance with the specification of structural steel for bridges of the American Society for Testing Materials, serial designation A7-29.

Mill Inspection

(13) Access. - The Engineer and his inspectors shall have free access, at all times, to all parts of the works where material for these tests is being manufactured, handled or stored. The manufacturer shall extend to the Inspector, free of cost, all reasonable facilities to satisfy him that the material is being properly furnished in accordance with these Specifications.

(14) Notice. - The mills shall notify the Inspector at least eight (8) hours in advance when material for this work is to be rolled, giving him a schedule of sections. The material shall be handled to the extent necessary to permit inspection of all surfaces.

(15) Approval before Shipment. - No material shall be loaded and shipped from the mills before the tests thereon have been completed and before the Inspector has approved the material in every respect as to quality as well as surface. Surface imperfections, except those which in the opinion of the Engineer do not impair the strength or appearance, will be cause for rejection.

Tests

(16) Size of Specimens. - Specimens for tensile tests of rolled material shall be of the size and number shown by the "Bill of Material and Cutting Lists." The specimens shall be marked as designated. The Contractor shall machine the round tension specimens designated.

All bend test specimens of rolled material shall be of the full thickness of material as rolled and shall be not less than two (2) inches wide. Bend test specimens shall withstand being bent cold without cracking on the outside of the bent portion. All successful bends shall be further closed in until broken or bent flat.

(17) Speed of Test Machines. - The speed of the testing machine up to the yield point shall not exceed one and one-half (1-1/2) inches per minute for specimens with eight (8) inches gauge length, and shall be reduced on request of the Inspector so as to accurately determine the yield point. Beyond the yield point the speed may be increased to six (6) inches per minute until the specimen is broken.

(18) Determination of Yield Point. - The yield point shall be determined by the drop of the beam or halt of the gauge of the testing machine or by dividers, at the option of the Inspector. The testing machine shall not be stopped to obtain the drop of the beam or halt of the gauge.

(19) Type of Fracture. - All tension fractures shall be silky and of fine texture, free from coarse crystals. Square fractures shall be a sufficient cause for rejection.

Shopwork

(1) Quality. - Workmanship and finish shall be equal to the best general practice in modern bridge shops.

(2) Storage. - Structural material, before fabrication, shall be stored at the bridge shop above the ground upon suitable platforms, skids or other supports to prevent its becoming bent or distorted. It shall be kept free from dirt, grease and other foreign matter.

The different classes of steel shall be stored separately, and the mill mark designating such classes shall be carefully preserved.

(3) Straightening. - Rolled material shall be straightened at the shop by methods that will not injure it. It must be perfectly straight before being laid off or worked in any way.

(4) Cleaning. - All material shall be thoroughly cleaned of rust, loose scale and dirt before being assembled.

(5) Finish. - All sheared or burned edges or ends of plates and shapes shall be planed, faced or chipped so as to remove at least one-eighth (1/8) inch of metal, or more if the injury from cutting extends deeper.

All chipping shall be done in a neat and workmanlike manner, without breaking out of metal.

(6) Punching and Reaming. - Holes in all material three-fourths (3/4) inch thick, or less, except nickel steel, may be punched to a die one-eighth (1/8) inch smaller, and after assembling, reamed one-sixteenth (1/16) inch larger than the nominal size of the rivet. The punching must be sufficiently accurate to permit at least one-sixteenth (1/16) inch of metal to be taken out all around the hole by reaming.

No punching of nickel steel or heat treated steel will be permitted. All holes in nickel steel and heat treated steel and holes in other material over three-fourths (3/4) inch thick shall be drilled from the solid. Holes drilled before the component pieces are assembled together shall be at least one-sixteenth (1/16) inch smaller than the nominal size of the rivet. Reaming or drilling full size from the solid shall be done after the pieces forming the built member are assembled and firmly bolted or clamped together with the surfaces in close contact throughout. Burrs and sharp edges of each reamed or drilled hole under the rivet head shall be removed with a counter-sinking tool making a one-sixteenth (1/16) inch fillet. The piece shall be taken apart before riveting and any shavings and burrs removed.

Reaming or drilling shall be done in a neat manner, the tool being held at right angles to the surface of the metal. Tools shall not be directed by hand where mechanically guided tools can be used.

(7) Drifting. - No drifting will be allowed which would cause enlargement of the holes or cause injurious initial strains in any way to the assembled pieces.

(8) Weighing. - Immediately before final assembly each component of each test specimen shall be accurately weighed, and a record of the weights furnished the Inspector.

(9) Coating Finished Surfaces. - All finished surfaces shall be given a coat of blue lacquer.

(10) Sandblasting. - Not more than twenty-four hours prior to delivery to the testing laboratory, the Contractor shall remove all mill scale by sandblasting.

(11) Riveting. - Steel surfaces in contact shall be thoroughly cleaned of rust, mill scale, dirt, grease or other foreign matter and shall be in such condition immediately prior to riveting. No paint shall be applied to contact surfaces.

The actual diameter of the rivets shall be such as to require, when heated, a slight pressure to force them into the hole. Rivets with a grip equal to, or exceeding five (5) times their nominal diameter shall be tapered. The amount of tapering shall be determined by test and shall be sufficient to result in the metal completely filling the hole after the rivet is upset.

Rivet heads, when not countersunk or flattened, shall be of approved shape and of uniform size for the same diameter of rivet. Rivet heads shall be full, neatly made, concentric with the rivet holes and in full contact with the surface of the member.

Rivets shall be driven by approved pressure tools wherever practicable. The speed and pressure used shall be regulated to secure the best results in the work. When necessary to drive rivets with pneumatic percussion hammers, a pneumatic bucker-up shall be used, wherever possible.

Rivets, when heated to proper temperature and ready for driving, shall be free from scale and shall not be used if burned. When driven, they shall completely fill the holes and be tight. Caulking will not be permitted. Loose, burned or otherwise defective rivets shall be promptly replaced. In removing rivets, care shall be taken not to injure the adjacent metal and if necessary they shall be removed by drilling.

Countersunk rivets shall be so driven as to fill the countersunk holes completely, and in such manner as to dispense with chipping as much as possible.

(12) Accuracy. - Members, when finished, shall be straight and true and free from twists, kinks, buckles and open joints between component pieces.

All bearing surfaces shall be truly faced to a smooth surface, so that the abutting members will have full and even bearing when properly aligned.

(13) Pin Holes. - Pin holes shall be bored after all riveting is completed and at a single set-up of the member. At least one-half (1/2) of an inch of metal shall be removed by the boring tool. The diameter of the pin holes shall not vary from that shown on the Drawings by more than one one-hundredth (.01) of an inch. The boring shall be carefully done and a fine finishing cut shall always be taken. Roughness in a pin hole shall be sufficient cause for rejection.

(14) Loading. - All members shall be carefully loaded, and protected from injury during transportation by such means as will be satisfactory to the Inspector.

All bolts, pins, rivets, etc., shall be carefully boxed and protected against injury in transit.

All fabricated material transported by water shall be placed below deck.

DESIGN CALCULATIONS
S.F.O.B.B. – FLOOR SYSTEM

M.S. MacCalden

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

Sheet ___ of ___

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Checked by

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STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

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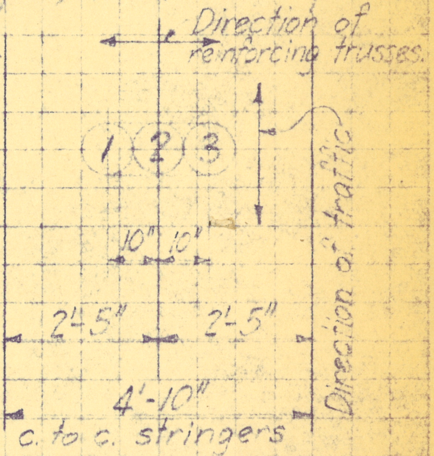
STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

Roadway Slab – Lower Deck.

For 288' Spans, 504' Spans, Suspension Bridge, and Continuous Span

Live Load: H-30 + $33\frac{1}{3}$% impact.
Dead Load: 90# per sq. ft. Slab span 4'-10" c. to c. supports.
Reinforcing ⊥ to traffic. Slab depth $6\frac{1}{2}$" overall. $n = 12$
Bearing area of one rear wheel assumed to be divided into 3 circles of 10" diameter, the load on each circle being 10,570# (incl. impact).



Live Load moments at ℄ slab span (moments by Westergaard's equations – see "Public Roads," Vol. 11, No. 1):

Load No.	x	$\frac{x}{s}$	$\frac{M}{P}$	Simple Beam Moment
1	10"	0.172	0.1184	1275
2	0	0	0.2687	2870
3	10"	0.172	0.1184	1275

L.L. moment = 5420'# per ft.
D.L. moment $90 \times (4.83)^2/8$ = 262
Total simple beam moment = 5680'# per ft.

Design slab for 80% of simple beam moment $= .80 \times 5680 = 4540$'# per ft.
Use reinforcing trusses as shown in sketch below.

$A_s = A_s' = 0.628$ in.² per ft. of slab.

$p = p' = \frac{0.628}{66} = 0.00951$

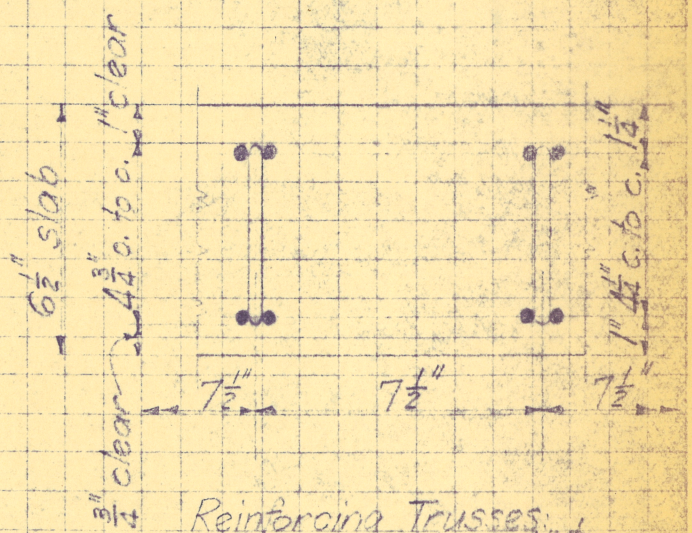
$n = 12$

$\frac{d'}{d} = \frac{1.25}{5.50} = 0.227$

$k = 0.348$
$j = 0.864$

$f_s = \frac{12 \times 4540}{0.628 \times 0.864 \times 5.50} = 18,300$#/in.²

$f_c = \frac{18,300}{12} \times \frac{0.348}{0.652} = 815$#/in.²



Reinforcing Trusses:
Each chord = 2-$\frac{1}{2}$" ø bars.
Web = $\frac{7}{16}$" ø continuous.
Spacing of trusses = $7\frac{1}{2}$" c. to c.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

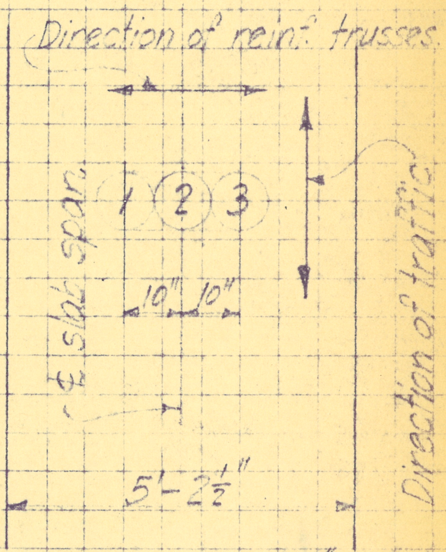
Roadway Slab - Lower Deck (cont'd)

For Yerba Buena Spans (Stringers spaced 5'-2½" max. c to c)

Live Load: H-30 + 33⅓% impact. Slab span = 5'-2½" c. to c. supports.
Dead Load: 90# per sq. ft. Slab depth = 6½" overall.
Reinforcing ⊥ to traffic.
Bearing area of each rear wheel assumed to be divided into 3 circles of 10" diameter, the load on each circle being 10,670# (incl. impact).

Live Load moment at ℄ span by Westergaard's equations (see "Public Roads" Vol. 11, No. 7):

Load No.	x	$\frac{x}{s}$	$\frac{M}{P}$	Simple Beam Moment
1	10"	0.160	0.125	1335
2	0	0	0.276	2940
3	10	0.160	0.125	1335
	L.L. moment			= 5610
	D.L. moment $90 \times (5.21)^2/8$			= 310
	Total simple beam moment			= 5920'# per ft.



Design slab for 80% of simple beam moment = .80 × 5920 = 4740'# per ft.

Use design shown on Sheet No. (trusses @ 7½" c-c's, 2-½"φ bars each chord).

$$f_s = \frac{12 \times 4740}{0.628 \times 0.864 \times 5.50} = 19,100\ \#/in.^2$$

$$f_c = \frac{19,100}{12} \times \frac{0.342}{0.658} = 850\ \#/in.^2$$

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

Roadway Slab - Lower Deck (cont'd.)

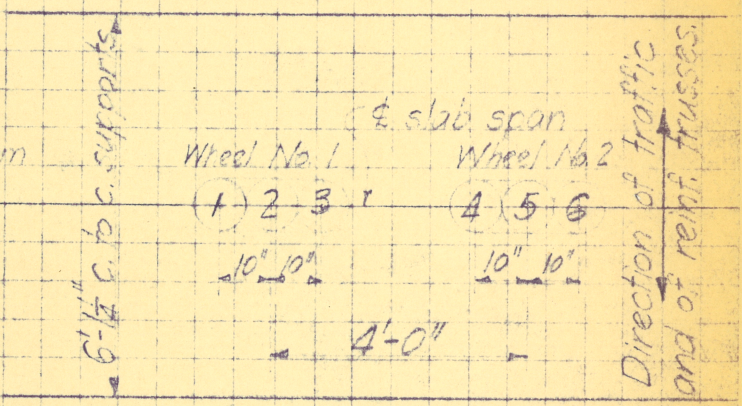
For Cantilever Bridge

Live Load: H-30 + $33\frac{1}{3}$% impact.
Dead Load: 90# per sq. ft. — Slab span 6'-1¼" c. to c. supports.
Reinforcing parallel to traffic. — Slab depth 6½" overall. $n = 12$
Bearing area of each rear wheel assumed to be divided into 3 circles of 10" diameter, the load on each circle being 10,670# (incl. impact).

Live Load moments at circle #3 (by Westergaard's equations — see "Public Roads," Vol. 11, No. 1):

Load No.	y	y/S	M/P	Simple Beam Moment
1	20"	.273	.1443	1540
2	10"	.1365	.2093	2230
3	0	0	.2900	3090
4	28	.382	.1112	1185
5	38	.52	.0814	865
6	48	.655	.0600	640

L.L. moment = 9550 (9520 by AASHO Specs. - 1935)
D.L. moment $90 \times (6.1)^2/8$ = 420
Total simple beam moment = 9970 #' per ft.



Design slab for 80% of simple beam moment = .80 × 9970 = 7980#' per ft.

Use reinforcing trusses as shown in sketch below.

$A_s = A_s' = 1.193$ in² per ft. of slab

$p = p' = \frac{1.193}{12 \times 5.47} = 0.0182$

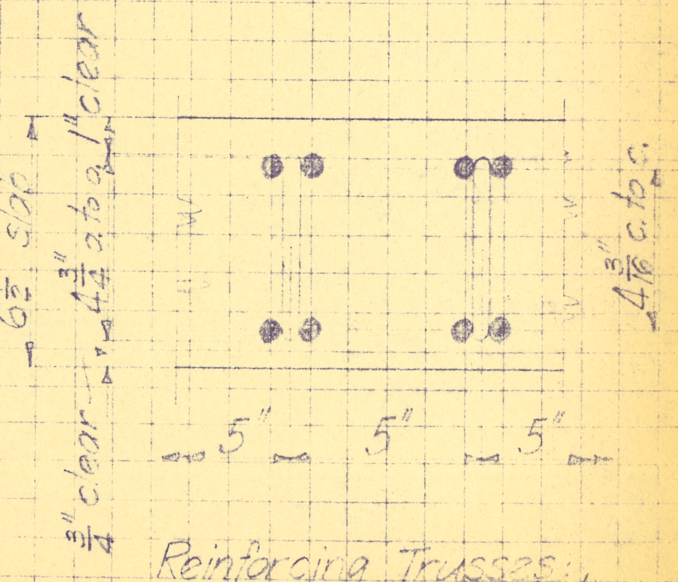
$n = 12$

$\frac{d'}{d} = \frac{1.28}{5.47} = 0.234$

$k = 0.418$
$j = 0.832$

$f_s = \frac{12 \times 7980}{1.193 \times 0.832 \times 5.47} = 17{,}600$ #/in²

$f_c = \frac{17{,}600}{12} \times \frac{0.418}{0.582} = 1055$ #/in²

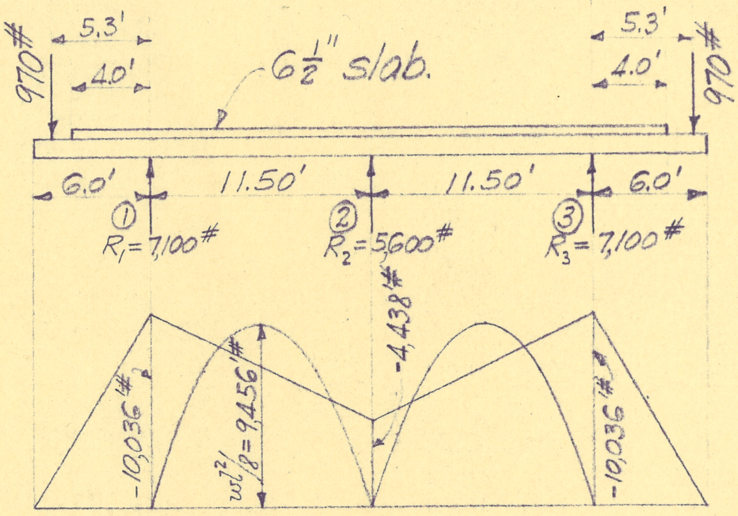


Reinforcing Trusses:
Each chord = 2 - 9/16" ϕ bars
Web = 7/16" ϕ continuous.
Spacing of trusses = 5" c. to c.

Rev. 1/17/35

LOWER DECK CROSS BEAMS

Cross beam spacing 6'-0" c. to c.
Span = 11'-6" (= distance c. to c. stringers).
Dead Load - Floor 6 × 90 = 540 ($6\frac{1}{2}$" slab).
Cross beam = 32
572 #/ft.
" " - North curb, rail, etc. 970#
" " - South " " " 970#



DEAD LOAD MOMENTS

		M_1	Shear left of ①
Dead Load - Curb, rail, etc.	970 × 5.3	- 5140	970
Cross beam	$32 \times (6.0)^2/2$	- 576	192
Slab	$540 \times (4.0)^2/2$	- 4320	2160
		-10,036 '#	3322 #

$$M_2 = -\frac{1}{4}\left(M_1 + M_3 + \frac{1}{2} wl^2\right)$$
$$= -\frac{1}{4}\left(-20{,}072 + 572 \times \overline{11.5}^2/2\right)$$
$$= -\frac{1}{4}\left(-20{,}072 + 37{,}823\right)$$
$$= -4{,}438 \text{ '\#}$$

$wl^2/2 = 37{,}823$ '#
$wl^2/8 = 9{,}456$ '#

R_1 = 7,100# = R_3 R_2 = 5,600#

Live Load - H-40 trucks (no impact) Rear wheel load = 32,000#

Negative Moment at ①:

Assuming no distribution of L.L. -

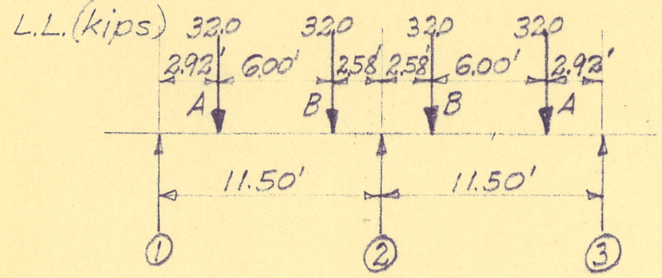
			M_1
L.L.	- 32,000 × 2.0	=	- 64,000
D.L.		=	- 10,040
			- 74,040 '#

Assuming L.L. distribution, 6/8 to 1 cross beam -

L.L.	- 64,000 × 6/8	=	- 48,000
D.L.		=	- 10,040
			- 58,040 '#

LOWER DECK CROSS BEAMS (CONT'D)

Negative Moment at ②:



Assuming no distribution of L.L. - M_2

L.L. Wheels "A" $[-32{,}000 \times 2.92(11.5^2 - 2.92^2)/(4 \times 11.5^2)] \times 2 = -64{,}000 \times 0.683 =$ −43,700'#

" "B" $[-32{,}000 \times 8.92(11.5^2 - 8.92^2)/(4 \times 11.5^2)] \times 2 = -64{,}000 \times 0.887 =$ −56,700

−100,400

D.L. (from previous sheet) −4440

−104,840'#

Assuming L.L. distribution, 6/8 to 1 cross beam -

L.L. −100,400 × 6/8 −75,300'#

D.L. −4,440

−79,740'#

SUMMARY

	Max. Shear	Max. Mom.	S.M. req'd. (Silicon Steel)
Assuming no L.L. distribution	L.L. 54,400; D.L. 2,220 } 56,620	−104,840'#	44.9
Assuming L.L. distribution (6/8 to 1 cross bm.)	40,800; 2,220 } 43,020	−79,740	34.2

12" I @ 31.8# Silicon Steel Web 3/8"

S.M. = 36.0 in.^{3}

$12 \times 79{,}740 / 36.0 = 26{,}600$ #/in.^{2}

Lower Deck Roadway Stringers for Continuous Spans

Stringer Span = 31.92'   Stringer Spacing = 4.83' c. to c.

Dead Load:

		Interior Stringer		Outside Stringer
Slab	90×4.83 =	435	90×3.42 =	310
Stringer		70		70
Total		505 #/ft.		380 #/ft.

Live Load: H-40

Wheel lines to interior stringer = 4.83/5 = 0.966

" " " outside " = 3.83/4.83 = 0.794

	Interior Stringer		Outside Stringer	
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.	8.1	64	6.1	48
L.L.	35.3	257	29.0	212
Total	43.4	321	35.1	260

<u>21" C.B. @ 68# Silicon Steel</u>   S.M. = 139.9   Web 0.430"

Ratio Span/Depth = 31.92/1.75 = 18.3   Flange 8¼"

Max. stress = 12×321,000/139.9 = 27,600 #/in.² (interior stringer)

" " = 12×260,000/139.9 = 22,300 #/in.² (outside stringer)

Allowable stress = 28,000 #/in.² (tension or compression).

Lower Deck Roadway Stringers for Suspension Bridge.

Stringer Span = 30.32' Stringer Spacing = 4.83' c. to c.

Dead Load:

		Interior Stringer		Outside Stringer
Slab	90 x 4.83 =	435	90 x 3.42 =	310
Stringer		65		65
Total		500 #/ft.		375 #/ft.

Live Load: H-40

Wheel lines to interior stringer = 4.83/5 = 0.966

" " " outside " = 3.83/4.83 = 0.794

	Interior Stringer		Outside Stringer	
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.	7.6	58	5.7	43
L.L.	35.0	241	28.8	198
Total	42.6	299	34.5	241

21" C.B. @ 63# Silicon Steel S.M. = 128.0 Web 0.410"

Ratio Span/Depth = 30.32/1.75 = 17.3 Flange 8¼"

Max. stress = 12 x 299,000/128.0 = 28,000 #/in.^{2} (int. stringer).

" " 12 x 241,000/128.0 = 22,600 #/in.^{2} (outside stringer).

Allowable stress = 28,000 #/in.^{2} (tension or compression).

Lower Deck Roadway Stringers for 288' Spans YB1-E1 and E9-E11.

L.L. - H40

For 27' Span:

	INTERIOR STRINGER		OUTSIDE STRINGER	
Stringer Spacing (c.-c.)	4.83'		4.83'	
Wheel lines to stringer	4.83/5 = 0.966		4.14/4.83 = 0.857	
Dead Load: Slab	90 × 4.83 = 435		90 × 3.42 = 310	
Stringer	65		65	
Total	500 #/ft.		375 #/ft.	
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.	6.8	46	5.1	34
L.L.	34.7	210	30.8	186
Total	41.5	256	35.9	220
Section	21" C.B. @ 63# Silicon		21" C.B. @ 63# Silicon	

S.M. = 128.0 Web 0.41" Flange 8½
Depth ratio = 27/1.75 = 15.4
Max. stress = 24,000#/in.²

For 36' Span:

	INTERIOR STRINGER		OUTSIDE STRINGER
Stringer Spacing (c-c)	5.21' max.		5.21' max.
Wheel lines to stringer	5.21/5 = 1.04		
Dead Load: Slab	90 × 5.21 = 470		
Stringer	75		
Total	545 #/ft.		
	Shear (kips)	Moment (kip-ft.)	
D.L.	9.8	88	
L.L.	38.4	319	
Total	48.2	407	
Section	24" C.B. @ 74# Silicon		24" C.B. @ 74# Silicon

S.M. = 170.4 Web 0.43" Flange 9"
Depth ratio = 18
Max. stress = 28,600#/in.²

24465 9-35 10M EST. 2966
100 TO PAD. S.P.O.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

Lower Deck Roadway Stringers for 288' Spans YB1-E1 & E9-E11
L.L. - H40. Stringer spacing 4.85' c. to c. (max.)

	INTERIOR STRINGER		OUTSIDE STRINGER
For 37' Span:			
Wheel lines to stringer	4.85/5 = 0.97		3.85/4.85 = 0.795
Dead Load: Slab	90 × 4.85 = 440		
Stringer	75		
Total	515		
	Shear (kips)	Moment (kip-ft.)	
D.L.	9.5	89	
L.L.	35.9	307	
Total	45.4	396	
Section	24" C.B. @ 74# Silicon S.M.=170.4 Web 0.43" Flange 9" Depth ratio = 37/2.00 = 18.5 Max. stress = 27,900 #/in.²		24" C.B. @ 74# Silicon
For 39' Span:			
Wheel lines to stringer	0.97		0.795
Dead Load: Slab	440		
Stringer	75		
Total	515		
	Shear (kips)	Moment (kip-ft.)	
D.L.	10.1	99	
L.L.	36.0	326	
Total	46.1	425	
Section	24" C.B. @ 80# Silicon S.M.=185.8 Web 0.455 Flge. 9" Depth ratio = 39/2.00 = 19.5 Max. stress = 27,500 #/in.²		24" C.B. @ 80# Silicon

3500 × 6.25/4.83 = 4520
Brkt. 250
4770
Say 4800

Lower Deck Roadway Stringers for 504' Spans

Stringer Span = 42.00'   Stringer Spacing = 4.83' c. to c.

Dead Load:

		Interior Stringer		Outside Stringer
Slab	90 × 4.83 =	435	90 × 3.42 =	310
Stringer		90		90
Total uniform dead load		525 #/ft.		400 #/ft.
Concentrated dead load (curb, rail, and bracket)				4800# at ℄ span.

Live Load: H-40

Wheel lines to interior stringer = 4.83/5 = 0.966

" " " outside " = 3.83/4.83 = 0.794

	Interior Stringer Shear (kips)	Interior Stringer Moment (kip-ft.)	Outside Stringer Shear (kips)	Outside Stringer Moment (kip-ft.)
D.L.-Uniform	11.0	116	8.4	88
Concentrated			2.4	50
L.L.	36.1	354	29.6	291
Total	47.1	470	40.4	429

Special 27" Beam @ 88# Silicon Steel

Depth 26.78"   Web 0.473"

Flange width = 9.973"

" thickness = 0.682"

Axis 1-1: I = 3005.6   S.M. = 224.5   r = 10.77

Axis 2-2: I = 103.70   S.M. = 20.8   r = 2.00

Area = 25.90

Ratio Span/Depth = 42/2.25 = 18.7

Max. stress = 12 × 470,000/224.5 = 25,200 #/in.² (interior stringer)

" " = 12 × 429,000/224.5 = 23,000 #/in.² (outside stringer)

Allowable stress = 28,000 #/in.² (tension or compression)

Lower Deck Roadway Stringers for Tower Span E9

Stringer Span 50'   Stringer Spacing = 4.83' c. to c.

Dead Load:

		Interior Stringer		Outside Stringer
Slab	90 × 4.83 =	435	90 × 3.42 =	310
Stringer		125		125
Total uniform D.L.		560#/ft.		435#/ft.

Concentrated D.L. (curb, rail, and bracket) 4350# at each 1/3 pt.

Live Load: H-40

Wheel lines to interior stringer = 4.83/5 = 0.966

" " " outside " = 3.83/4.83 = 0.794

	Interior Stringer		Outside Stringer	
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.-Uniform	14.0	175	10.8	136
Conc.			4.4	73
L.L.	39.2	431	32.3	355
Total	53.2	606	47.5	564

33" C.B. @ 125# Silicon Steel   S.M. = 385.1   Web 0.570"

Ratio Span/Depth = 50/2.75 = 18.2   Flange 11½"

Max. stress = 12 × 606,000/385.1 = 18,900#/in.²

Allowable stress = 28,000#/in.² (tension or compression).

Lower Deck Roadway Stringers for 288' Spans E11–E23.

Stringer Span = 36.00'
Stringer Spacing = 4.83' c. to c.
} Standard for Spans E11–E23.

Dead Load:

		Interior Stringer		Outside Stringer
Slab	90 x 4.83 =	435	90 x 3.42 =	310
Stringer		75		75
Total uniform D.L.		510 #/ft.		385 #/ft.

Concentrated D.L. (curb, rail, and bracket) 4150# at ℄ span (south side only).

Live Load: H-40

Wheel lines to interior stringer = 4.83/5 = 0.966
" " " outside " = 3.83/4.83 = 0.794

	Interior Stringer		Outside Stringer	
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.-Uniform	9.2	83	6.9	63
Conc.			2.1	38
L.L.	35.6	296	29.3	243
Total	44.8	379	38.3	344

24" C.B. @ 74# Silicon Steel S.M. = 170.4 Web 0.430"

Ratio Span/Depth = 36/2 = 18 Flange 9"

Max. stress = 12 x 379,000/170.4 = 26,700 #/in.² (interior stringer)
" " = 12 x 344,000/170.4 = 24,200 #/in.² (outside stringer)

Allowable stress = 28,000 #/in.² (tension or compression).

Brkt. 250
4130
4150

DESIGN OF LOWER DECK ROADWAY STRINGERS

Live Load: H-40

Table "A" — Roadway slab supported on upper flange of stringer. Loads and stresses shown are for interior stringer, and control stringer design. Outside stringer to be same section as interior stringer. Wheel lines to interior stringer = S/5. I/b = 0. Slab 90#/sq. ft.

Stringer Span (ft.)	Stringer Spacing (ft.)	D.L. per ft.	Wheel lines to stringer	Shear (kips)			Moment (kip-ft.)			Stringer Design					Max. stress (tension or comp.)	Allowable Stress	Ave. web shear	Span/Depth
				D.L.	L.L.	Total	D.L.	L.L.	Total	Section	Mat'l.	Web	Flange	S.M.				
27.0	4.83	500#	0.966	6.8	34.7	41.5	46	210	256	21"CB@63#	S	0.410"	8 1/4"	128.0	24,000	28,000	4,800	15.4
30.32	4.83	500	.966	7.6	35.0	42.6	58	241	299	21"CB@63#	S	.410	8 1/4	128.0	28,000	28,000	5,000	17.3
31.92	4.83	505	.966	8.1	35.3	43.4	64	257	321	21"CB@68#	S	.430	8 1/4	139.9	27,600	28,000	4,800	18.3
36.00	4.83	510	.966	9.2	35.6	44.8	83	296	379	24"CB@74#	S	.430	9	170.4	26,700	28,000	4,300	18.0
36.00	5.21	545	1.04	9.8	38.4	48.2	88	319	407	24"CB@74#	S	.430	9	170.4	28,600	28,000	4,700	18.0
37.00	4.85	515	0.97	9.5	35.9	45.4	89	307	396	24"CB@74#	S	.430	9	170.4	27,900	28,000	4,400	18.5
39.00	4.85	520	.97	10.1	36.0	46.1	99	326	425	24"CB@80#	S	.455	9	185.8	27,500	28,000	4,200	19.5
42.00	4.83	525	.966	11.0	36.1	47.1	116	354	470	*27" I @ 88#	S	.473	10	224.5	25,200	28,000	3,700	18.7
50.00	4.83	560	.966	14.0	39.2	53.2	175	431	606	33"CB@125#	S	.570	11 1/2	385.1	18,900	28,000	2,900	18.2

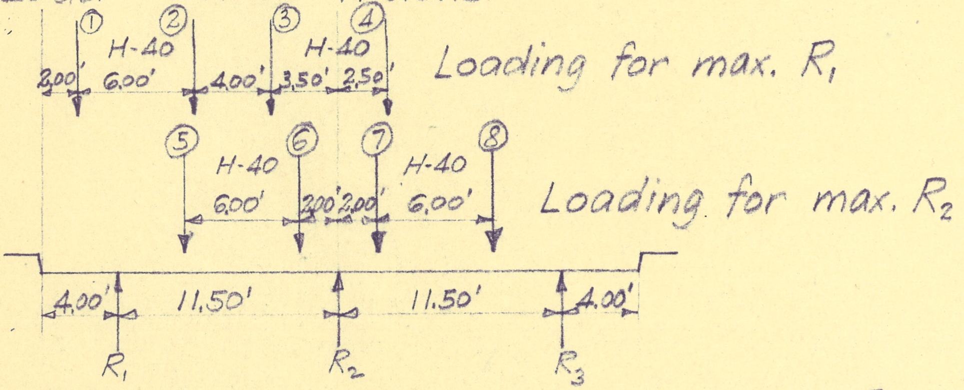
*Special beam.

Rev. 1/17/35

LOWER DECK ROADWAY STRINGERS

Dead Loads - Cross beam reactions - On north stringer 7.1 k.
" center " 5.6
" south " 7.1
(See previous sheet.)

Live Load - H-40 trucks.



R_1 Simple Beam Reaction		R_2 Simple Beam Reaction		By Specification Formula
①	13.5	⑤	3.5	
②	7.5	⑥	9.5	$\frac{11.5}{5}$ = 2.3
③	3.5	⑦	9.5	= H-46
④	—	⑧	3.5	
	24.5/11.5 = 2.13 = H-42.6		26.0/11.5 = 2.26 = H-45.2	
	Use H-42		Use H-46	

48' Panels

Center Stringer

	Shear (kips)	Moment (kip-ft.)
D.L. - Slab and cross beams (5.6 k.)	22.4	269
Stringer $0.180 \times \overline{48}^2/8$	4.3	52
L.L. H-46	91.3	978
	118.0	1299

		Gross Area	Net Area	Gross I	Net I
Web 48 × 7/16	Silicon	21.00	17.1	4032	3280
4 Ls 6 × 4 × 9/16	"	21.24	19.0	11499	10290
		42.24	36.1	15,531	13,570

S.M. = 560 in.^{3} (net sect.) 640 in.^{3} (gross sect.)
Unit stress = 12 × 1,299,000/560 = 27,800 #/in.^{2} tension.
" " = 12 × 1,299,000/640 = 24,400 #/in.^{2} compression.

North Stringer

	Shear (kips)	Moment (kip-ft.)
D.L. - Slab and cross beams (7.1 k.)	28.4	340
Stringer	4.3	52
L.L. H-42	83.4	894
	116.1	1286

Use same section as for center stringer (see above)
Unit stress = 12 × 1,286,000/560 = 27,600 #/in.^{2} tension.
" " = 12 × 1,286,000/640 = 24,100 #/in.^{2} comp.

Rev. 10/5/33
1/17/35

Lower Deck Roadway Stringers (cont'd.)

48' Panels (cont'd.)

South Stringer

		Shear (kips)	Moment (kip-ft.)
D.L.	Slab and cross beams (7.1 k.)	28.4	340
	Lateral Bracing 9.000 × 22×26/48	4.9	107
	Stringer 0.190 × $48^2/8$	4.6	55
L.L. -	H-42	83.4	894
		121.3	1396

	Gross Area	Net Area	Gross I	Net I
Web 48"×7/16" Sil.	21.00	17.06	4032	3280
4 Ls 6"×4"×5/8" Sil.	23.44	20.94	12668	11300
	44.44		16700	14580

S.M. = 14580/24.25 = 601 $in.^3$ (net sect.) or 689 $in.^3$ (gr. section)
Unit stress = 12×1,396,000/601 = 27,800 #/$in.^2$ (max. tension.)
" " = 12×1,396,000/689 = 24,300 #/$in.^2$ (max. comp.)

Allowable stress in compression flanges of roadway stringers in 48' panels = 28,000 − 280 l/b
= 28,000 − 280 × 6
= 26,320 #/$in.^2$ - Silicon Steel.

Lower Deck Roadway Stringers (cont'd.) Rev. 10/5/33. 1/17/35

55' Panels

Center Stringer

		Shear (kips)	Moment (kip-ft)
D.L. - Slab and cross beams (5.6 k.)		25.7	353
	Stringer $0.210 \times \overline{55}^2/8$	5.8	80
L.L.	H-46	98.5	1140
		130.0	1573

S.M. req'd. = 667 in.^{3} Silicon (net section).

	Gross Area	Net Area	Gross I	Net I
Web 48" x 7/16" Sil.	21.00	17.50	4032	3360
4 Ls 6" x 6" x 5/8" Sil.	28.44	25.94	14520	13240
	49.44	43.44	18552	16600

S.M. = $16,600/24\frac{1}{4}$ = 685 in.^{3} (765 in.^{3} - gr. sect.)
Unit stress = 12 x 1,573,000/685 = 27,600 #/in.^{2}
Ratio depth to span length = 4/55 = 1/13.75

North Stringer

		Shear	Moment
D.L. - Slab and cross beams (7.1 k.)		32.5	447
	Stringer $0.210 \times \overline{55}^2/8$	5.8	80
L.L.	H-42	90.0	1040
		128.3	1567

S.M. req'd. = 666 in.^{3} Silicon (net section).
Use same design as for center stringer (see above)
Unit stress = 12 x 1,567,000/685 = 27,400 #/in.^{2} (max. tens.)
" " = 12 x 1,567,000/765 = 24,600 #/in.^{2} (max. comp.)

South Stringer

		Shear	Moment
D.L. - Slab and cross beams (7.1 k.)		32.5	447
	Lat. bracing 12.0 x 24 x 31/55	6.8	163
	Stringer $0.230 \times \overline{55}^2/8$	6.3	87
L.L. -	H-42	90.0	1040
		135.6	1737

S.M. req'd. = 780 in.^{3} Silicon (net section).

	Gross Area	Net Area	Gross I	Net I
Web 48" x 7/16" Sil.	21.00	17.50	4032	3360
4 Ls 6" x 6" x 3/4" Sil.	33.76	30.76	17158	15610
	54.76	48.26	21190	18970

S.M. = $18970/24\frac{1}{4}$ = 782 in.^{3} (874 in.^{3} - gross section)
Unit stress = 12 x 1,737,000/782 = +26,600 #/in.^{2} (max. tens.)
" " = 12 x 1,737,000/874 = −23,900 #/in.^{2} (max. comp.)

Allowable stress in compression flange = 26,320 #/in.^{2} - Silicon Steel.

DESIGN OF LOWER DECK ROADWAY STRINGERS

Live Load: H-40

Table B – Lower deck roadway stringers for cantilever bridge. Floor system consists of 6½" slab (90#/sq. ft.) on cross joists (at 6' ctrs.) which rest on upper flanges of roadway stringers. Roadway stringers spaced 11'-6" c. to c.

	Stringer Span (ft)	Wheel lines to stringer	Shear (kips)			Moment (kip-ft.)			Stringer Design				Max. Stress		Ave. web shear	$\frac{l}{b}$	Allow. Stress		Span / Depth
			D.L.	L.L.	Total	D.L.	L.L.	Total	Section	Mat'l.	S.M. (gross)	S.M. (net)	Comp.	Tens.			Comp.	Tens.	
N	9.0	2.1	5.7	67.3	73.0	39	151	190	20" I @ 75#	C	126.3	126.3	18,100	18,100	5,700	6.9	20,500	22,000	5.4
Ctr.	9.0	2.3	4.6	73.6	78.2	31	166	197	20" I @ 75#	C	126.3	126.3	18,700	18,700	6,100	6.9	20,500	22,000	5.4
S	9.0	2.1	5.7	67.3	73.0	39	151	190	20" I @ 75#	C	126.3	126.3	18,100	18,100	5,700	6.9	20,500	22,000	5.4
N	48.00	2.1	32.7	83.4	116.1	392	894	1286	1 web 48×7/16 4Ls 6×4×9/16	S	640	560	24,100	27,600	5,500	6.0	26,300	28,000	12.0
Ctr.	48.00	2.3	26.7	91.3	118.0	321	978	1299	do	S	640	560	24,400	27,800	5,600	6.0	26,300	28,000	12.0
S	48.00	2.1	37.9	83.4	121.3	502	894	1396	1 web 48×7/16 4Ls 6×4×5/8	S	689	601	24,300	27,800	5,800	6.0	26,300	28,000	12.0
N	55.00	2.1	38.3	90.0	128.3	527	1040	1567	1 web 48×7/16 4Ls 6×6×5/8	S	765	685	24,600	27,400	6,100	6.0	26,300	28,000	13.7
Ctr.	55.00	2.3	31.5	98.5	130.0	433	1140	1573	do	S	765	685	24,700	27,600	6,200	6.0	26,300	28,000	13.7
S	55.00	2.1	45.6	90.0	135.6	697	1040	1737	1 web 48×7/16 4Ls 6×6×3/4	S	874	782	23,900	26,600	6,500	6.0	26,300	28,000	13.7

R.R. Stringers for Continuous Spans

Panel length = 31.92' (max.) L.L. - 90-ton cars.

Dead Load:		
	Track, ties, etc.	250
	Stringer	85
	Stringer bracing	25
	Total	360 #/ft.

	Shear (kips)	Moment (kip-ft.)
D.L.	5.8	46
L.L.	42.9	285
Total	48.7	331

24" C.B. @ 80# Silicon Steel S.M.=185.8 Web 0.455"

Depth ratio = 16 Flange 9"

Max. stress = 12 × 331,000/185.8 = 21,400 #/in.^{2}

Compression flange L/b = 15/0.75 = 20

Allowable compression = 28,000 - 280 × 20 = 22,400 #/in.^{2}

R.R. Stringers for Suspension Bridge

Panel length = 30.32' L.L. - 90-ton cars.

Dead Load:		
	Track, ties, etc.	250
	Stringer	75
	Stringer bracing	25
	Total	350 #/ft.

	Shear (kips)	Moment (kip-ft.)
D.L.	5.3	40
L.L.	41.5	267
Total	46.8	307

24" C.B. @ 74# Silicon Steel S.M.=170.4 Web 0.43"

Depth ratio = 30.32/2.0 = 15.2 Flange 9"

Max. stress = 12 × 307,000/170.4 = 21,600 #/in.^{2}

Compression flange L/b = 14/0.75 = 18.7

Allowable compression = 28,000 - 280 × 18.7 = 22,750 #/in.^{2}

R. R. Stringers for 288' Spans

Panel Length (standard) = 36.00'

Dead Load -	Track, ties, etc.	250#/ft.
	Stringer	110
	Stringer Bracing	25
	Total	385#/ft.

Live Load - 90-ton cars.

	Shear (kips)	Moment (kip-ft.)
D.L. - 0.385 x 18 x 9	6.9	62
L.L.	46.3	330
Total	53.2	392

30" C.B. @ 108# Carbon Steel. S.M. = 299.2 Web 9/16"

Ratio Span/Depth = 36/2.50 = 14.4 Flange 10½"

Max. Stress = 12 x 392,000/299.2 = 15,700#/in.²

Unsupported length of compression flange = 17'

Allowable compression = 22,000 - 220 x 17/0.87 = 17,700#/in.²

" tension = 22,000#/in.²

R. R. Stringers for End Panels of Span YB1-YB2.

Panel Length = 27.0' (max.)

Dead Load = 355#/ft.

	Shear (kips)	Moment (kip-ft.)
D.L. - 0.355 x 13.5 x 6.75	4.8	32
L.L.	39.2	230
Total	44.0	262

24" C.B. @ 74# Carbon Steel. S.M. = 170.4 Web 7/16"

Ratio Span/Depth = 27/2.00 = 13.5 Flange 9"

Max. stress = 12 x 262,000/170.4 = 18,500#/in.²

Unsupported length of compression flange = 6.5'

Allowable compression = 22,000 - 220 x 6.5/0.75 = 20,100#/in.²

" tension = 22,000#/in.²

Note: 24" C.B. @ 80# being used.

R.R. Stringers for Cantilever Structure
Live Load – 90-ton cars.

48' Panels

D.L.–Track, ties, etc.	250 #/ft.
Stringer	160
Stringer bracing	20
Total	430 #/ft.

	Shear (kips)	Moment (kip-ft.)
D.L.	10.3	124
L.L.	57.2	503
Total	67.5	627

	Material	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net
1 Web 48×7/16	C	21.00		4032	3160		
4 Ls 5×3½×½ (48¼" b.-b.)	C	16.00	14.00	8639	7560		
		37.00		12,671	10,720	525	444

Max. tension = 12×627,000/444 = 17,000 #/in.^{2}
Max. compression = 12×627,000/525 = 14,300
Compression flange L/b = 15/0.87 = 17.2
Allowable compression = 22,000 − 220×17.2 = 18,200 #/in.^{2}
Ratio span/depth = 48/4 = 12

55' Panels

D.L.–Track, ties, etc.	250 #/ft.
Stringer	165
Stringer bracing	20
Total	435 #/ft.

	Shear (kips)	Moment (kip-ft.)
D.L.	12.0	164
L.L.	61.4	653
Total	73.4	817

	Material	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net
1 Web 48×7/16	S	21.00		4032	3160		
4 Ls 5×3½×9/16 (48¼" b.-b.)	S	17.88	15.63	9637	8420		
		38.88		13,669	11,580	567	480

Max. tension = 12×817,000/480 = 20,400 #/in.^{2}
Max. compression = 12×817,000/567 = 17,300
Compression flange L/b = 13/0.87 = 14.9
Allowable compression = 28,000 − 280×14.9 = 23,800 #/in.^{2}
Depth ratio = 55/4 = 13.7

R.R. Stringers for 504' Spans

Panel length 42'

D.L. - Track, ties, etc.	250 #/ft.	L.L. - 90-ton cars.	
Stringer	125		
Stringer bracing	25		
Total	400 #/ft.		

	Shear (kips)	Moment (kip-ft.)
D.L.	8.4	88
L.L.	52.5	403
Total	60.9	491

33" C.B. @ 125# Carbon Steel S.M.=385.1 Web 0.57"
Depth ratio = 42/2.75 = 15.3 Flange $1\frac{1}{2}$"
Max. stress = 12 × 491,000 / 385.1 = 15,300 #/in.²
Compression flange L/b = 14/0.96 = 14.6
Allowable compression = 22,000 − 220 × 14.6 = 18,800 #/in.²
(Note: Contractor has increased some of these stringers to 132# for use in falsework.)

R.R. Stringers for Tower Span E9

Stringer span 50'

D.L. - Track, ties, etc.	250 #/ft.	L.L. - 90-ton cars.	
Stringer	165		
Stringer bracing	20		
Total	435 #/ft.		

	Shear (kips)	Moment (kip-ft.)
D.L.	10.9	136
L.L.	58.5	545
Total	69.4	681

	Material	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net
1 Web 48 × 7/16	C	21.00		4032	2880		
4 Ls 5 × $3\frac{1}{2}$ × 9/16 ($48\frac{1}{2}$" b.-b.)	C	17.88	15.63	9637	8420		
		38.88		13,669	11,300	567	468

Max. tension = 12 × 681,000 / 468 = 17,400 #/in.²
Max. compression = 12 × 681,000 / 567 = 14,400 #/in.²
Compression flange L/b = 16/0.87 = 18.4
Allowable compression = 22,000 − 220 × 18.4 = 17,900 #/in.²
Depth ratio = 50/4.0 = 12.5

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San Francisco-Oakland Bay Bridge

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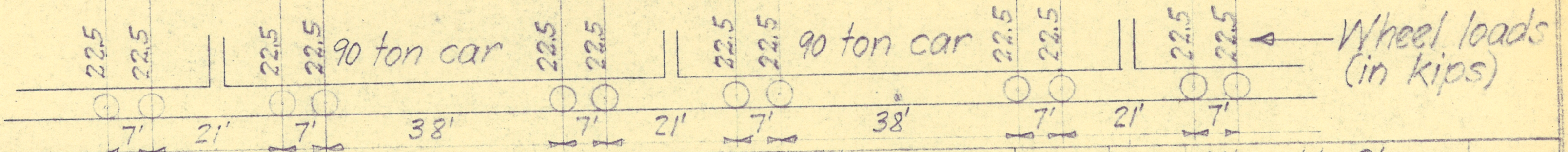
Design of Railroad Stringers

Live Load – 90-ton cars as shown in diagram (impact included in loads shown).

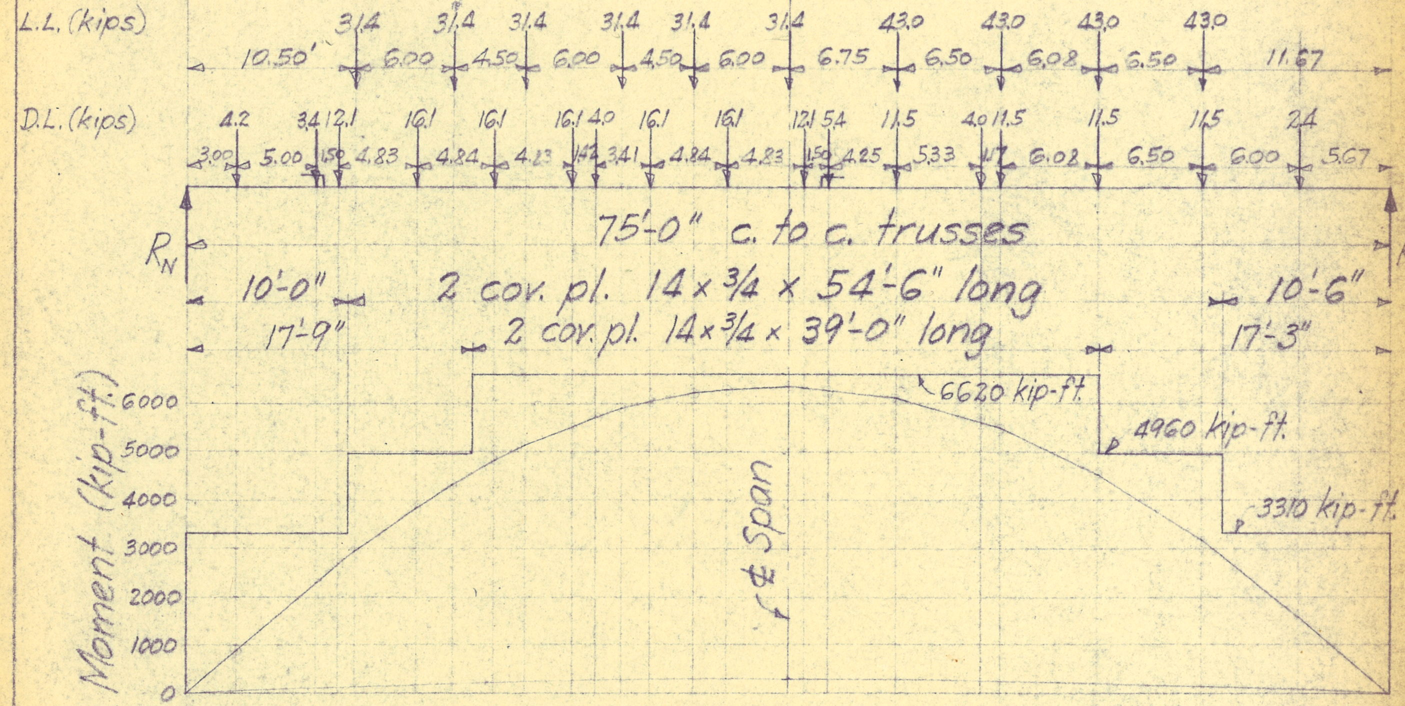


Stringer Span (ft.)	D.L. per ft.	Shear (kips) D.L.	Shear (kips) L.L.	Shear (kips) Total	Moment (kip-ft.) D.L.	Moment (kip-ft.) L.L.	Moment (kip-ft.) Total	Stringer Design Section	Mat'l.	Web	S.M. (gross)	S.M. (net)	Max. Stress Comp.	Max. Stress Tens.	Ave. web shear	l/b	Allowable Stress Comp.	Allowable Stress Tens.	Allowable Stress Shear	Span/Depth
9.0	310#	1.4	27.5	28.9	3	51	54	15" I @ 55#	C	0.648"	67.8	67.8	9,600	9,600	3,000	19.6	17,700	22,000	12,500	7.2
27.0	355	4.8	39.2	44.0	32	230	262	* 24" CB @ 80#	C	.455	185.8	185.8	16,900	16,900	4,000	8.7	20,100	22,000	12,500	13.5
30.32	350	5.3	41.5	46.8	40	267	307	24" CB @ 74#	S	.430	170.4	170.4	21,600	21,600	4,600	18.7	22,800	28,000	16,000	15.2
31.51 31.92	360	5.8	42.9	48.7	46	285	331	24" CB @ 80#	S	.455	185.8	185.8	21,400	21,400	4,500	20.0	22,400	28,000	16,000	16.0
36.00	385	6.9	46.3	53.2	62	330	392	30" CB @ 108#	C	.548	299.2	299.2	15,700	15,700	3,300	19.5	17,700	22,000	12,500	14.4
42.00	400	8.4	52.5	60.9	88	403	491	33" CB @ 125#	C	.570	385.1	385.1	15,300	15,300	3,300	14.6	18,800	22,000	12,500	15.3
48.00	430	10.3	57.2	67.5	124	503	627	1 web 48 × 7/16, 4Ls 5 × 3½ × ½	C	.437	525	444	14,300	17,000	3,200	17.2	18,200	22,000	12,500	12.0
50.00	435	10.9	58.5	69.4	136	545	681	1 web 48 × 7/16, 4Ls 5 × 3½ × 9/16	C	.437	567	468	14,400	17,400	3,300	18.4	17,900	22,000	12,500	12.5
55.00	435	12.0	61.4	73.4	164	653	817	1 web 48 × 7/16, 4Ls 5 × 3½ × 9/16	S	.437	567	480	17,300	20,400	3,500	14.9	23,800	28,000	16,000	13.7

*Increased from 74# to 80# beam for erection purposes.

Standard Lower Deck Floor Beam (Fl. Bm. "B") for Continuous Spans

D.L. fl. bm. = 425#/ft.



MOMENT DIAGRAM

	Shear (kips) R_N	Shear (kips) R_S	Moment (kip-ft)
D.L. - Concentrated	97.9	76.2	1960
Uniform	16.0	16.0	300
L.L.	176.8	183.6	4090
Total	290.7	275.8	6350

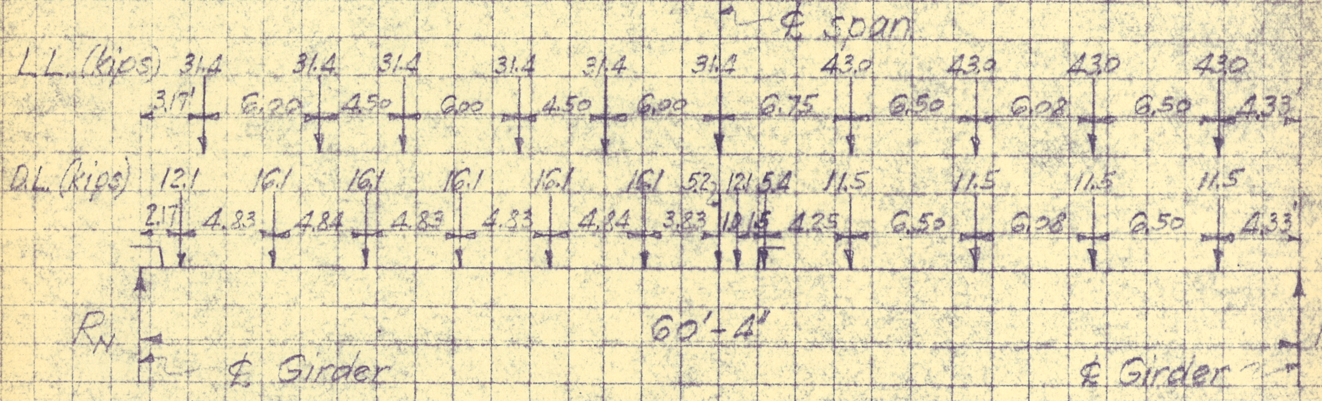
	Gross Area	Net Area	Gross I	Net I	Section Mod. Gross	Section Mod. Net	Resisting Mom. Gr. Sect. @ 26,200	Resisting Mom. Net Sect. @ 28,000
1 Web 81 x 1/2	40.50	28.50	22,143	15,580				
4 Ls 6 x 6 x 3/4 (81 1/2" b.-b.)	33.76	27.76	51,382	42,250				
	74.26		73,525	57,830	1804	1419	3940	3310
2 Cov. 14 x 3/4 x 54-6	21.00	18.00	35,518	30,440				
	95.26		109,043	88,270	2628	2127	5740	4960
2 Cov. 14 x 3/4 x 39-0	21.00	18.00	36,825	31,560				
	116.26		145,868	119,830	3452	2836	7540	6620

Max. compression = 12 × 6,350,000 / 3452 = 22,100 #/in.²

Max. tension = 12 × 6,350,000 / 2836 = 26,900 #/in.²

Silicon Steel.

Lower Deck Floor Beam "G" for Continuous Spans (at Panel Point L7)
D.L. Fl. bm. = 370#/ft.



	Shear (kips) R_N	Shear (kips) R_S	Moment (kip-ft.)
D.L. - Concentrated	92	70	1338
Uniform	11	11	168
L.L.	176	184	2766
Total	279	265	4272

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. Sect. @ 26,200	Resisting Mom. Net Sect. @ 28,000
1 Web $102\frac{1}{2} \times \frac{1}{2}$	51.25	40.75	44,880	35,700				
4 Ls $6 \times 6 \times \frac{11}{16}$	31.12	25.62	77,200	63,600				
	82.37		122,080	99,300	2370	1928	5170	4500

Max. compression = 12 × 4,272,000 / 2370 = 21,600 #/in.²
Max. tension = 12 × 4,272,000 / 1928 = 26,600 #/in.²
Silicon Steel

24485 6-35 10M EST. 2966
100 TO PAD S.P.O.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

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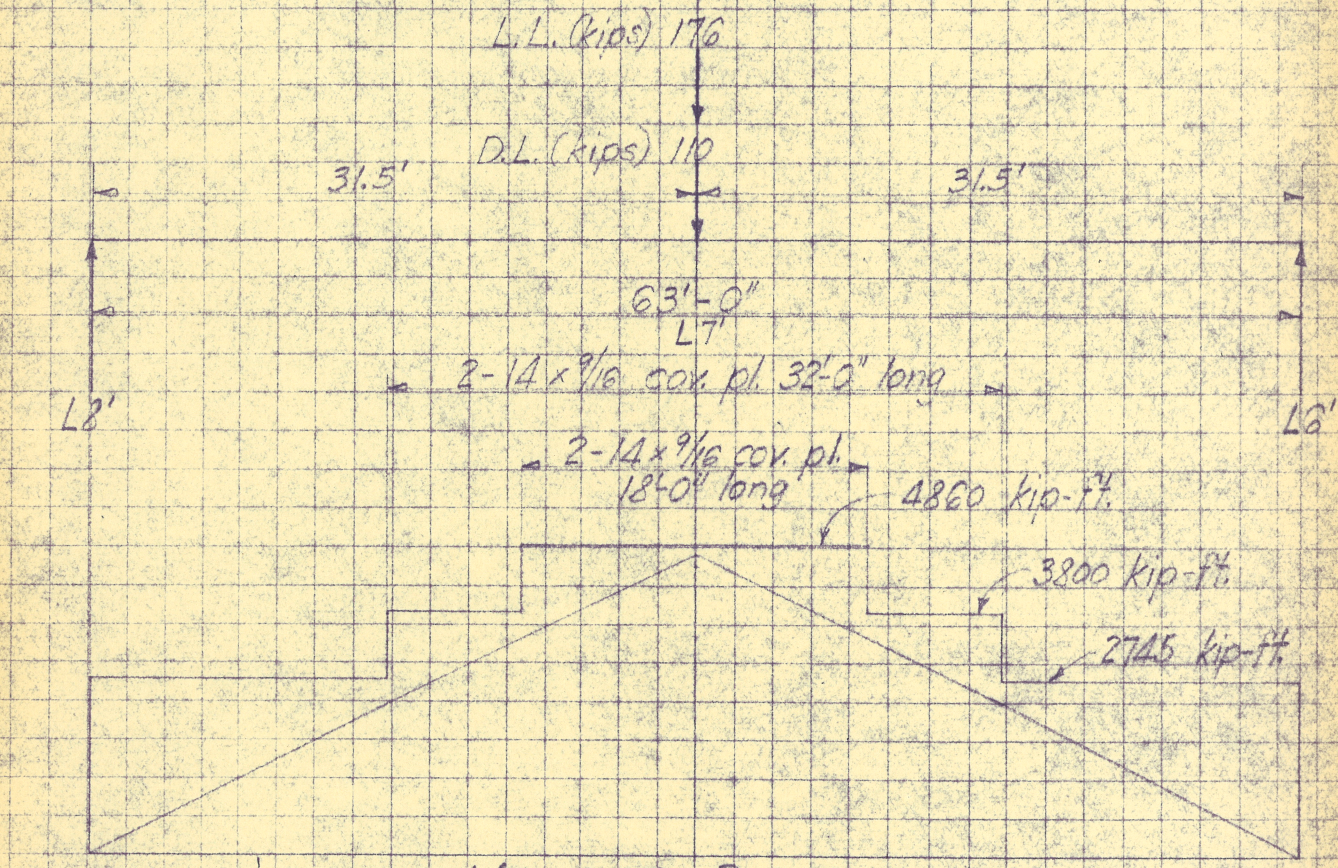
Continuous Spans – Lower Deck Girder "B" (Panel Point L6' to L8')

D.L. Girder = 350#/ft.



MOMENT DIAGRAM

	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	55	1735
Uniform	11	175
L.L.	28	2775
Total	154	4685

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. Sect. @ 22,500	Resisting Mom. Net Sect. @ 28,000
1 Web 81 x 1/2	40.50	33.50	22,140	18,300				
4Ls 6 x 6 x 5/8	28.44	23.44	43,400	35,750				
	68.94		65,540	54,050	1609	1324	2745	3090
2 Cov. 14 x 9/16 x 32-0	15.75	13.50	26,520	22,730				
	84.69		92,060	76,780	2225	1858	3800	4330
2 Cov. 14 x 9/16 x 18-0	15.75	13.50	27,240	23,350				
	100.44		119,300	100,130	2845	2390	4860	5520

Max. compression = 12 x 4,685,000 / 2845 = 19,800#/in.²

Max. tension = 12 x 4,685,000 / 2390 = 23,500#/in.² Silicon Steel.

Max. allowable compression $= 28000 - 280 \frac{l}{b} = 28000 - 280 \times \frac{31.5}{1.17} = 20{,}500$#/in.²

24455 3-35 10M EST. 3366
100 TO PAD. S. P. O.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

Made by Wood
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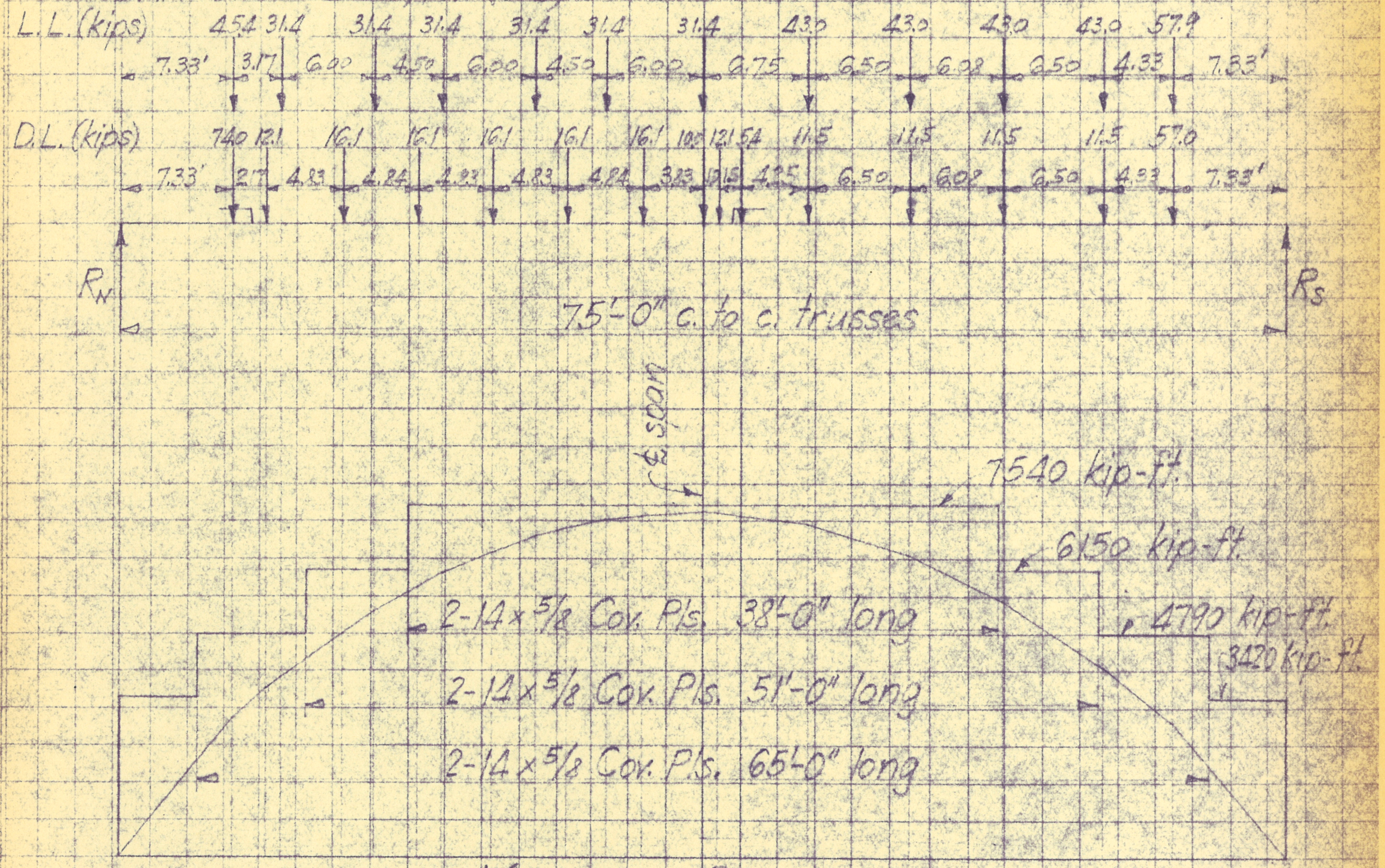
Continuous Spans - Lower Deck Floor Beams F6 and F8 (at Panel Pts. L6' & L8)

D.L. Fl. bm. = 600#/ft. (F8)



MOMENT DIAGRAM

	Shear (kips) R_N	Shear (kips) R_S	Moment (kip-ft)
D.L. - Concentrated	164	133	2500
Uniform	23	23	422
L.L.	224	240	4470
Total	411	396	7392

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. Sect. @ 26,400	Resisting Mom. Net Sect. @ 28,000
1 Web 81 x 1/2	40.50	32.00	22,140	17,500				
4 Ls 6 x 6 x 3/4	33.76	27.76	51,380	42,200				
	74.26		73,520	59,700	1802	1465	3960	3420
2 Cov. 14 x 5/8 x 65-0	17.50	15.00	29,510	25,290				
	91.76		103,030	84,990	2490	2050	5480	4790
2 Cov. 14 x 5/8 x 51-0	17.50	15.00	30,410	26,070				
	109.26		133,440	111,060	3175	2640	6980	6150
2 Cov. 14 x 5/8 x 38-0	17.50	15.00	31,330	26,850				
	126.76		164,770	137,910	3860	3230	8500	7540

Max. compression = 12 x 7,392,000 / 3860 = 23,000#/in²

Max. tension = 12 x 7,392,000 / 3230 = 27,500#/in²   Silicon Steel

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San Francisco-Oakland Bay Bridge

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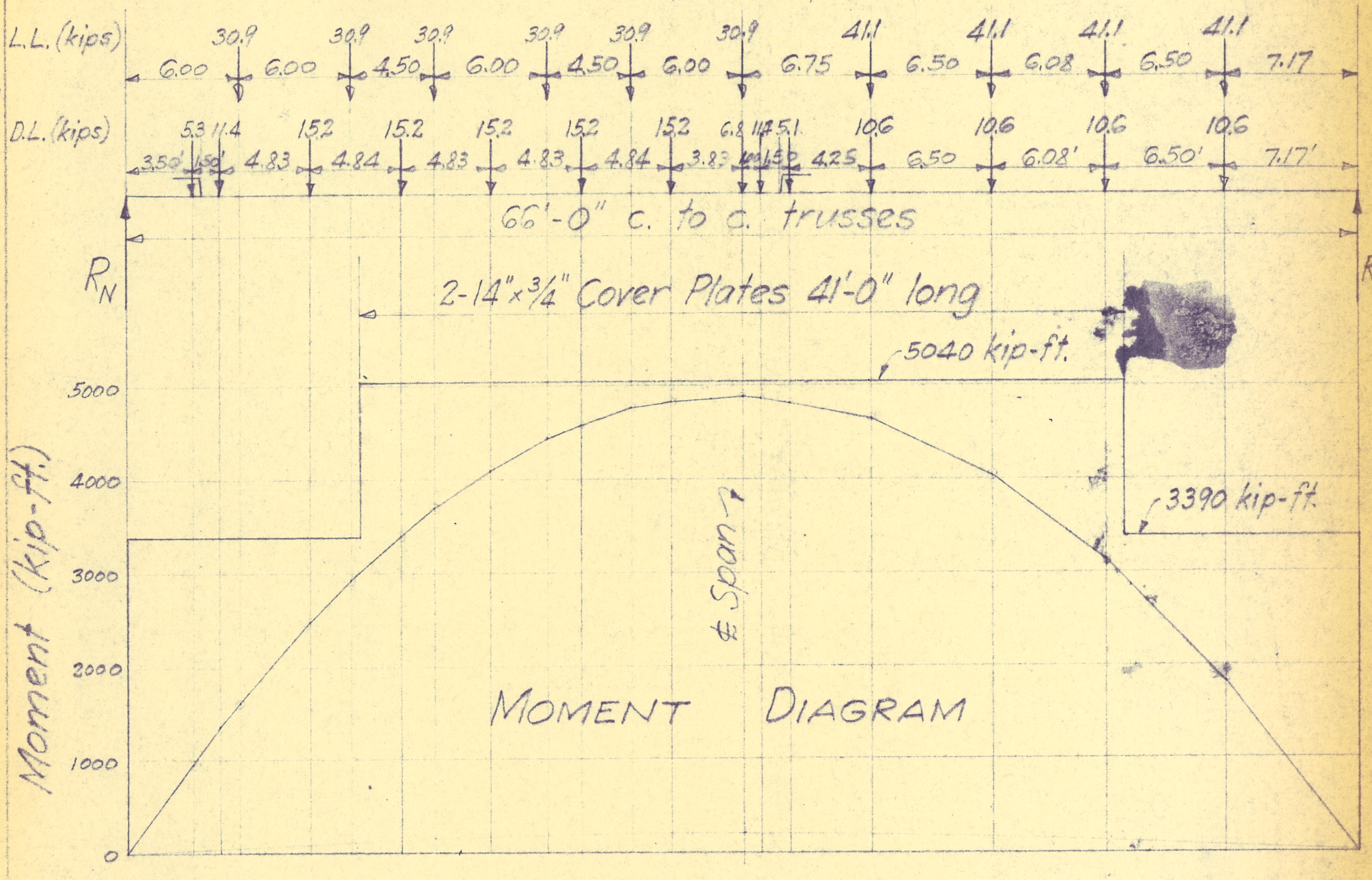
Lower Deck Floor Beams for Suspension Bridge   D.L. fl. bm. = 375#/ft.



Shear.

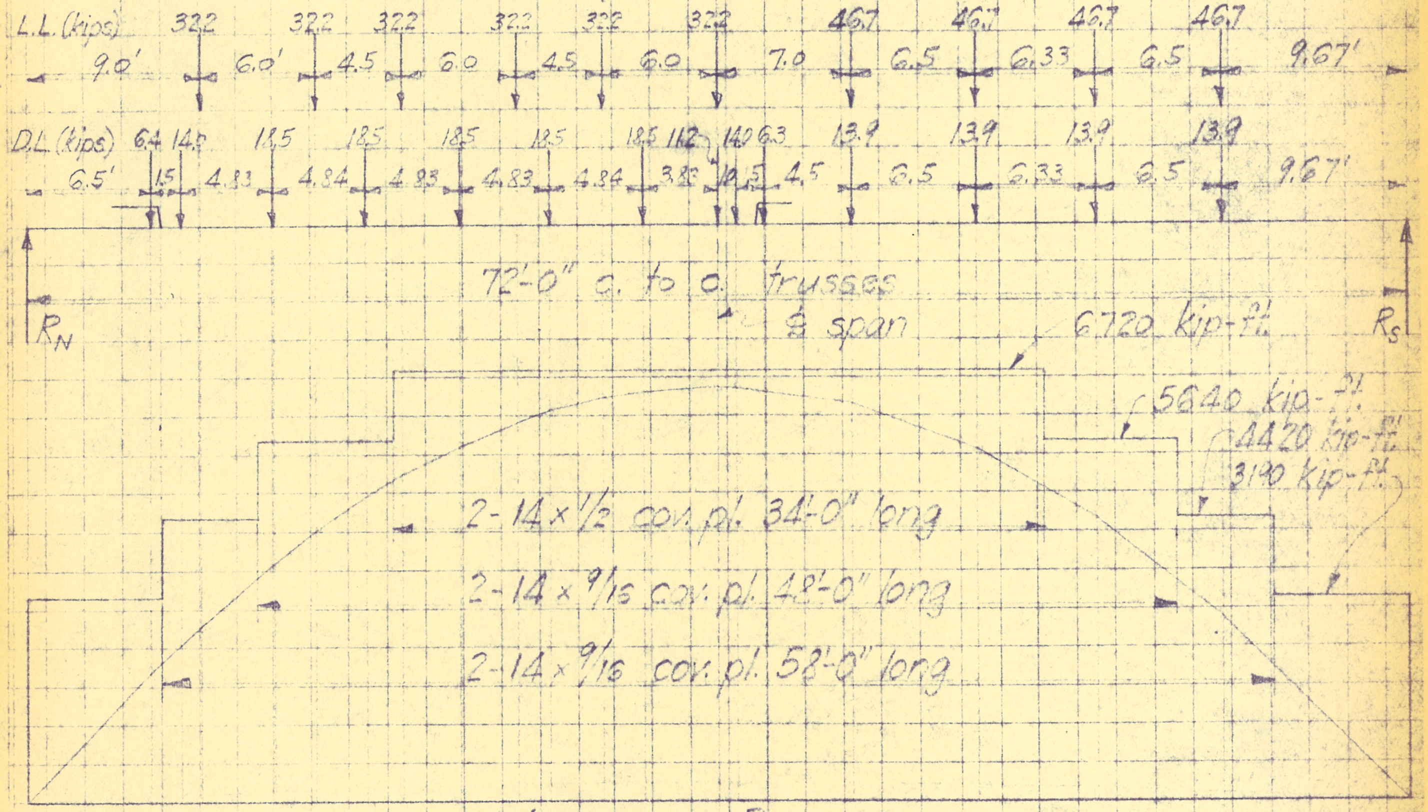
	R_N	R_S	Moment (kip-ft.)
D.L. - Concentrated	91.1	67.3	1505
Uniform	12.4	12.4	204
L.L.	172.2	177.6	3180
Total	275.7	257.3	4889

	Gross Area	Net Area	Gross I	Net I	Section Mod. Gross	Section Mod. Net	Resisting Mom. Gr. Sect. @26,200	Resisting Mom. Net Sect. @28,000
1 Web $80\frac{3}{4} \times \frac{1}{2}$	40.37	32.37	21,939	17,590				
4 Ls $6 \times 6 \times \frac{3}{4}$ ($81\frac{1}{4}$" b.-b.)	33.76	27.76	50,388	41,430				
	74.13	60.13	72,327	59,020	1780	1453	3880	3390
2 cov. $14 \times \frac{3}{4} \times 41'$-0"	21.00	18.00	35,301	30,260				
	95.13	78.13	107,628	89,280	2601	2158	5680	5040

Max. compression = 12 × 4,889,000/2601 = 22,600#/in.²

Max. tension = 12 × 4,889,000/2158 = 27,200#/in.²   Silicon Steel

Lower Deck Floor Beams for 288' Spans on Yerba Buena Island.
D.L.-Fl. bm. = 440#/ft



MOMENT DIAGRAM

	Shear (kips)			Moment (kip-ft.)
	Max. R_N	R_N	R_S	
D.L. - Concentrated	124	112	88	2210
Uniform	16	16	16	285
L.L.	206	183	197	3975
Total	346	311	301	6470

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. Sect. @ 26,400	Resisting Mom. Net Sect. @ 28,000
1 Web 80 × 1/2	40.00	32.00	21,330	17,260				
4 Ls 6 × 6 × 11/16	31.12	25.62	46,230	38,030				
	71.12		67,560	55,090	1679	1368	3690	3190
2 Cov. 14 × 9/16 × 52'-0	15.75	13.50	25,870	22,180				
	86.87		93,430	77,270	2285	1892	5030	4420
2 Cov. 14 × 9/16 × 48-0	15.75	13.50	26,600	22,800				
	102.62		120,030	100,070	2900	2418	6380	5640
2 Cov. 14 × 1/2 × 34-0	14.00	12.00	24,260	20,790				
	116.62		144,290	120,860	3440	2880	7570	6720

Max. compression = 12 × 6,470,000 / 3440 = 22,600 #/in²
Max. tension = 12 × 6,470,000 / 2880 = 27,000 #/in² Silicon Steel.

Z4415 8-35 10M EST. 9966
100 TO PKG. S.P.O.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

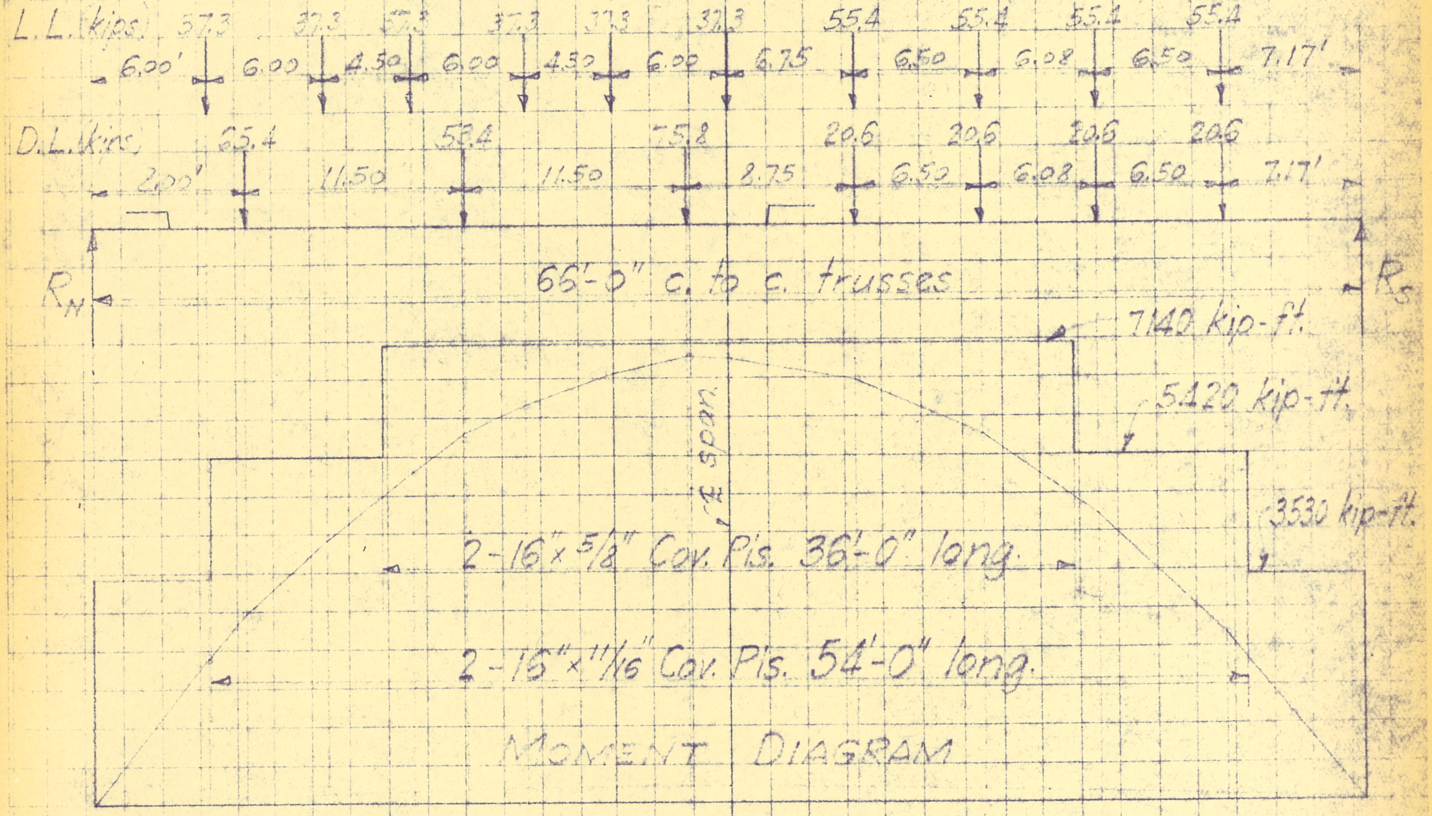
SAN FRANCISCO-OAKLAND BAY BRIDGE

Made by Wood
Checked by

Lower Deck Floor Beams for Cantilever Structure - 48' Panels

D.L. - Fl. bm. 475 #/ft.
R.R. Stringers (each) 20.4 k
Roadway Stringers - North 65.4
Center 53.4
South 75.8

L.L. + Fl. bm. reactions:
H-20 - 1 wheel line = .85 × 43.9 = 37.3 k.
R.R. - 1 wheel line = .85 × 65.2 = 55.4



	Shear (kips) R_N	Shear (kips) R_S	Moment (kip-ft.)
D.L. - Concentrated	156	120	2718
Uniform	16	16	258
L.L.	214	232	3986
Total	386	368	6962

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. Sect. @ 26,600	Resisting Mom. Net Sect. @ 28,000
1 Web 86 × 1/2	43.00	34.50	26,500	21,250				
4 Ls 6 × 6 × 11/16	31.12	25.62	53,700	44,210				
	74.12		80,200	65,460	1854	1512	4010	3530
2 Cov. 16 × 11/16 × 54-0	22.00	19.25	41,810	36,580				
	96.12		122,010	102,040	2780	2325	6160	5420
2 Cov. 16 × 5/8 × 36-0	20.00	17.50	39,160	34,270				
	116.12		161,170	136,310	3620	3060	8030	7140

Max. compression = 12 × 6,962,000 / 3620 = 23,100 #/in² Silicon
Max. tension = 12 × 6,962,000 / 3060 = 27,300 #/in² Steel

24465 8-35 10M EST 9966
100 TO PAD. S.P.O.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

Made by Wood. 19
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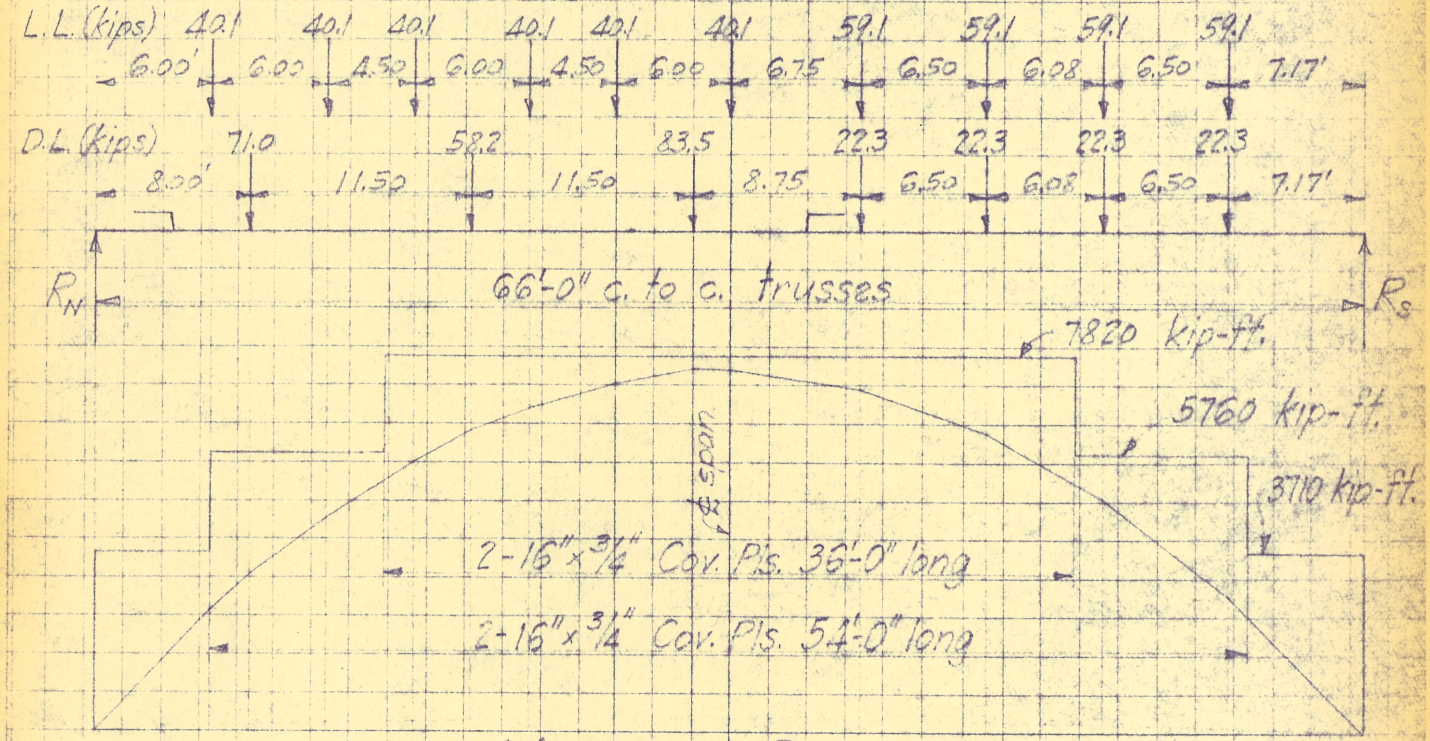
Lower Deck Floor Beams for Cantilever Structure – At Panel Points LA4 & LC4.

D.L. – Fl. bm. = 505#/ft.
R.R. Stringers – each 22.3 k
Roadway Stringers – North 71.0
Center 58.2
South 83.5

L.L. – Fl. bm. reactions:
H-20 – 1 wheel line = .85 × 47.2 = 40.1 k.
R.R. – 1 wheel line = .85 × 69.6 = 59.1



MOMENT DIAGRAM

	Shear (kips) R_N	Shear (kips) R_S	Moment (kip-ft.)
D.L. – Concentrated	170	132	2976
Uniform	17	17	275
L.L.	229	248	4265
Total	416	397	7516

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. sect. @ 26,600	Resisting Mom. Net sect. @ 28,000
1 Web 86 × 1/2	43.00	34.00	26,500	20,950				
4 Ls 6 × 6 × 3/4	33.76	27.76	58,170	47,820				
	76.76		84,670	68,770	1958	1590	4330	3710
2 Cov. 16 × 3/4 × 54-0	24.00	21.00	45,680	39,970				
	100.76		130,350	108,740	2960	2470	6560	5760
2 Cov. 16 × 3/4 × 36-0	24.00	21.00	47,260	41,350				
	124.76		177,610	150,910	3960	3350	8790	7820

Max. compression = 12 × 7,516,000 / 3960 = 22,800 #/in² Silicon Steel.
Max. tension = 12 × 7,516,000 / 3350 = 26,900 #/in²

24465 8-35 10M. EST. 9986
100 TO PAD S.P.O.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

Made by Wood
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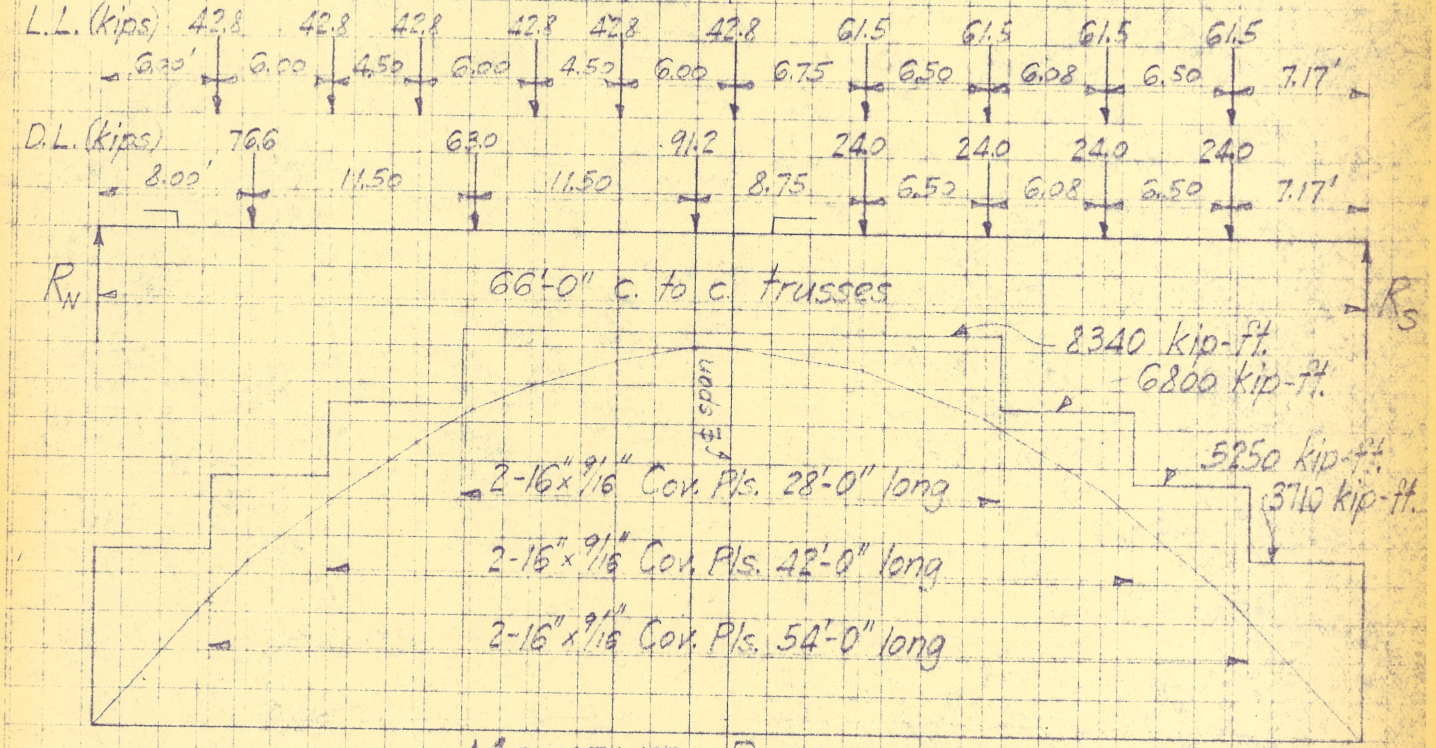
Lower Deck Floor Beams for Cantilever Structure - 55' Panels.

D.L.-Fl. Bm. = 515#/ft
R.R. Stringers (each) 24.0k
Roadway Stringers-North 76.6
Center 63.0
South 91.2

L.L.-Fl. bm. reactions:
H-40 - 1 wheel line = .85 x 50.3 = 42.8k
R.R. - 1 wheel line = .85 x 72.4 = 61.5



MOMENT DIAGRAM

	Shear (kips) R_N	Shear (kips) R_S	Moment (kip-ft.)
D.L.-Concentrated	184	142	3230
Uniform	17	17	281
L.L.	243	260	4500
Total	444	419	8011

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. Sect. @ 26,500	Resisting Mom. Net Sect. @ 28,000
1 Web 86 x 1/2	43.00	34.00	26,500	20,950				
4 Ls 6 x 6 x 3/4	33.76	27.76	58,170	47,820				
	76.76		84,670	68,770	1958	1590	4330	3710
2 Cov. 15 x 9/16 x 54-0	18.00	15.75	34,110	29,850				
	94.76		118,780	98,620	2710	2250	6000	5250
2 Cov. 16 x 9/16 x 42-0	18.00	15.75	35,000	30,620				
	112.76		153,780	129,240	3460	2910	7660	6800
2 Cov. 16 x 9/16 x 28-0	18.00	15.75	35,900	31,410				
	130.76		189,680	160,650	4215	3575	9350	8340

Max. compression = 12 x 8,011,000/4215 = 22,800 #/in² Silicon Steel
Max. tension = 12 x 8,011,000/3575 = 26,900 #/in²

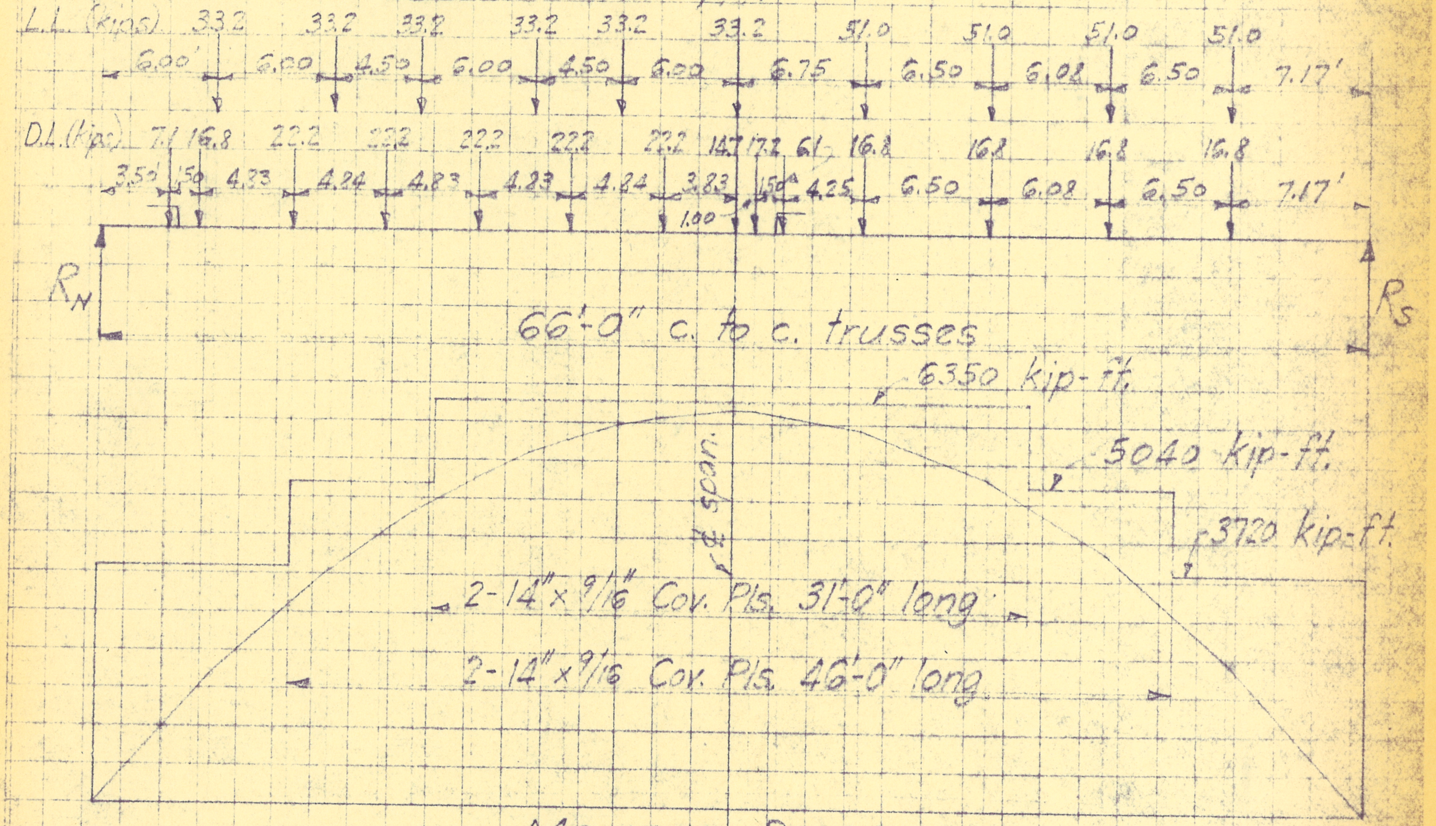
STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

Made by Wood
Checked by

Lower Deck Floor Beams for 504' Spans.

D.L. Floor Beam = 435#/ft.



MOMENT DIAGRAM

	Shear (kips) R_N	R_S	Moment (kip-ft.)
D.L.-Concentrated	136	104	2311
Uniform	14	14	237
L.L.	192	211	3643
Total	342	329	6191

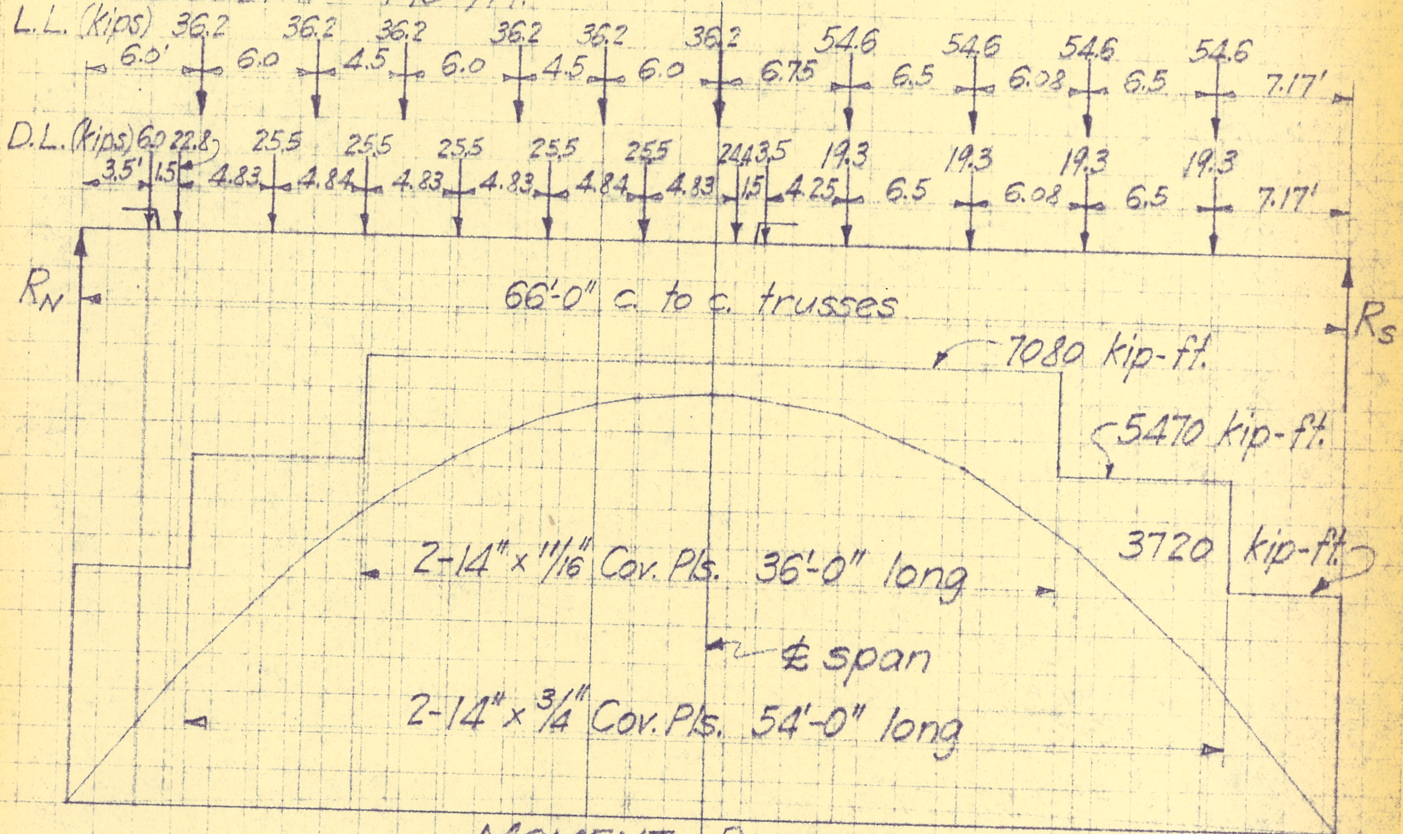
	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. Sect. @26,200	Resisting Mom. Net Sect. @28,000
1 Web 86 x 1/2	43.00	34.50	26,500	21,250				
4 ∟s 6x6x3/4	33.76	27.76	58,170	47,820				
	76.76	62.26	84,670	69,070	1957	1597	4270	3720
2 Cov. 14x9/16x46-0	15.75	13.50	29,850	25,580				
	92.51	75.76	114,520	94,650	2613	2160	5700	5040
2 Cov. 14x9/16x31-0	15.75	13.50	30,620	26,250				
	108.26	89.26	145,140	120,900	3273	2720	7150	6350

Max. compression = 12 x 6,191,000 / 3273 = 22,700 #/in.²
Max. tension = 12 x 6,191,000 / 2720 = 27,300 #/in.²
Silicon Steel.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

Lower Deck Floor Beam at Bent E9W.

D.L. Fl. Bm. = 495#/ft.



MOMENT DIAGRAM

	Shear (kips) R_N	Shear (kips) R_S	Moment (kip-ft.)
D.L. - Concentrated	150	112	2405
Uniform	16	16	270
L.L.	208	227	3945
Total	374	355	6620

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. sect. @ 26,200	Resisting Mom. Net sect. @ 28,000
1 Web 86 x 1/2	43.00	34.50	26,500	21,250				
4 Ls 6 x 6 x 3/4	33.76	27.76	58,170	47,820				
	76.76		84,670	69,070	1958	1595	4270	3720
2 Cov. 14 x 3/4 x 54'-0	21.00	18.00	39,970	34,260				
	97.76		124,640	103,330	2830	2345	6180	5470
2 Cov. 14 x 11/16 x 36'-0	19.25	16.50	37,850	32,440				
	117.01		162,490	135,770	3630	3030	7930	7080

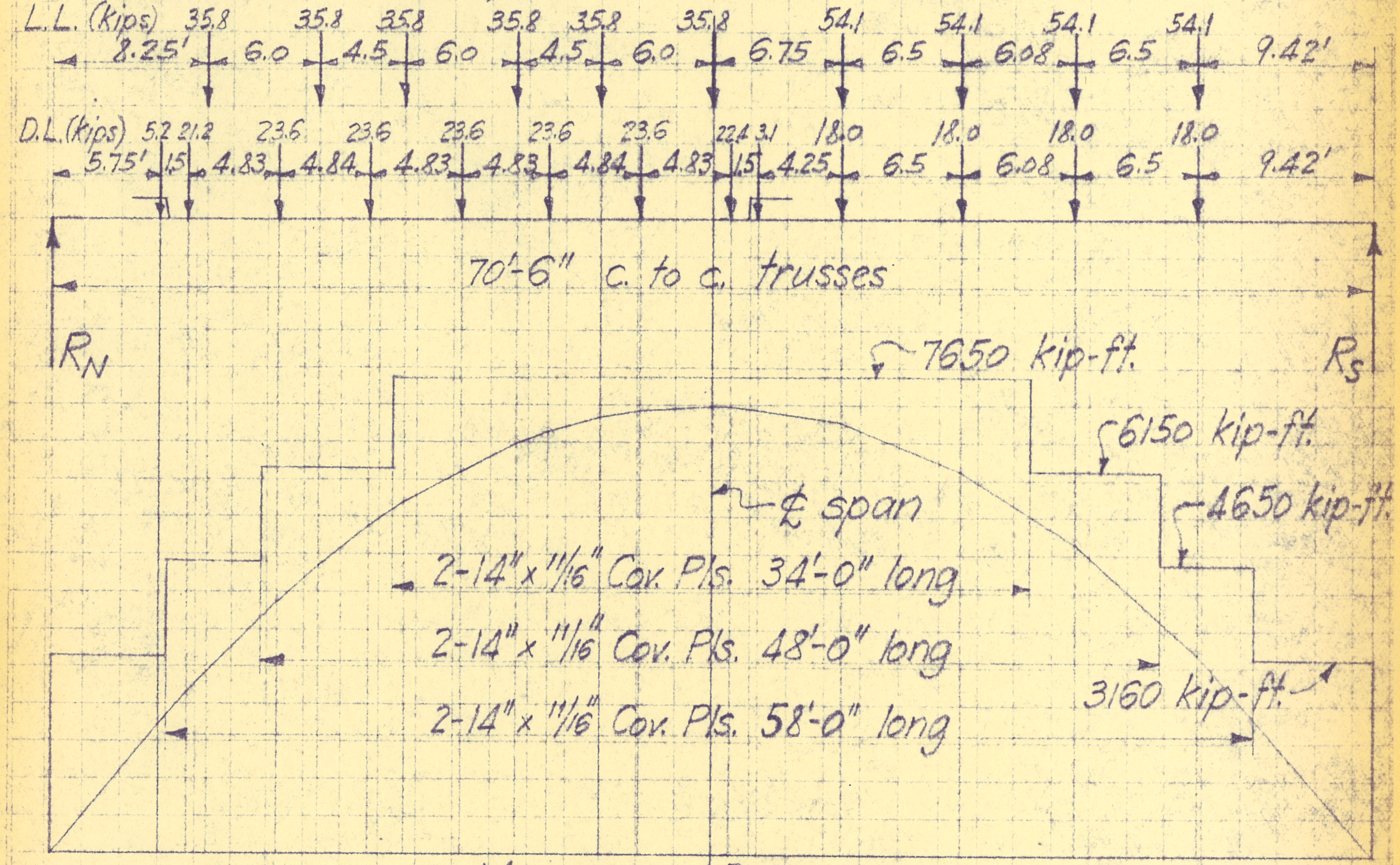
Max. compression = 12 x 6,620,000/3630 = 21,900 #/in.²
Max. tension = 12 x 6,620,000/3030 = 26,200 #/in.²
Silicon Steel

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

Lower Deck Floor Beam at Bent E9E

D.L. Fl. Bm. = 495#/ft.



MOMENT DIAGRAM

	Shear (kips) R_N	Shear (kips) R_S	Moment (kip-ft.)
D.L.-Concentrated	137	105	2493
Uniform	17	17	308
L.L.	207	225	4387
Total	361	347	7188

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. sect. @ 26,200	Resisting Mom. Net sect. @ 28,000
1 Web 80 x 1/2	40.00	31.00	21,330	16,540				
4 Ls 6 x 6 x 11/16	31.12	25.52	46,230	38,060				
	71.12		67,560	54,600	1679	1356	3665	3160
2 Cov. 14 x 11/16 x 58'-0	19.25	16.50	31,720	27,190				
	90.37		99,280	81,790	2425	1997	5290	4650
2 Cov. 14 x 11/16 x 48'-0	19.25	16.50	32,700	28,120				
	109.62		131,980	109,910	3170	2640	6920	6150
2 Cov. 14 x 11/16 x 34'-0	19.25	16.50	33,910	29,070				
	128.87		165,890	138,980	3915	3280	8550	7650

Max. compression = 12 x 7,188,000/3915 = 22,000#/in.²

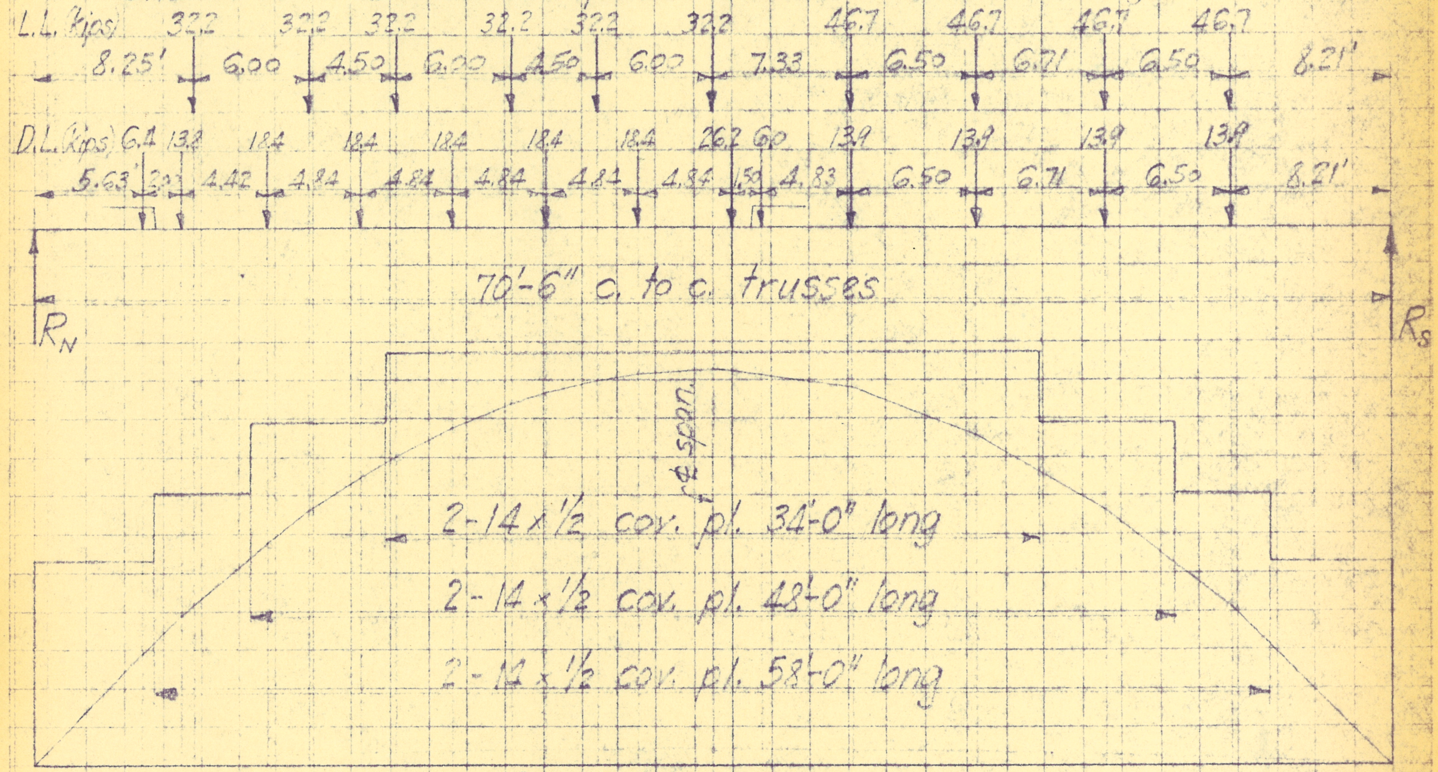
Max. tension = 12 x 7,188,000/3280 = 26,300#/in.²

Silicon Steel.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

Lower Deck Floor Beams for 288' Spans E9-E10 and E10-E11.
D.L.-Fl. bm. = 415#/ft. Positions of concentrated loads vary. The sketch below shows the positions assumed for design.



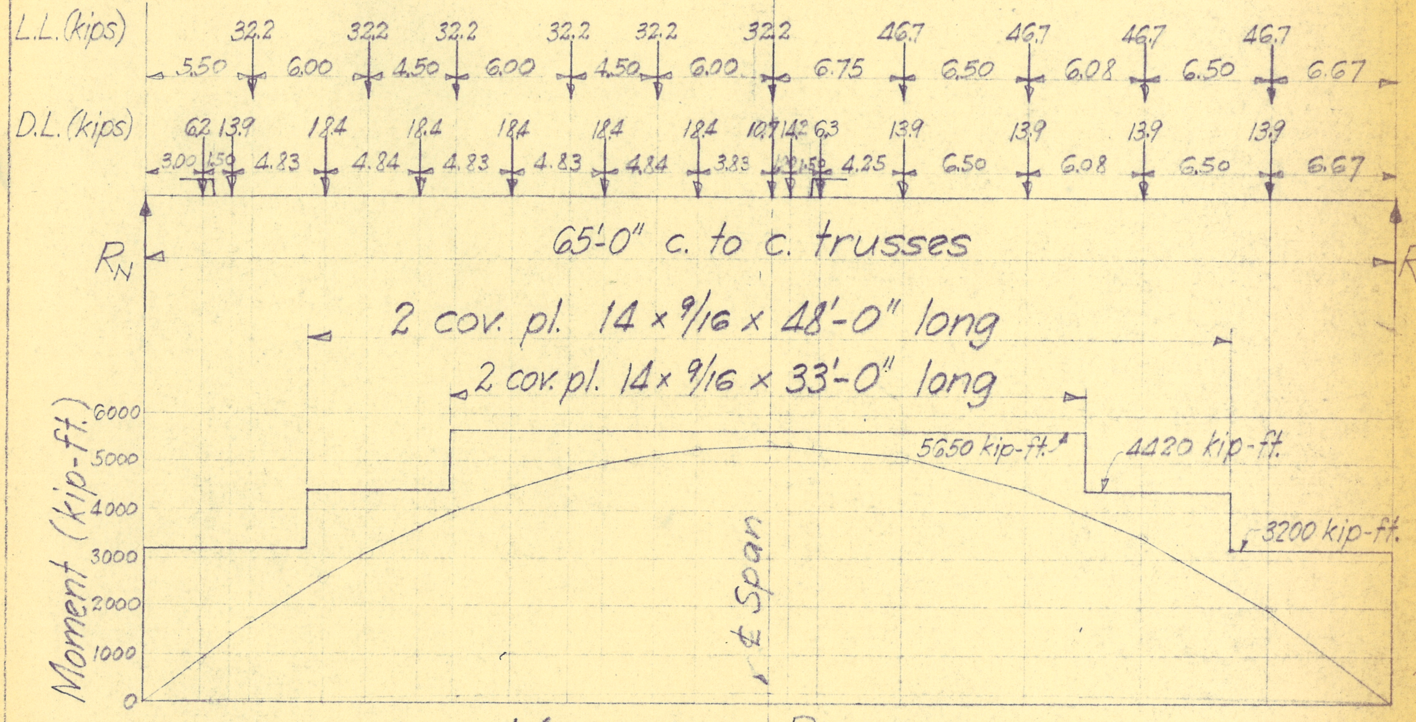
MOMENT DIAGRAM

	Shear (kips) Max. R_N	R_N	R_S	Moment (kip-ft.)
D.L.-Concentrated	124	114	86	2127
Uniform	15	15	15	258
L.L.	206	187	193	3786
Total	345	316	294	6171

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Gr. Sect. @26,400	Resisting Mom. Net Sect. @28,000
1 Web 80 x ½	40.00	32.00	21,330	17,060				
4 Ls 6 x 6 x 11/16	31.12	25.62	46,230	38,030				
	71.12		67,560	55,090	1679	1368	3690	3190
2 Cov. 14 x ½ x 58-0	14.00	12.00	22,970	19,680				
	85.12		90,530	74,770	2220	1833	4880	4275
2 Cov. 14 x ½ x 48-0	14.00	12.00	23,530	20,170				
	99.12		114,060	94,940	2765	2300	6090	5360
2 Cov. 14 x ½ x 34-0	14.00	12.00	24,110	20,670				
	113.12		138,170	115,610	3305	2765	7280	6450

Max. compression = 12 x 6,171,000 / 3305 = 22,400 #/in.²
Max. tension = 12 x 6,171,000 / 2765 = 26,800 #/in.² Silicon Steel.

Lower Deck Floor Beams for 288' Spans E11-E23
D.L. floor beam 385#/ft.



MOMENT DIAGRAM

	Shear (kips) R_N	Shear (kips) R_S	Moment (kip-ft.)
D.L. - Concentrated	113	86	1790
Uniform	13	13	204
L.L.	183	197	3418
Total	309	296	5412

	Gross Area	Net Area	Gross I	Net I	Section Mod. Gross	Section Mod. Net	Resisting Moment Gr. Sect. @26,200	Resisting Moment Net Sect. @28,000
1 Web 80 × 1/2	40.00	32.00	21,333	17,070				
4 Ls 6×6×11/16 (80 1/2" b.-b.)	31.12	25.62	46,232	38,060				
	71.12	57.62	67,565	55,130	1679	1370	3660	3200
2 cov. 14×9/16×48'-0"	15.75	13.50	25,874	22,180				
	86.87	71.12	93,439	77,310	2290	1894	5000	4420
2 cov. 14×9/16×33'-0"	15.75	13.50	26,597	22,800				
	102.62	84.62	120,036	100,110	2901	2420	6330	5650

Max. compression = 12×5,412,000/2901 = 22,400#/in.²

Max. tension = 12×5,412,000/2420 = 26,800#/in.²

Silicon Steel.

Roadway Slab – Upper Deck.

For Suspension Bridge, Continuous Span, and Girder Spans on Mole.

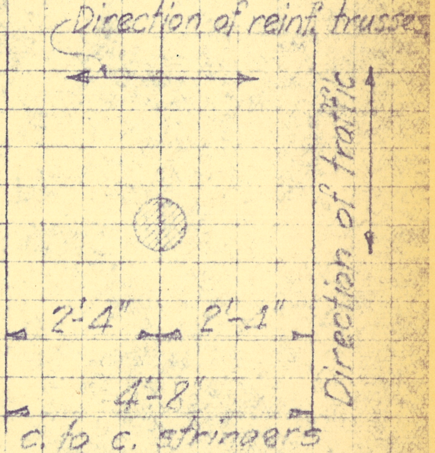
Live Load: H-10 + $33\frac{1}{3}$% impact.
Dead Load: 60# per sq. ft.
Reinforcing ⊥ to traffic.
Bearing area of each rear wheel assumed to be a circle of 10" diameter.

Slab span 4'-8" c. to c. stringers.
Slab depth 6" overall.
$n = 15$

Live Load moment by Westergaard's equations (see "Public Roads", Vol. 11, No. 1):

$c = 10''$ $h = 6''$ $s = 4'\text{-}8''$

L.L. Simple beam moment $= 0.266 \times 10{,}670 = 2840'$# per ft.
D.L. " " " $= 60 \times (4.67)^2/8 = \underline{164}$
Total simple beam moment $= 3004'$# per ft.



Design slab for 80% of simple beam moment $= .80 \times 3004 = 2400'$# per ft.

Use reinforcing trusses as shown in sketch below.

$A_s = A'_s = 0.471$ in.² per ft of slab.

$p = p' = \frac{0.471}{60} = 0.00785$

$n = 15$

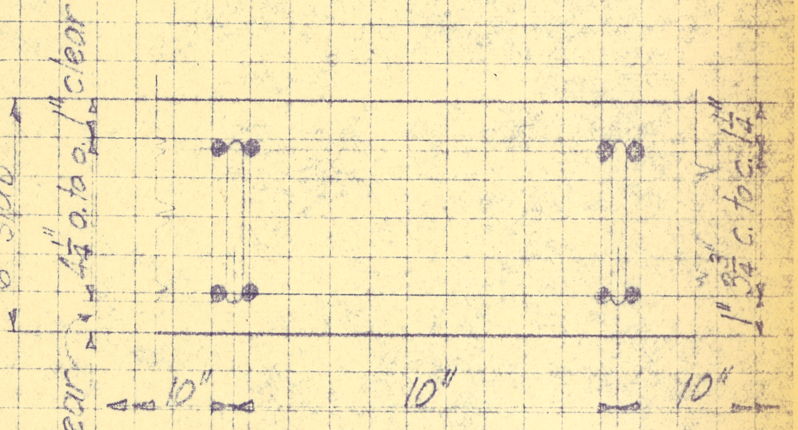
$\frac{d'}{d} = \frac{1.25}{5.00} = 0.25$

$k = 0.356$

$j = 0.860$

$f_s = \frac{12 \times 2400}{0.471 \times 0.860 \times 5} = 14{,}200$ #/in²

$f_c = \frac{14{,}200}{15} \times \frac{0.356}{0.644} = 525$ #/in²



Reinforcing Trusses:
Each chord = 2-$\frac{1}{2}$"φ bars.
Web = $\frac{7}{16}$"φ bar continuous.
Spacing of trusses = 10" c. to c.

Concrete – light weight.

24487 9-35 10M EST 9968
100 TO 1AD, S.P.O.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

Roadway Slab - Upper Deck

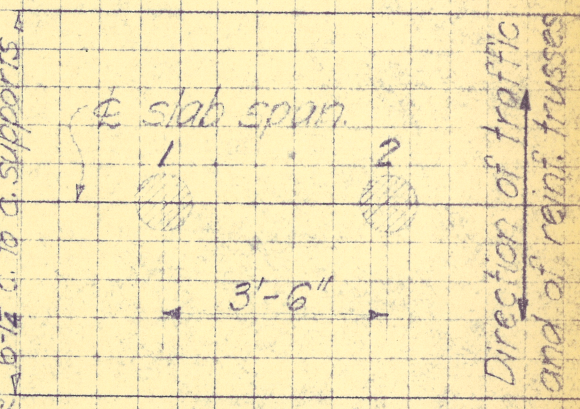
For Cantilever Structure, 504' Spans, and 288' Spans.

Live Load: H-10 + $33\frac{1}{3}$% impact. Slab span = $6'-1\frac{1}{4}''$ c. to c. supports.
Dead Load: 60# per sq. ft. Slab depth = 6" overall.
Reinforcing parallel to traffic. n = 15
Bearing area of each rear wheel assumed to be a circle of 10" diameter. Rear wheel load = 10,670# (incl. impact).

Live Load moments by Westergaard's equations (see "Public Roads," Vol. 11, No. 1):

$c = 10''$ $h = 6''$ $s = 6'-1\frac{1}{4}''$

Wheel No.	y	$\frac{y}{s}$	$\frac{M}{P}$	Simple Beam Mom. (at wheel '#)
1	0	0	0.290	3100
2	42"	0.574	0.072	770
L.L. moment				3870
D.L. moment $60\times(6.0)^2/8$				270
Total simple beam moment				4140 '# per ft.



Design slab for 80% of simple beam moment = $.80\times 4140 = 3310$ '# per ft.

Use reinforcing trusses as shown in sketch below.

$A_s = A'_s = 0.589$ in² per ft. of slab.

$p = p' = \frac{0.589}{60} = 0.00982$

$n = 15$

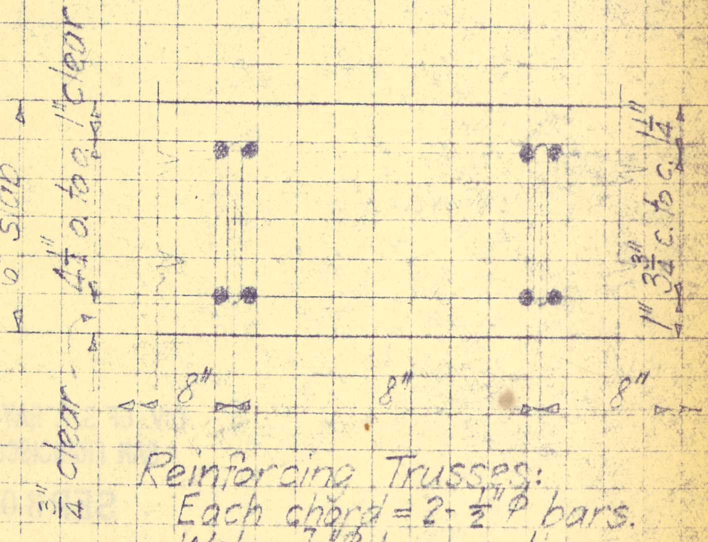
$\frac{d'}{d} = \frac{1.25}{5.00} = 0.25$

$k = 0.380$

$j = 0.847$

$f_s = \frac{12\times 3310}{0.589\times 0.847\times 5} = 15,900$ #/in²

$f_c = \frac{15,900}{15}\times\frac{0.380}{0.620} = 650$ #/in²

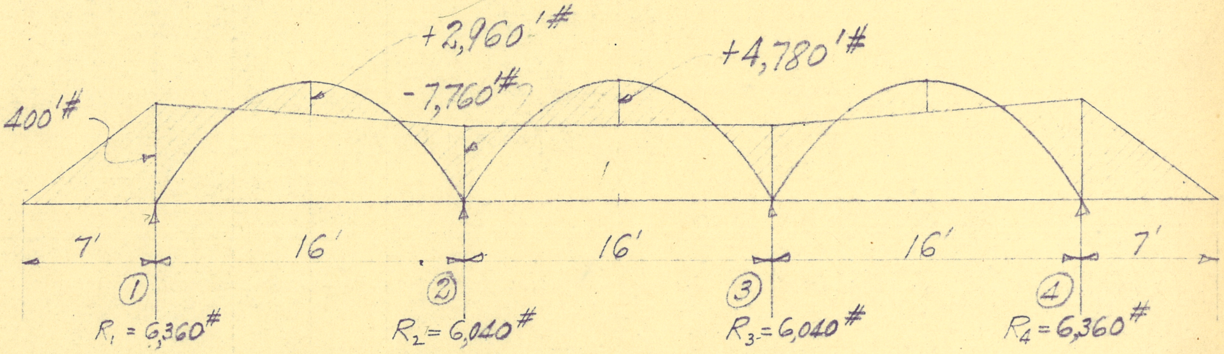


Reinforcing Trusses:
Each chord = 2 - $\frac{1}{2}''\phi$ bars.
Web = $\frac{7}{16}''\phi$ bar continuous.
Spacing of trusses = 8" c. to c.
Concrete - light weight.

Upper Deck Cross Beams (for Cantilever Structure & 504' Spans).

Spacing 6'-0" c. to c.
Supported on stringers 16'-0" c. to c.

Dead Load -	Floor	6 × 60	= 360
	Cross beam		= 32
			392# per ft. of cross beam.



DEAD LOAD MOMENTS AND REACTIONS.

			M_1	Shear left of R_1
D.L. -	Curb, rail, etc.	970 × 6.3	- 6,110'#	970
	Cross beam	$32 \times (7)^2/2$	- 790	225
	Slab	$360 \times (5)^2/2$	- 4,500	1,800
			M_1 = -11,400'#	2,995#

$M_1 + 5M_2 = -\frac{1}{2} \times 392 \times (16)^2$ $\quad M_2 = -7,760$'#

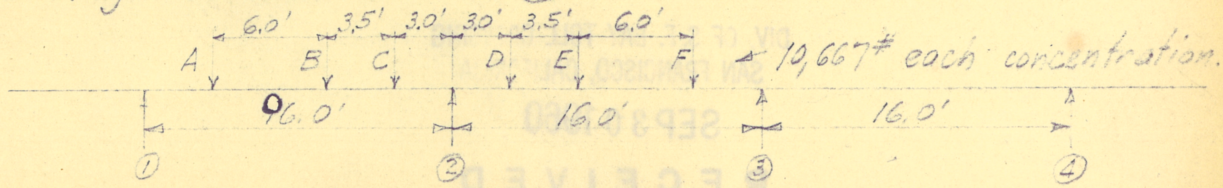
$wl^2/8 = 392 \times (16)^2/8 = 12,540$'#

L.L. - 13 1/3 ton trucks. Rear wheel load = 10,667#

Negative Moment at ①

D.L.		-11,400
L.L.	10,667 × 3.50	-37,400 (assuming no distribution)
		-48,800'#

Negative Moment at ②



For 2 lanes loaded C = 1.00
" 3 " " C = 0.90

(contd. on next sheet)

Upper Deck Cross Beams (cont'd.)

Negative Moment at ② (cont'd.)

Wheel	$M_{②}$ coeff. (for span of 10')
A	- 0.553
B	- 1.023
C	- 0.730
D	- 0.610
	- 2.916 × 1.00 = -2.916 (2 lanes)
E	- 0.797
F	- 0.352
	- 4.065 × 0.90 = -3.658 (3 lanes)

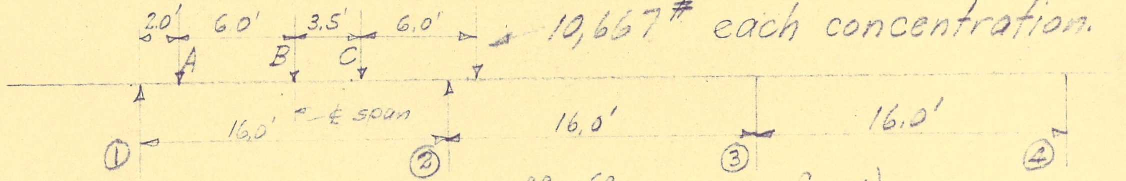
Assuming 6/8 to 1 cross beam, (L.L. only)

L.L. M_2 = -3.658 × 1.6 × 10,667 × 6/8 — - 46,800'#
D.L. M_2 = — - 7,760
— - 54,560

Assuming no distribution of L.L.

L.L. M_2 = -3.658 × 1.6 × 10,667 — -62,400'#
D.L. M_2 = — - 7,760
— -70,160'#

Positive Moment in first span -



Wheel	+M coeff. (for span of 10')
A	+ 0.464
B	+ 2.000
C	+ 0.943
	+ 3.407

Assuming 6/8 to cross beam,

L.L. M. = + 3.407 × 1.6 × 10,667 × 6/8 = +43,600'#
D.L. M. = + 2,960
+46,560'#

Assuming no distribution,

L.L. M. = +3.407 × 1.6 × 10,667 = + 58,200'#
D.L. M. = + 2,960
+ 61,160

	Max. Moment	Section Modulus Required	
Assuming distribution (6/8 to cross beam)	-54,560'#	29.8 in^3 Carbon	23.4 in^3 Silicon
Assuming no distribution	-70,160	38.3 in^3 "	30.1 in^3 "

Note: Condition of no distribution is approached at joints in slab. ←

12" I @ 31.8# Silicon
S.M. = 36.0 in^3

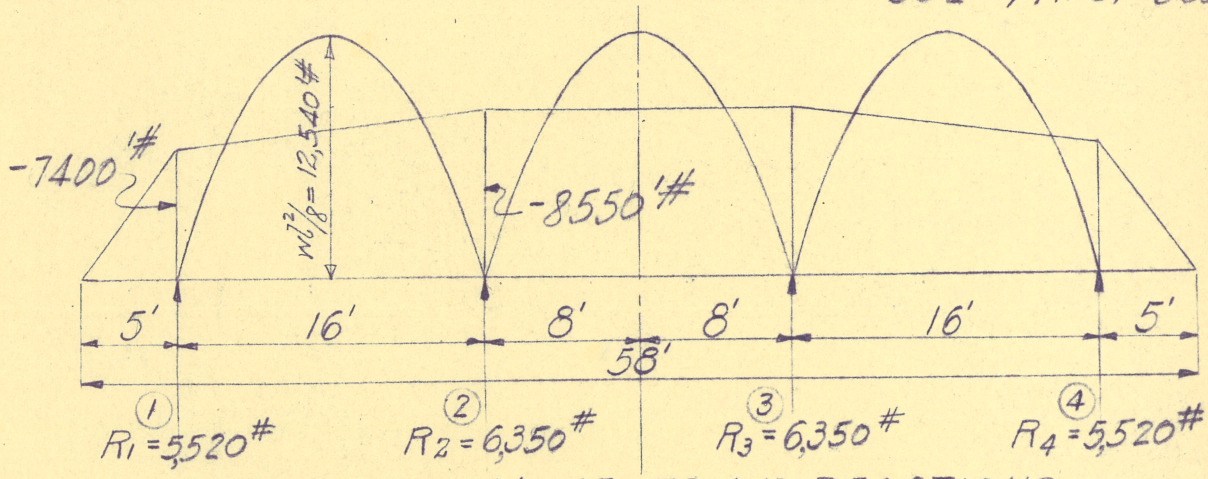
State of California - Department of Public Works
San Francisco - Oakland Bay Bridge
East Bay Crossing - 288' Spans
Floor System

Made by Wood 7/24/33
Checked by
Sheet No. 41

Upper Deck Crossbeams

Spacing 6'-0" c. to c.
Supported on stringers 16'-0" c. to c.

Dead Load - Floor 6×60 = 360
Cross beam 32
392 #/ft. of beam.



DEAD LOAD MOMENTS AND REACTIONS.

		M_1	Shear left of R_1
D.L. - Curb, etc.	-500 × 5	-2500	-500
Beam + Slab	$-392 \times (5)^2/2$	-4900	-1960
	M_1 =	-7400 '#	-2460 #

$M_1 + 5M_2 = -\frac{1}{2}(392)(16)^2$

$5M_2 = +7{,}400 - 50{,}160 = -42{,}760$

$M_2 = -8{,}550$ '#

$\frac{wl^2}{8} = 12{,}540$ '#

$\frac{wl^2}{2} = 50{,}160$ '#

$M_2 = -8{,}550 = -7{,}400 - 2{,}460 \times 16 - 50{,}160 + 16R_1$

$16R_1 = -8{,}550 + 7{,}400 + 50{,}160 + 39{,}360 = 88{,}370$

$R_1 = 5{,}520\# = R_4$

Shear left of $R_2 = -2{,}460 - 6270 + 5{,}520$ (392 × 16)
$= -3{,}210\#$

$M_3 = -8{,}550 = -8{,}550 - 3210 \times 16 - 50{,}160 + 16R_2$

$16R_2 = +3210 \times 16 + 50{,}160$

$R_2 = 3{,}210 + 3{,}140 = 6{,}350\# = R_3$

Upper Deck Crossbeams (cont'd.)

L.L. 13 1/3 ton trucks. Rear wheel load = 10,667#

Negative moment at (1)

D.L.	- 7,400'#	
L.L. 10,667×3.5	-37,335	assuming no distribution
	-44,735'#	

Negative moment at (2)

Assuming 6/8 to 1 beam (L.L. only):

D.L	- 8,550'#	
L.L. -3.658×1.6×10,667×6/8	-46,800	same as for cantilever structure
	55,350'#	

Assuming no distribution of L.L.:

D.L.	- 8,550'#	
L.L. -3.658×1.6×10,667	-62,400	same as for cantilever structure
	-70,950	

	Max. Moment	Section Modulus Req'd.	
Assuming L.L. distribution (6/8 to 1 beam)	-55,350	30.2 in³ Carbon	23.7 in³ Silicon
" no L.L. distribution	-70,950	38.7 in³ "	30.4 in³ "

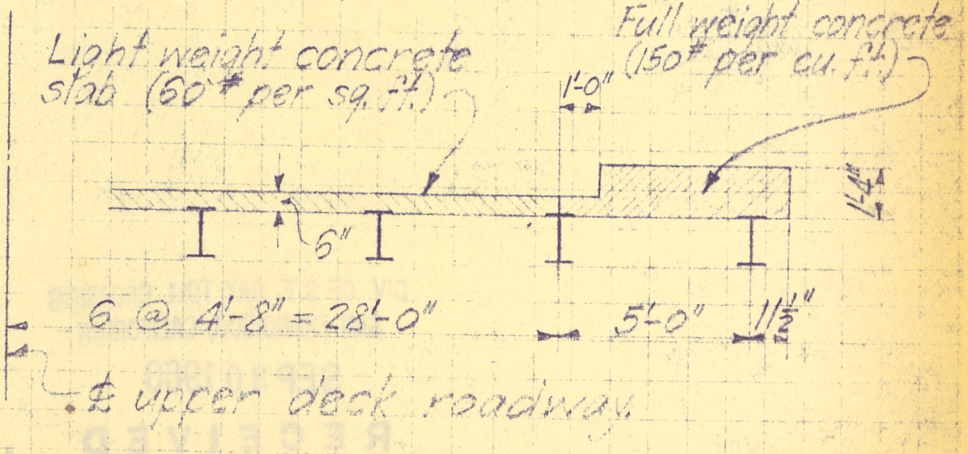
12" I @ 31.8# Silicon Steel

S.M. = 36.0 in³ Web 3/8"

Upper Deck Stringers for San Francisco Anchorage

Max. stringer span = 21.2′ Stringer spacing = 4′-8″ c. to c.

	INTERIOR STRINGER	OUTSIDE STRINGER (1 ft. from curb line)
Dead Load:		
Slab	280	560 (incl. curb)
Stringer	50	50
Total	330 #/ft.	610 #/ft.
Live Load (H 13⅓):		
Wheel lines to stringer	0.933	0.893
Shear:		
D.L.	3.5	6.5
L.L.	10.8	10.3
Total	14.3	16.8
Moment:		
D.L.	19	34
L.L.	53	51
Total	72	85
Section	14″ C.B. @ 48# Carbon S.M. = 70.2 Web 0.339″	14″ C.B. @ 48# Carbon. S.M. = 70.2 Web 0.339″ Flange 8″ Ratio Span/Depth = 18.2 Max. stress = 14,500 #/in.²



Upper Deck Stringers

Stringer spacing = 4'-8" c. to c. L.L. - H 13 1/3

	INTERIOR STRINGER		OUTSIDE STRINGER	
Wheel lines to stringer	4.67/5 = 0.933		4.17/4.67 = 0.893	
D.L. slab (60#/ft.²)	60 × 4.67 = 280#/ft.		60 × 3.33 = 200#/ft.	
For Continuous Spans (stringer span 31.92'):				
D.L. Stringer		60		60
Total D.L.		340#/ft.		260#/ft.
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.	5.4	43	4.2	33
L.L.	11.3	83	10.8	79
Total	16.7	126	15.0	112
Section	21" C.B. @ 59# Carbon S.M. = 119.3 Web 0.34" Flge. 8 1/4" Ratio Span/Depth = 18.2 Max. stress = 12,700#/in.²		21" C.B. @ 59# Carbon	
At Pier W1 (Cable Bent - stringer span 16'):				
D.L. Stringer		65		65
Total D.L.		345#/ft.		265#/ft.
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.	2.8	11		
L.L.	10.2	40		
Total	13.0	51		
Section	12" C.B. @ 64# Carbon S.M. = 85.8 Web 0.405" Flge. 10" Ratio Span/Depth = 16 Max. stress = 7,150#/in.²		12" C.B. @ 64# Carbon.	
For Suspension Bridge (stringer span 30.32'):				
D.L. Stringer		60		60
Total D.L.		340#/ft.		260#/ft.
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.	5.2	39	3.9	30
L.L.	11.3	78	10.9	74
Total	16.5	117	14.8	104
Section	20" C.B. @ 55# Carbon S.M. = 107.6 Web 0.37" Flge. 8" Ratio Span/Depth = 18.2 Max. stress = 13,100#/in.²		20" C.B. @ 55# Carbon	

Upper Deck Stringers for Center Anchorage

Max. stringer span = 36.5' Stringer spacing = 4'-8" c. to c.

	Interior Stringer	Outside Stringer
Dead Load:		
Slab	280 #/ft.	200 #/ft.
Stringer	80	80
Total	360	280
Live Load (H 13⅓):		
Wheel lines to stringer	0.933	0.893
Shear:		
D.L.	6.6	5.1
L.L.	11.5	11.0
Total	18.1	16.1
Moment:		
D.L.	60	47
L.L.	97	93
Total	157	140
Section	24" C.B. @ 74#	24" C.B. @ 74#
Material	Carbon Steel	Carbon Steel
	S.M. = 170.4 Web 0.430"	
	Flange 9"	
	Ratio Span/Depth = 18.2	
	Max. stress = 11,100 #/in²	

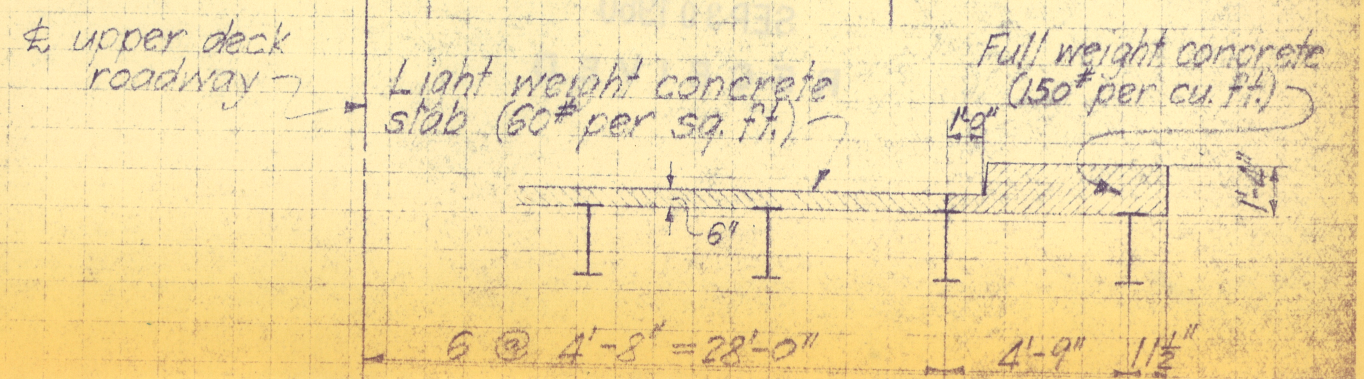
24493 8-35 10M. EST. 9906
100 TO PAD. S.P.O.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

Upper Deck Stringers for Yerba Buena Island Anchorage

Stringer span varies. Stringer spacing = 4'-8" c. to c.

	INTERIOR STRINGER		OUTSIDE STRINGER (1 ft. from curb line)	
Dead Load - Slab	280 #/ft.		535 #/ft. (incl. curb)	
Live Load (H13⅓): Wheel lines to stringer	0.933		0.893	
For 31.25' Span:				
D.L. Stringer	65 #/ft.		65 #/ft.	
Total D.L.	345 #/ft.		600 #/ft.	
	Shear (kips)	Moment (kip-ft)	Shear (kips)	Moment (kip-ft)
D.L.	5.4	42	9.4	73
L.L.	11.3	81	10.8	77
Total	16.7	123	20.2	150
Section	21" C.B. @ 59# Carbon		21" C.B. @ 59# Carbon S.M.=119.3 Web 0.39" Flange 8¼" Ratio Span/Depth = 18 Max. stress = 15,100 #/in.²	
For 36' Span:				
D.L. Stringer	80 #/ft.		80 #/ft.	
Total D.L.	360 #/ft.		615 #/ft.	
	Shear (kips)	Moment (kip-ft)	Shear (kips)	Moment (kip-ft.)
D.L.	6.5	58	11.1	100
L.L.	11.5	95	11.0	91
Total	18.0	153	22.1	191
Section	24" C.B. @ 74# Carbon		24" C.B. @ 74# Carbon. S.M.=170.4 Web 0.43" Flange 9" Ratio Span/Depth = 18 Max. stress = 13,500 #/in.²	



24465 8-33 10M VST 9595
103 TO PAD.

"Upper Deck Stringers for 288' Spans
Stringer spacing = 16'-0" c. to c. Stringer span varies.

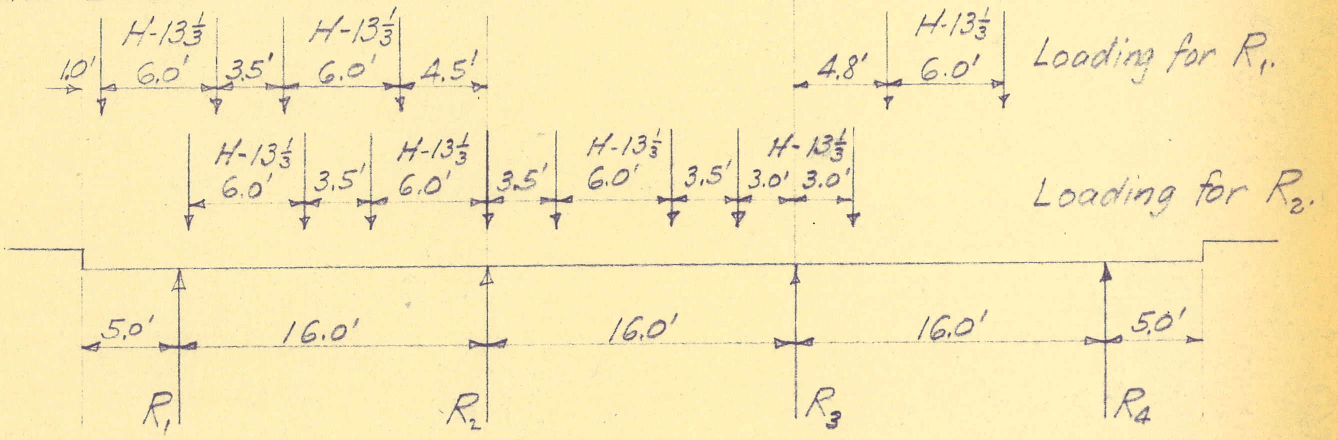
	OUTSIDE STRINGER		INTERIOR STRINGER	
D.L. from cross beams	5520/6 = 920 #/ft.		6350/6 = 1,060 #/ft.	
L.L. (see sh. # 47)	H 20		H 23	
For 27' Span:				
D.L. stringer (#/ft.)	75		75	
Total D.L. (#/ft.)	995		1,135	
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.			15.3	104
L.L.			41.3	250
Total			56.6	354
Section	24" C.B. @ 74# Silicon		24" C.B. @ 74# Silicon S.M. = 170.4 Web 0.43" Flge. 9" Depth ratio = 13.5 Max. stress = 24,900 #/in.² Max. allow. comp. = 25,800 #/in.²	
For 37' Span (standard stringer):				
D.L. stringer (#/ft.)	100		100	
Total D.L. (#/ft.)	1,020		1,160	
	Shear	Moment	Shear	Moment
D.L.			21.5	198
L.L.			42.5	364
Total			64.0	562
Section	27" C.B. @ 98# Silicon.		27" C.B. @ 98# Silicon. S.M. = 255.3 Web 0.50" Flge. 10" Depth ratio = 16.4 Max. stress = 26,400 #/in.² Max. allow. comp. = 26,000 #/in.²	
For 39' Span				
D.L. stringer (#/ft.)	110		110	
Total D.L. (#/ft.)	1,030		1,170	
			Shear	Moment
D.L.			22.8	222
L.L.			42.7	386
Total			65.5	608
Section	27" C.B. @ 106# Silicon		27" C.B. @ 106# Silicon. S.M. = 277.2 Web 0.53" Flge. 10" Depth ratio = 17.3 Max. stress = 26,300 #/in.² Max. allow. comp. = 26,000 #/in.²	

Upper Deck Stringers - 16'-0" c. to c.

(Cross beam reactions calculated as for continuous beam)

Dead Loads - Cross beam reactions - Outside stringer 6,360#
Interior " 6040#
(See sh. #39)

Live Loads - Wheel Lines



R_1

H-6⅔ × 1.317	=	H-8.78
6⅔ × 0.843	=	5.62
6⅔ × 0.576	=	3.84
6⅔ × 0.189	=	1.26
		H-19.50 (H-20.4 as simple beam)
6⅔ × 0.024	=	0.16
6⅔ × 0.019	=	0.13
		H-19.79 × 0.90 = H-17.8

Use H-20 for outside stringers.

R_2

H-6⅔ × 1.000	=	H-6.67
6⅔ × 0.851	=	5.68
6⅔ × 0.879	=	5.85
6⅔ × 0.447	=	2.98
		H-21.18
6⅔ × 0.049	=	0.33
6⅔ × 0.611	=	4.08
		H-25.59 × 0.90 = H-23.0
6⅔ × 0.186	=	1.24
6⅔ × (-0.109)	=	-0.73
		H-26.10 × 0.83 = H-21.6

Use H-23 for interior stringers

H-20.1 if 16-ton trucks are used on all but 1 lane

48' Panels - Interior Stringers

	Shear (kips)	Moment (kip-ft.)
Dead Load - Slab and cross beams (6040#)	24.2	290
Stringer 125#/ft.	3.0	36
Live Load - H-23	45.6	487
	72.8	813

S.M. reqd. = 444 in.³ Carbon Steel or 348 in.³ Silicon Steel.

— Use 33" C.B. @ 125# Silicon. S.M. = 384.7 Web 9/16"

12 × 813,000/384.7 = 25,400#/in.² Depth ratio = $\frac{2.75}{48} = \frac{1}{17.5}$

Outside Stringers

	Shear (kips)	Moment (kip-ft.)
Dead Load - Slab and cross beams (6360#)	25.5	306
Stringer 125#/ft.	3.0	36
Live Load - H-20	39.7	424
	68.2	766

S.M. reqd. = 416 in.³ Carbon Steel or 328 in.³ Silicon Steel.

— Use 33" C.B. @ 125# Silicon (same as for interior stringers).

Upper Deck Stringers (cont'd.)

55' Panels

Interior Stringers	Shear (kips)	Moment (kip-ft.)
D.L. - Slab and cross-beams (6,040#)	27.2	375
Stringer 150#/ft.	4.1	57
L.L. H-23	49.3	568
	80.6	1,000

S.M. req'd. = 545 in.^{3} Carbon Steel or 429 in.^{3} Silicon Steel.

Use 36" C.B. @ 150# Silicon. S.M. = 508.3 in.^{3} Web 5/8"

12 × 1,000,000/508.3 = 23,700 #/in.^{2} Depth ratio = $\frac{1}{18.3}$

Outside Stringers	Shear (kips)	Moment (kip-ft.)
D.L. - Slab and cross-beams (6,360#)	28.6	395
Stringer 150#/ft.	4.1	57
L.L. H-20	42.8	494
	75.5	946

S.M. req'd. = 516 in.^{3} Carbon Steel or 405 in.^{3} Silicon Steel.

Use 36" C.B. @ 150# Silicon (same as for interior stringers)

12 × 946,000/508.3 = 22,300 #/in.^{2}

Note:

Allowable stress in compression flanges

Carbon steel 22,000 − 220 l/b

Silicon " 28,000 − 280 l/b

In 48' panels l = 6'-0" b = 11½" l/b = 6.25

Carbon steel 22,000 − 220 × 6.25 = 20,620 #/in.^{2}

Silicon " 28,000 − 280 × 6.25 = 26,250

In 55' panels l = 6'-0" b = 1'-0"

Carbon steel 22,000 − 220 × 6.00 = 20,680 #/in.^{2}

Silicon steel 28,000 − 280 × 6.00 = 26,320

Upper Deck Stringers

Stringer spacing 16'-0" c. to c.

	OUTSIDE STRINGER		INTERIOR STRINGER	
D.L. from cross beams	6360/6 = 1,060 #/ft.		6040/6 = 1,010 #/ft.	
L.L. to stringer (sh.#47)	H20		H23	

For 504' Spans (stringer span 42'):

	OUTSIDE STRINGER		INTERIOR STRINGER	
D.L. stringer	110		120	
Total D.L.	1,170 #/ft.		1,130 #/ft.	
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.	24.6	258	23.7	249
L.L.	37.3	366	42.9	421
Total	61.9	624	66.6	670
Section	30" C.B. @ 108# Silicon		30" C.B. @ 116# Silicon.	
S.M.	299.2		327.9	
Web	0.548"		0.564"	
Flange	$10\frac{1}{2}$"		$10\frac{1}{2}$"	
Ratio Span/Depth	16.8		16.8	
Max. stress	25,100 #/in.²		24,500 #/in.²	
Max. allowable comp. $= 28000 - 280 \times \frac{72}{10.5} =$	26,100 #/in.²		26,100 #/in.²	

At Pier E1 (stringer span 9'):

	OUTSIDE STRINGER		INTERIOR STRINGER	
D.L. stringer	55		55	
Total D.L.	1,115 #/ft.		1,065 #/ft.	
	Shear (kips)	Moment (kip-ft.)	Shear (kips)	Moment (kip-ft.)
D.L.	5.0	11	4.8	11
L.L.	32.0	72	36.8	83
Total	37.0	83	41.6	94
Section	18" I @ 54.7# Carbon		18" I @ 54.7# Carbon.	
S.M.			88.4	
Web			0.46"	
Flange			6"	
Ratio Span/Depth			6	
Max. stress	11,300 #/in.²		12,800 #/in.²	
Max. allowable comp. $= 22000 - 220 \times \frac{43}{6} =$	20,400 #/in.²		20,400 #/in.²	

Upper Deck Stringers for 50' Tower Span E9
Stringer spacing = 16'-0" c. to c.   Stringer span = 50'

	OUTSIDE STRINGER	INTERIOR STRINGER
Stringer D.L.	135#/ft.	135#/ft.
D.L. from crossbeams	6360/6 = 1060	6040/6 1010
Total D.L.	1195#/ft.	1145#/ft.
L.L. (see sh. #47)	H20	H23
Shear - D.L.	29.9	28.6
L.L.	40.6	46.7
Total	70.5	75.3
Moment - D.L.	374	358
L.L.	446	512
Total	820	870
Section	33" C.B. or B.B. @ 132#	33" C.B. or B.B. @ 132#
Material	Silicon Steel	Silicon Steel
Section Modulus	413.7	413.7
Flange width	11.5"	11.5"
Web thickness	0.58"	0.58"
Ratio Span/Depth	18.2	18.2
Max. stress (tension or comp.)	23,800 #/in.²	25,200 #/in.²
Max. allowable comp. $= 28000 - 280 \times \frac{72}{11.5} =$	26,250	26,250

Upper Deck Stringers

Stringer Spacing = 4'-8" c. to c. L.L. - H13⅓

	INTERIOR STRINGER		OUTSIDE STRINGER
Wheel lines to stringer	4.67/5 = 0.933		4.17/4.67 = 0.893
D.L. slab (60#/ft.²)	60 x 4.67 = 280#/ft.		60 x 3.33 = 200#/ft.

At Pier E23 (stringer span 9.3'):

	Shear (kips)	Moment (kip-ft.)	
D.L. stringer		50	50
Total D.L.		330#/ft.	250#/ft.
D.L.	1.5	4	
L.L.	10.0	23	
Total	11.5	27	
Section	16" C.B. @ 45# Carbon		16" C.B. @ 45# Carbon

S.M. = 72.4 Web 0.346" Flge. 7"
Ratio Span/Depth = 7
Max. stress = 4,500#/in.²

For Girder Spans E23-E33 (stringer span 27.5'):

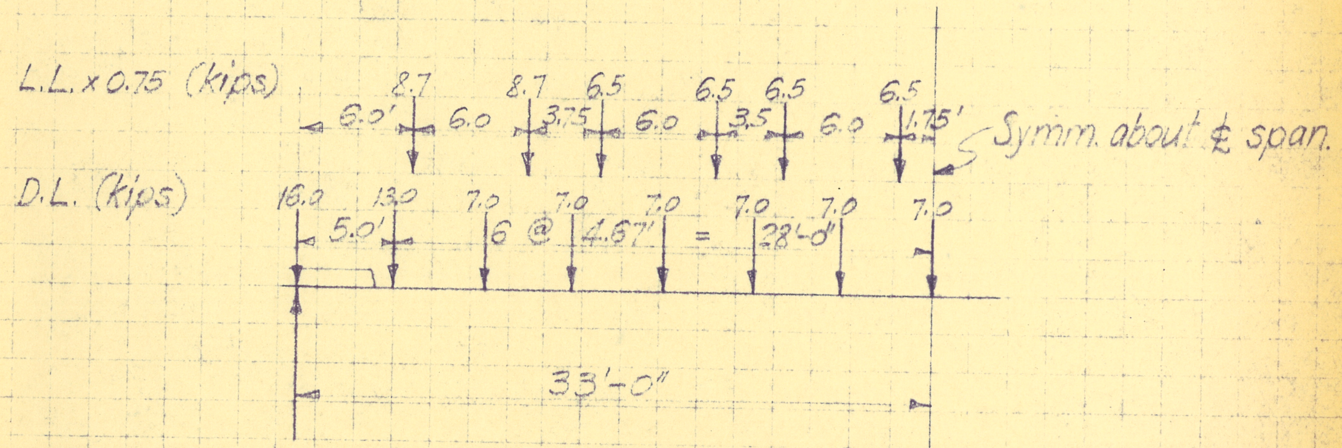
	Shear (kips)	Moment (kip-ft.)	
D.L. stringer		50	50
Total D.L.		330#/ft.	250#/ft.
D.L.	4.5	31	
L.L.	11.2	69	
Total	15.7	100	
Section	18" C.B. @ 47# Carbon		

S.M. = 82.3 Web 0.35" Flge. 7½"
Ratio Span/Depth = 18.3
Max. stress = 14,600#/in.²

Upper Deck Floor Beams at San Francisco Anchorage

D.L. Fl. Bm. = 250 #/ft.

Live Load: H13⅓ on each outside lane, H10 on 4 inside lanes.
6 lanes loaded. C = 0.75



	End Reaction (kips)	Moment (kip-ft.)
D.L.-Concentrated	68	846
Uniform	8	136
L.L.	43	767
Total	119	1749

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 68 × 7/16	29.75	23.62	11,460	9,100			
4 Ls 6 × 4 × ½	19.00	17.00	21,040	18,830			
	48.75		32,500	27,930	950	815	1900 k/l

Max. compression = 12 × 1,749,000/950 = 22,100 #/in.²

Max. tension = 12 × 1,749,000/815 = 25,700 #/in.²

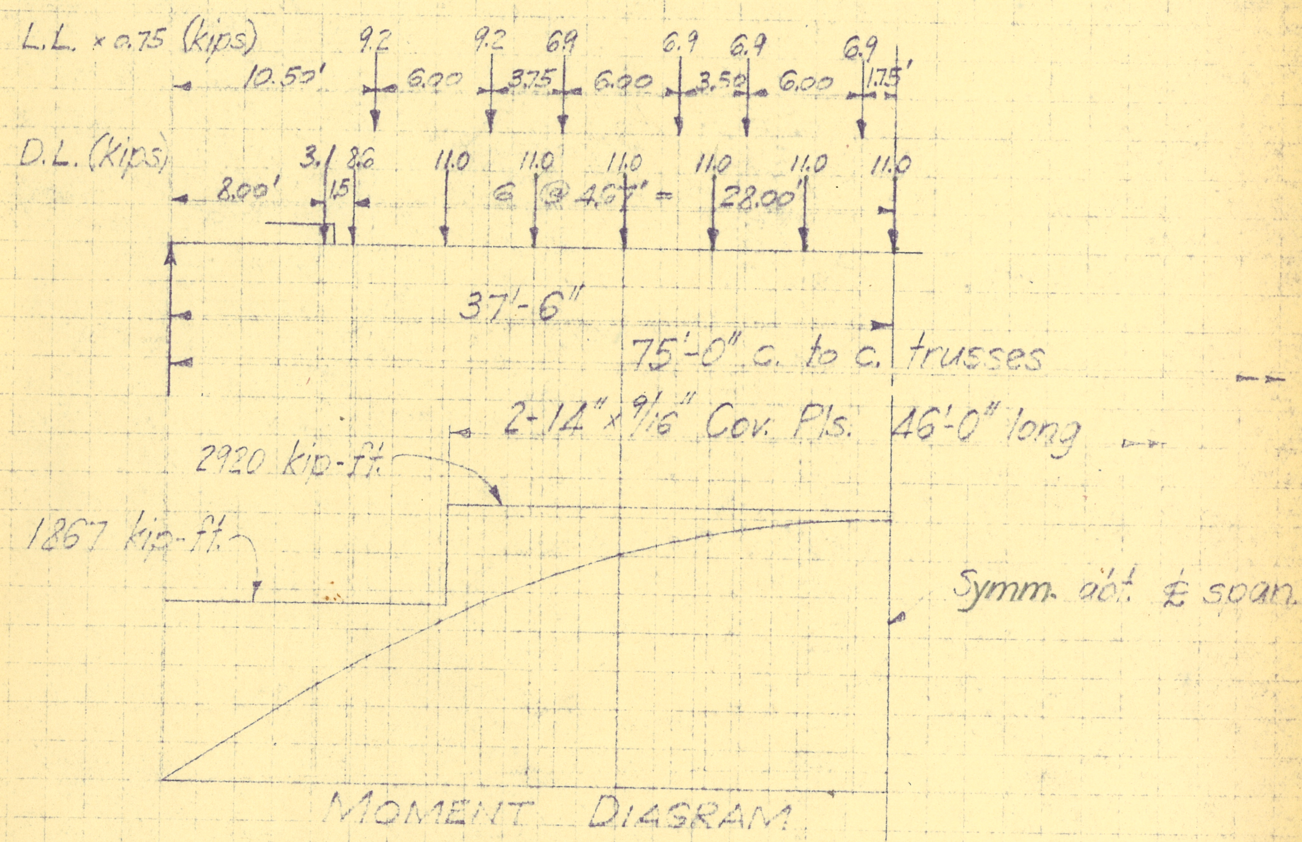
Silicon Steel.

Continuous Spans-Standard Upper Deck Floor Beam (Fl. Bm. "A")

D.L. Fl. Bm. = 285#/ft.

L.L. - H-13⅓ on each outside lane, H-10 on 4 inner lanes.

6 lanes loaded   C = 0.5 + 2/(S+2) = 0.75



	Shear (kips)	Moment (kip-ft)
D.L. - Concentrated	72	1606
Uniform	11	200
L.L.	46	1021
Total	129	2827

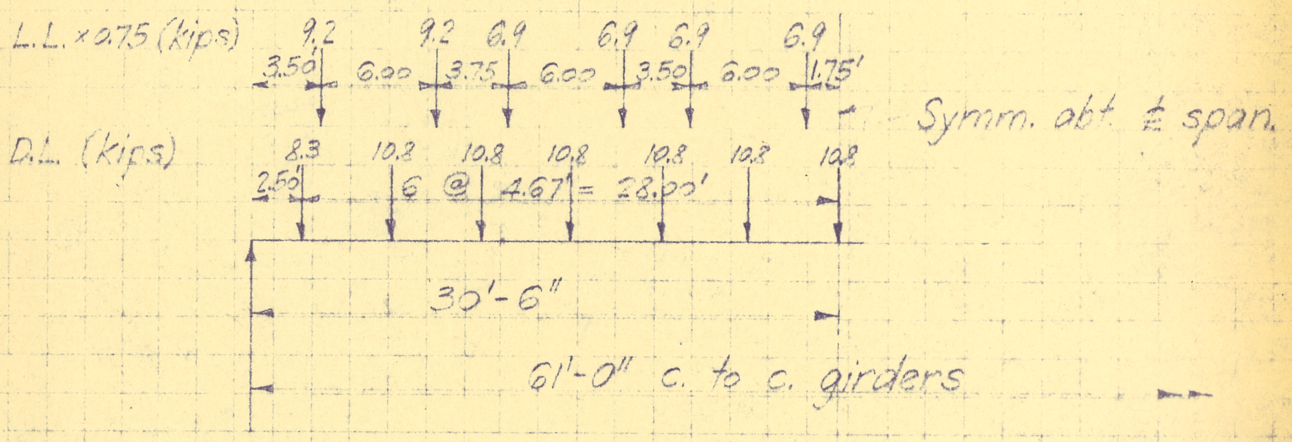
	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net Sect. @ 28,000
1 Web 68 × 7/16	29.75	23.18	11,460	8,930			
4 Ls 6 × 4 × 9/16	21.24	16.74	23,500	18,500			
	50.99		34,960	27,430	1020	800	1867
2 Cov. 14 × 9/16 × 46'-0"	15.75	13.50	18,780	16,100			
	66.74		53,740	43,530	1543	1250	2920

Max. compression = 12 × 2,827,000 / 1543 = 22,000#/in.²

Max. tension = 12 × 2,827,000 / 1250 = 27,200#/in.²

Silicon Steel.

Continuous Spans - Upper Deck Floor Beam "E" (at Panel Pts. U1' & U2')
D.L. Fl. Bm. = 260#/ft.
L.L. - H13⅓ on each outside lane, H10 on 4 inner lanes.
6 lanes loaded   C = 0.75



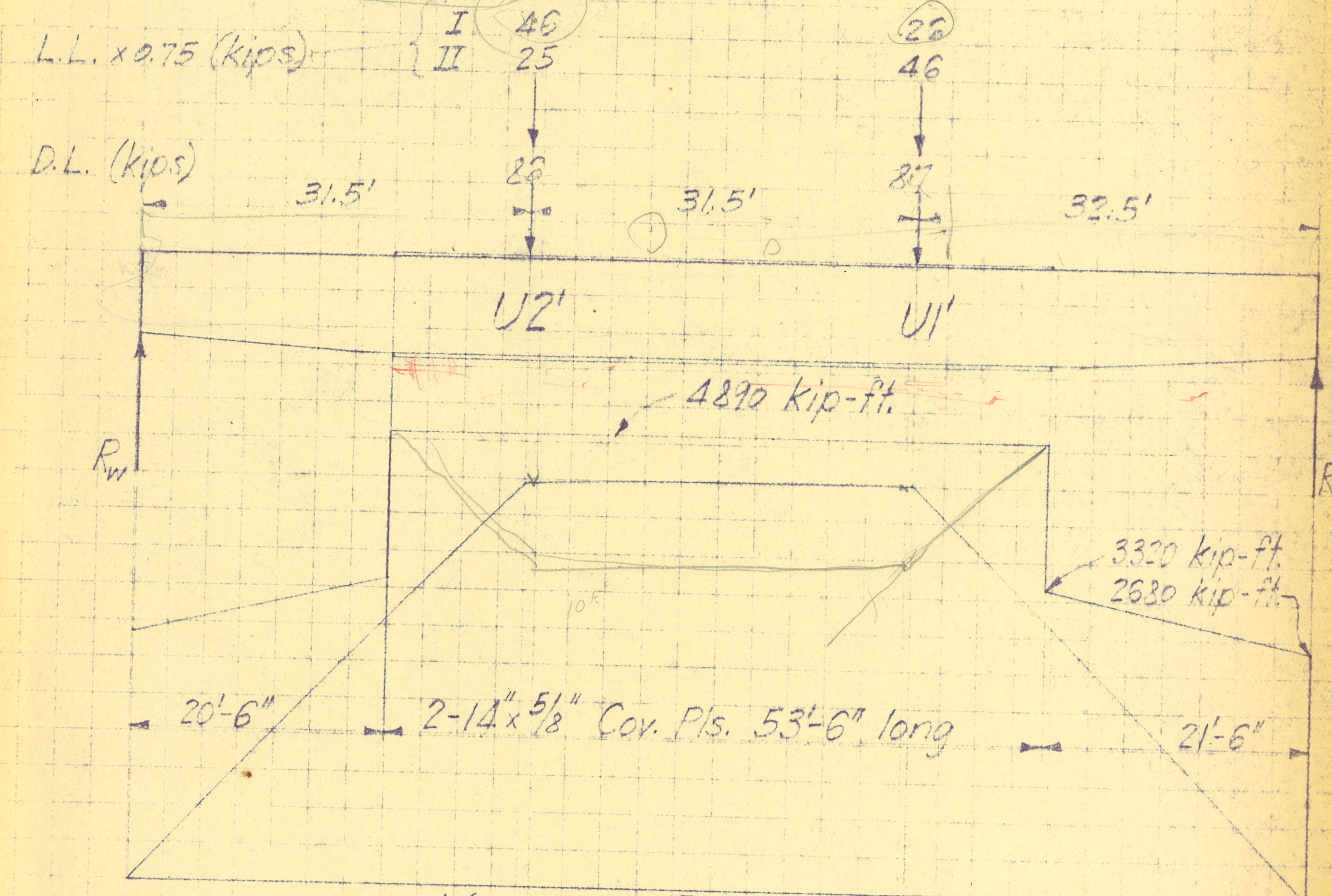
	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	68 } 76	1076
Uniform	8	121
L.L.	46	699
Total	122	1896

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 68 × 7/16	29.75	23.18	11,460	8,930			
4 Ls 6 × 4 × 5/8	23.44	20.94	25,900	23,140			
	53.19		37,360	32,070	1090	937	2185

Max. compression = 12 × 1896000/1090 = 20,800#/in.²
Max. tension = 12 × 1896000/937 = 24,300#/in.²
Silicon Steel.

Continuous Spans - Upper Deck Girder "A" (Panel Point U0' to U3').

D.L. Girder = 360#/ft.



MOMENT DIAGRAM

	Shear (kips) R_W	R_E	Moment (kip-ft) At U2'	At U1'
D.L.-Concentrated	87	86	2747	2795
Uniform	17	17	363	370
L.L. - I	40		1250	
II		39		1255
Total	144	142	4360	4420

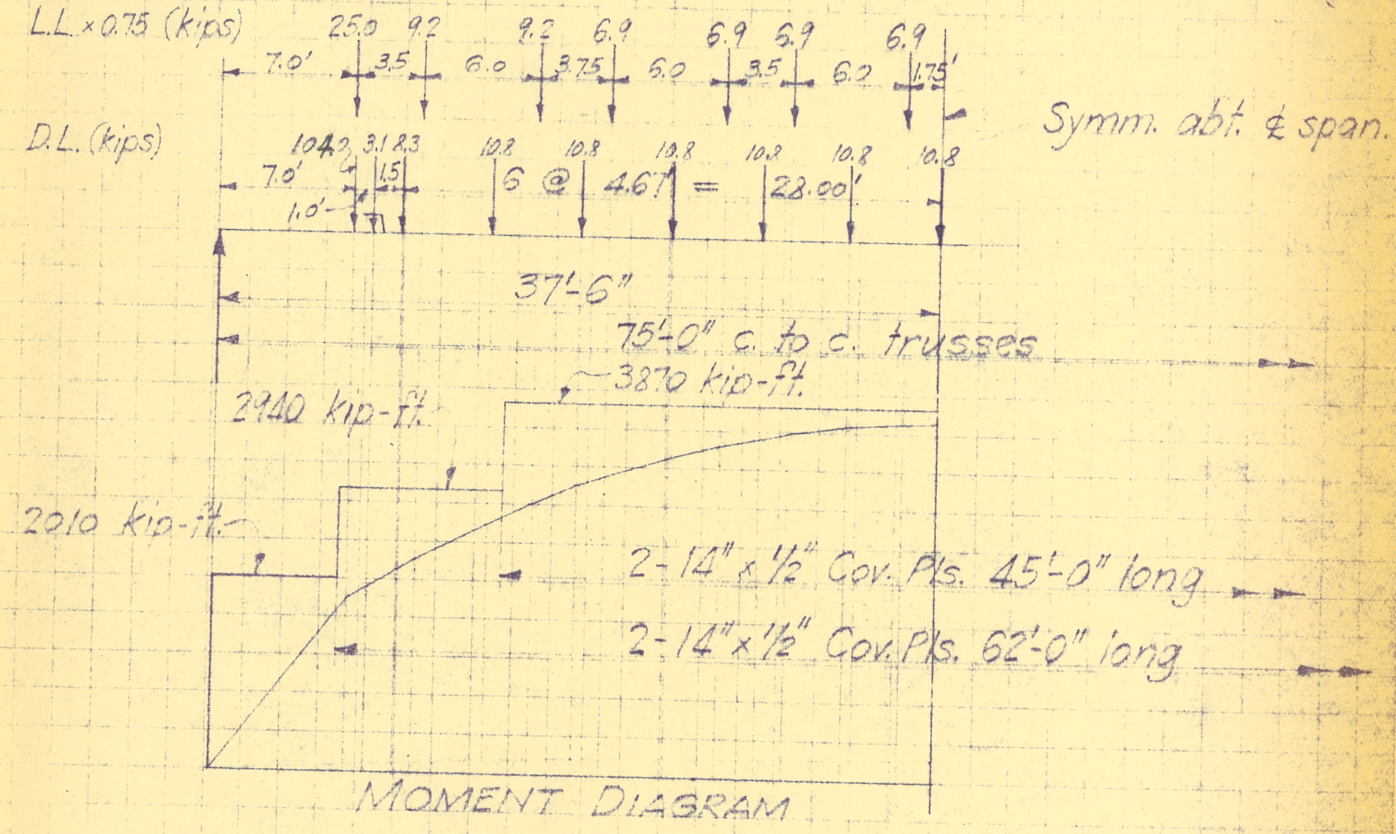
	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Net	Resisting Mom. Gr. sect. @ 25,760	Net sect. @ 28,000
1 Web 92 x 1/2	46.00	35.00	32,440	24,700				
4 Ls 6 x 4 x 11/16	25.60	20.10	52,310	41,050				
	71.60		84,750	65,750	1831	1421	3930	3320
2 Cov. 14 x 5/8 x 53'-6"	17.50	15.00	37,940	32,520				
	89.10		122,690	98,270	2615	2095	5610	4890

Max. compression = 12 x 4,420,000 / 2615 = 20,300#/in.^{2}

Max. tension = 12 x 4,420,000 / 2095 = 25,300#/in.^{2} Silicon Steel.

Max. allowable compression = $28{,}000 - 280\frac{l}{b} = 28{,}000 - 280 \times 8 = 25{,}760$ #/in.^{2}

Continuous Spans – Upper Deck Floor Beam "C" (at Panel Pt. U3')
D.L. Fl. Bm. = 335#/ft.



	Shear (kips)	Moment (kip-ft.)
D.L. – Concentrated	175	2304
Uniform	13	236
L.L.	71	1196
Total	259	3736

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 68 × 7/16	29.75	23.62	11,460	9,100			
4Ls 6 × 4 × 5/8	23.44	12.44	25,900	20,400			
	53.19		37,360	29,500	1090	861	2010
2 Cov. 14 × ½ × 62'-0	14.00	12.00	16,660	14,280			
	67.19		54,020	43,780	1555	1260	2940
2 Cov. 14 × ½ × 45-0	14.00	12.00	17,150	14,700			
	81.19		71,170	58,480	2020	1660	3870

Max. compression = 12 × 3,736,000 / 2020 = 22,200#/in.²
Max. tension = 12 × 3,736,000 / 1660 = 27,000#/in.²

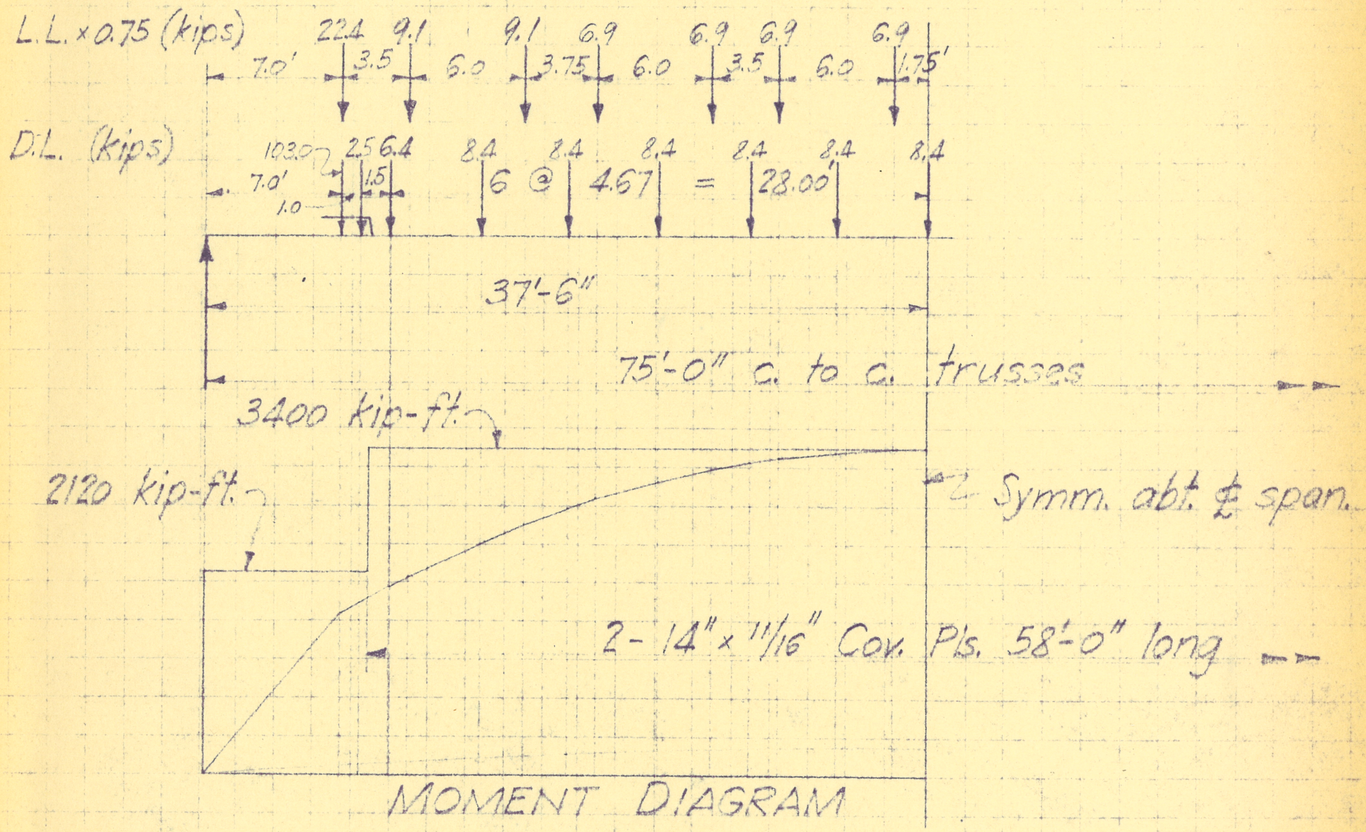
Silicon Steel.

STATE OF CALIFORNIA — DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

193

Made by Wood
Checked by

Continuous Spans — Upper Deck Floor Beam "D" (at Panel Point U0')
Uniform D.L. - Fl. bm. 345 #/ft. } Total 415 #/ft.
Exp. dams 70 }



	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	158	1948
Uniform	16	292
L.L.	68	1174
Total	242	3414

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 68 × 7/16	29.75	23.18	11,460	8,930			
4Ls 6 × 4 × 11/16	25.60	20.10	28,230	22,170			
	55.35		39,690	31,100	1160	909	2120
2 Cov. 14 × 11/16 × 58'-0	19.25	16.50	23,040	19,750			
	64.60		62,730	50,850	1795	1457	3400

Max. compression = 12 × 3,414,000 / 1795 = 22,800 #/in²
Max. tension = 12 × 3,414,000 / 1457 = 28,100 #/in²

Silicon Steel.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS

SAN FRANCISCO-OAKLAND BAY BRIDGE

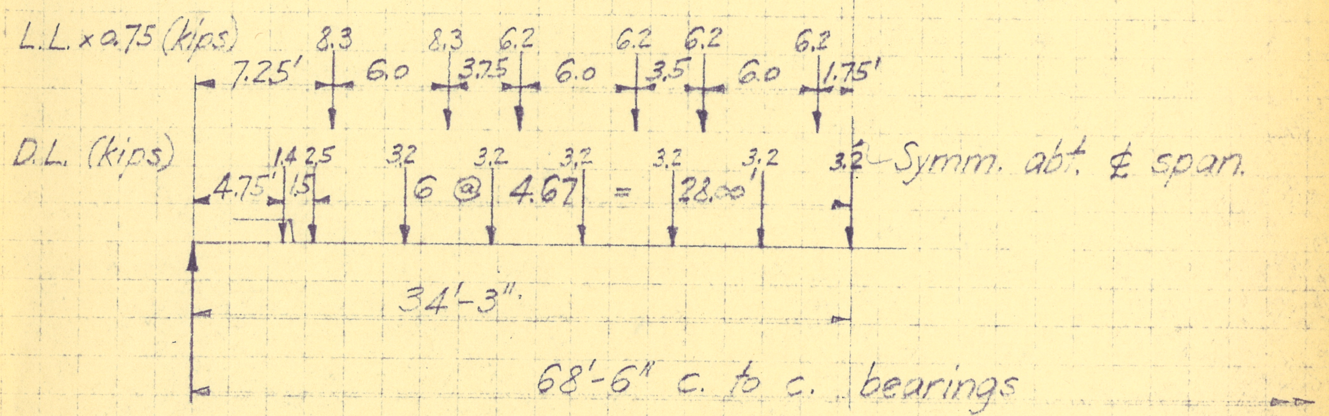
193

Made by Wood

Checked by

Continuous Spans - Upper Deck Floor Beam "H" (at Pier W1)

Uniform D.L. - Fl. Bm. (incl. exp. dam) = 310 #/ft. } 460 #/ft.
Gratings, etc. = 150 }



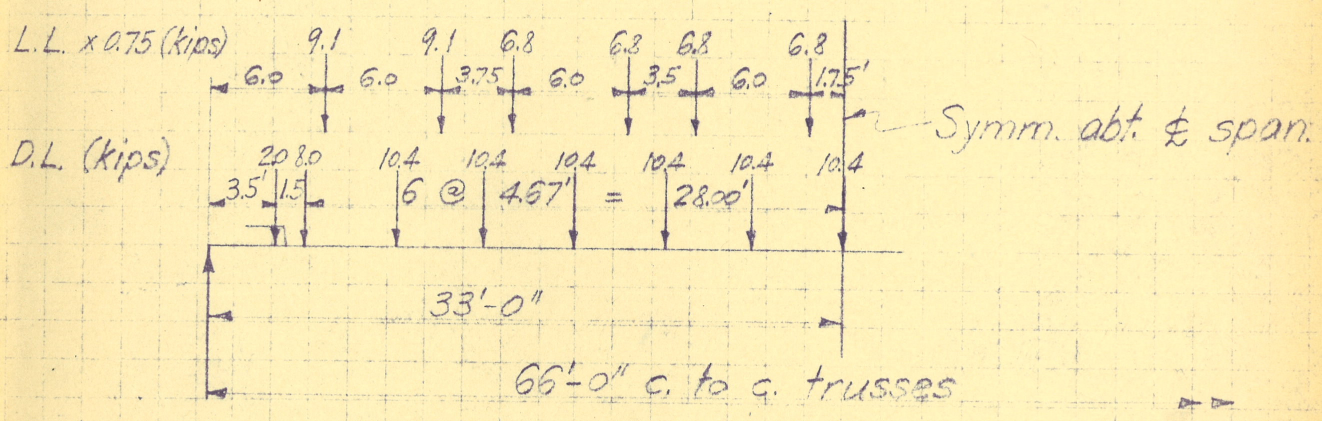
	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	22	400
Uniform	16	270
L.L.	41	780
Total	79	1450

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 68 × 7/16	29.75	23.18	11,460	8,930			
4 Ls 6 × 4 × 7/16	16.72	14.98	18,550	16,610			
	46.47		30,010	25,540	876	745	1740

Max. compression = 12 × 1,450,000 / 876 = 19,900 #/in.^{2}
Max. tension = 12 × 1,450,000 / 745 = 23,400 #/in.^{2}
Silicon Steel.

Suspension Bridge – Standard Upper Deck Floor Beam.

D.L. Fl. Bm. = 260 #/ft.



	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	67	1206
Uniform	9	142
L.L.	45	803
Total	121	2151

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 68 × 7/16	29.75	23.18	11,460	8,930			
4 Ls 6 × 4 × 11/16	25.60	22.85	28,230	25,200			
	55.35	46.03	39,690	34,130	1160	996	2325

Max. compression $= 12 \times 2{,}151{,}000 / 1160 = 22{,}300$ #/in.²

Max. tension $= 12 \times 2{,}151{,}000 / 996 = 25{,}900$ #/in.²

Silicon Steel.

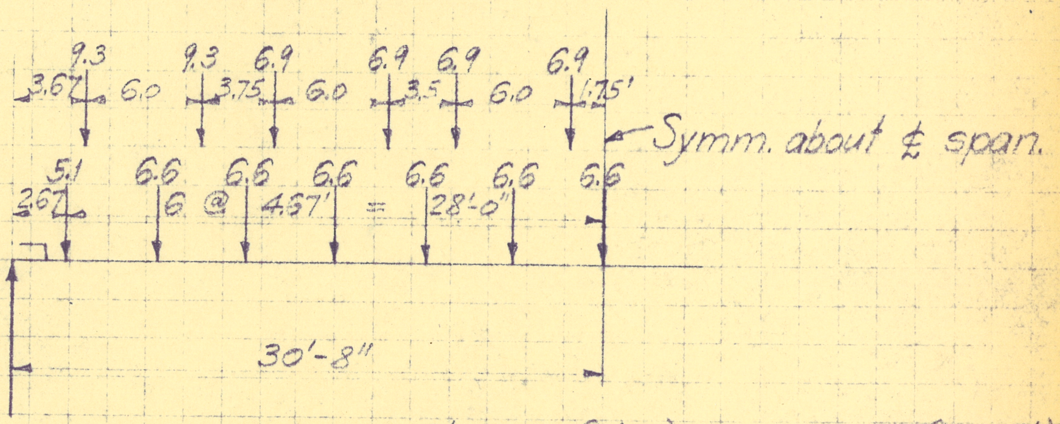
Center Anchorage - Upper Deck Floor Beam "A"

D.L. - Fl. Bm. (incl. exp. dam)	300 #/ft.
Exp. grating	160
Drainage details	150
Total uniform D.L.	610 #/ft.

Live Load: H13⅓ on each outside lane, H10 on 4 inside lanes.
6 lanes loaded. C = 0.75

L.L. × 0.75 (kips)

D.L. (kips)



	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	41	665
Uniform	19	288
L.L.	46	708
Total	106	1661

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 × 7/16	29.31	23.19	10,965	8,670			
4 Ls 6 × 4 × 5/8	23.44	20.94	25,125	22,440			
	52.75		36,090	31,110	1070	922	2150

Max. compression = 12 × 1,661,000 / 1070 = 18,700 #/in.²
Max. tension = 12 × 1,661,000 / 922 = 21,600 #/in.²
Silicon Steel.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

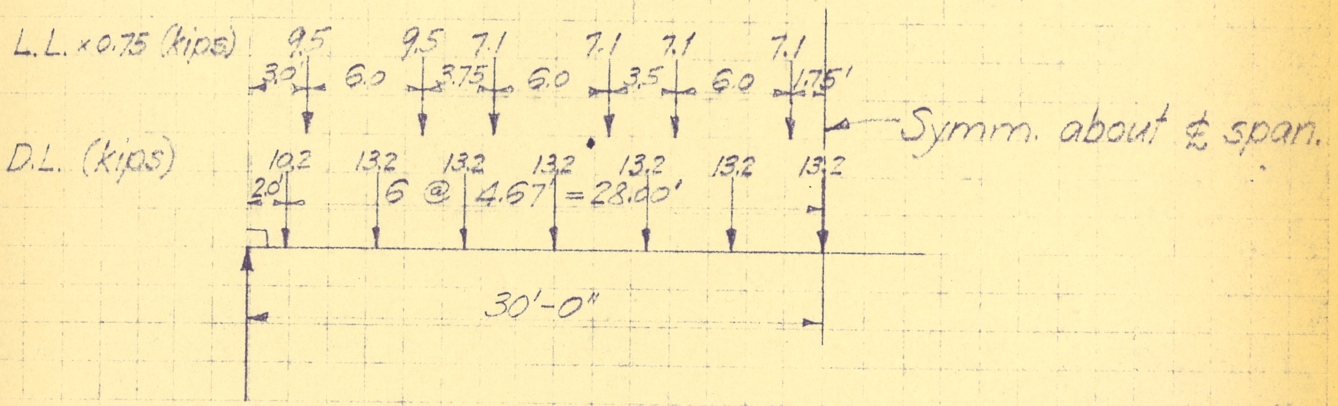
193

Made by Wood
Checked by

Center Anchorage – Upper Deck Floor Beam "B"

D.L. Fl. Bm. = 283#/ft.

Live Load: H13⅓ on each outside lane, H10 on 4 inside lanes.
6 lanes loaded. C = 0.75

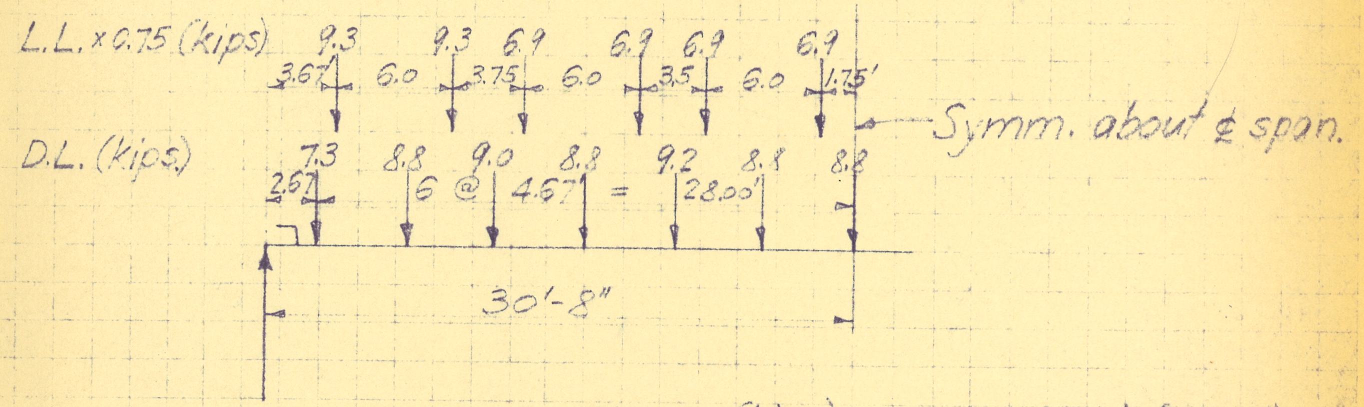


	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	83	1276
Uniform	9	128
L.L.	47	697
Total	139	2101

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 22,000
1 Web 67 × 7/16	29.31	23.19	10,965	8,670			
4 Ls 6 × 4 × 3/4	27.76	24.76	29,660	26,450			
	57.07		40,625	35,120	1204	1040	2425

Max. compression = 12 × 2,101,000 / 1204 = 21,000#/in.²
Max. tension = 12 × 2,101,000 / 1040 = 24,200#/in.²
Silicon Steel.

Center Anchorage – Upper Deck Floor Beam "C"
D.L. Fl. Bm. = 270#/ft.
Live Load: H13⅓ on each outside lane, H10 on 4 inside lanes.
6 lanes loaded. C = 0.75



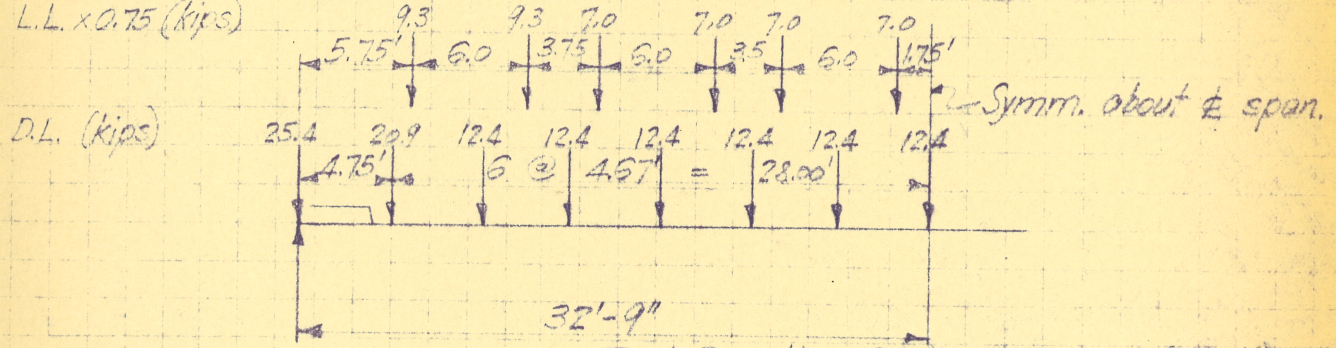
	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	56	911
Uniform	9	127
L.L.	46	708
Total		1746

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 × 7/16	29.31	23.19	10,965	8,670			
4 Ls 6 × 4 × 5/8	23.44	18.44	25,125	19,760			
	52.75		36,090	28,430	1070	842	1965

Max. compression = 12 × 1,746,000/1070 = 19,600 #/in.²
Max. tension = 12 × 1,746,000/842 = 24,900 #/in.²
Silicon Steel.

4

Yerba Buena Anchorage – Upper Deck Floor Beams D and E
D.L. Fl. Bm. = 265#/ft. Live Load: See sh. # 61

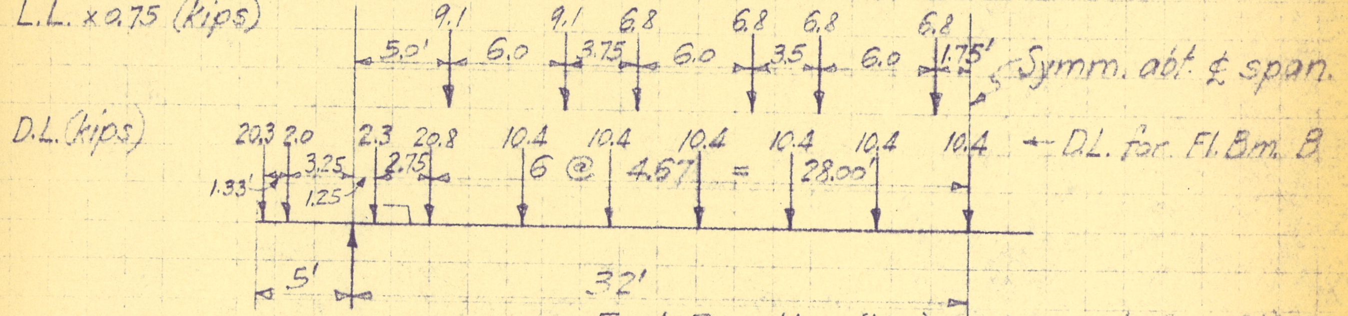


	End Reaction (kips)	Moment (kip-ft.)
D.L.-Concentrated	114	1466
Uniform	9	142
L.L.	47	814
Total	170	2422

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 x 7/16	29.31	22.75	10,965	8,510			
4 Ls 6 x 4 x 11/16	25.60	22.85	27,390	24,450			
	54.91		38,355	32,960	1135	975	2270

Max. compression = 12 x 2,422,000/1135 = 25,600 #/in.^{2}
Max. tension = 12 x 2,422,000/975 = 29,800 #/in.^{2} Silicon Steel.

Yerba Buena Anchorage – Upper Deck Floor Beams A and B
D.L. Fl. Bm. = 260#/ft. (Fl. Bm. B) Live Load: See sh. #

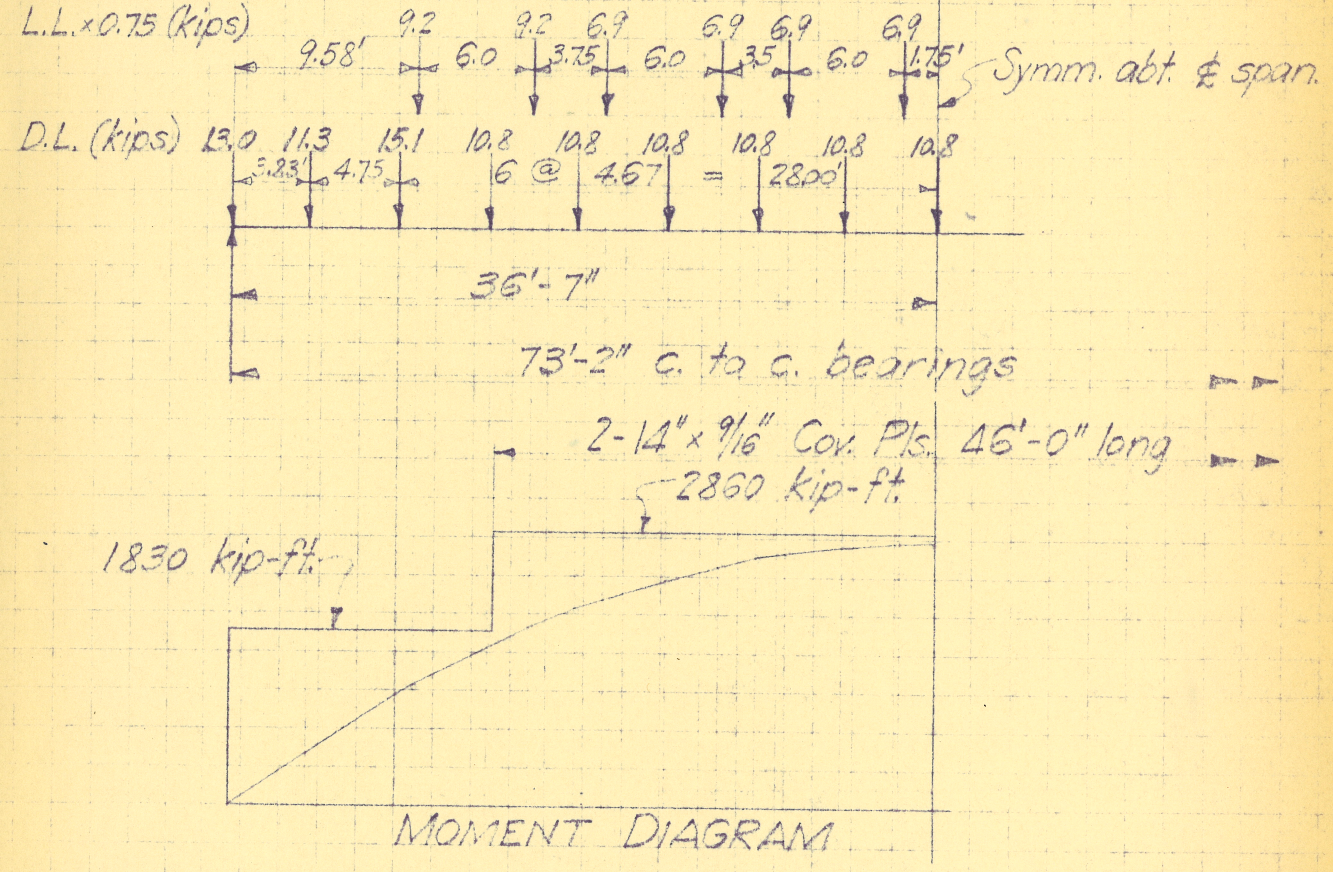


	End Reaction (kips)	Moment (kip-ft.)
D.L.-Concentrated	103	1088
Uniform	10	130
L.L.	45	754
Total	158	1972

Same design as for fl. bms. D and E (see above).

Max. compression = 12 x 1,972,000/1135 = 20,900 #/in.^{2}
Max. tension = 12 x 1,972,000/975 = 24,300 #/in.^{2}
Silicon Steel.

Yerba Buena Anchorage - Upper Deck Floor Beam C
D.L. Fl. Bm. = 280 #/ft.
Live Load: See sh. #61



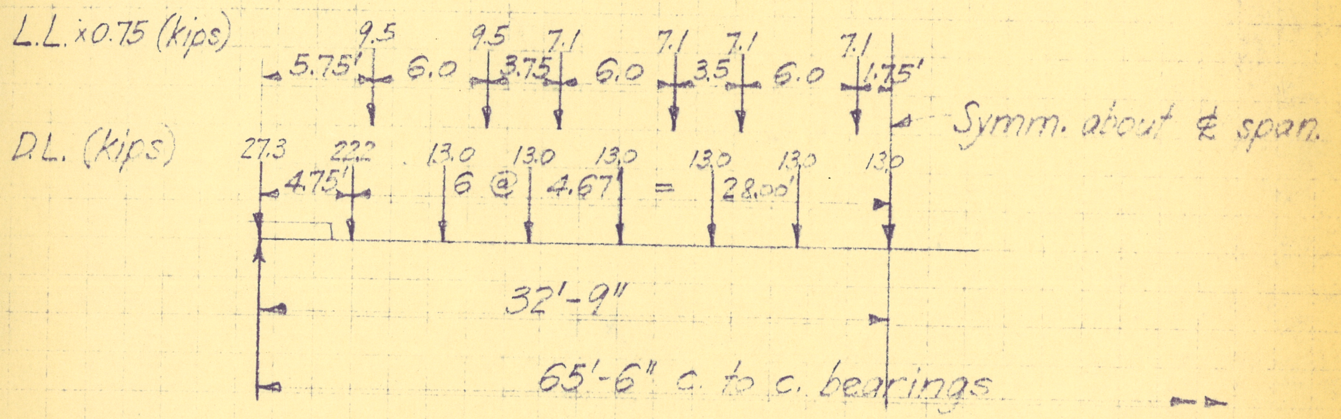
	End Reaction (kips)	Moment (kip-ft.)
D.L. - Concentrated	99	1589
Uniform	10	187
L.L.	46	979
Total	155	2755

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 × 7/16	29.31	22.75	10,965	8,510			
4 Ls 6 × 4 × 9/16	21.24	16.74	22,795	17,970			
	50.55		33,760	26,480	1000	785	1830
2 Cov. 14 × 9/16 × 46'-0	15.75	13.50	18,240	15,630			
	66.30		52,000	42,110	1516	1227	2860

Max. compression = 12 × 2,755,000 / 1516 = 21,800 #/in.²
Max. tension = 12 × 2,755,000 / 1227 = 27,000 #/in.²
Silicon Steel.

Yerba Buena Anchorage – Upper Deck Floor Beams F, G and H.
D.L. Fl. Bm. = 270#/ft.
Live Load: See sh. #61

✓



	End Reaction (kips)	Moment (kip-ft)
D.L. – Concentrated	121	1537
Uniform	9	145
L.L.	47	827
Total	177	2509

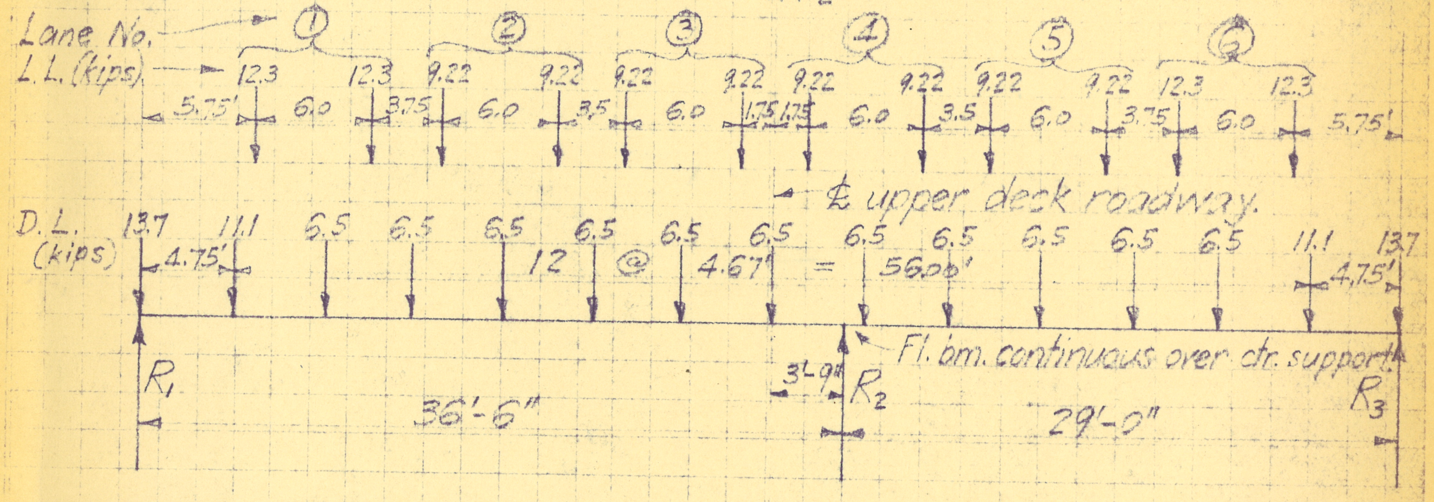
	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 x 7/16	29.31	23.19	10,965	8,670			
4 Ls 6 x 4 x 3/4	27.76	24.76	29,660	26,450			
	57.07		40,625	35,120	1204	1040	2425

Max. compression = 12 x 2,509,000/1204 = 25,000 #/in.²
Max. tension = 12 x 2,509,000/1040 = 29,000 #/in.²
Silicon Steel.

Yerba Buena Anchorage – Upper Deck Floor Beam J

Uniform D.L. – Fl. Bm. = 120 #/ft.
Concrete = 300
Total = 420 #/ft.

Live Load: H13⅓ on outside lanes, H10 on inside lanes.
Live loads shown in diagram are full loads without reduction. For more than two lanes loaded, use factor $C = 0.50 + \frac{2}{n+2}$



Load	Lanes Loaded	C	R_1 (kips)	Shear left of R_2	Shear right of R_2	R_2 (kips)	R_3 (kips)	M_2 (kip-ft.)	Pos. mom. 36'6" span
D.L.-Concentrated			34	29	30	59	28	-202	156
Uniform			6	9	8	17	4	-59	44
L.L.	1,2,3,4,5,6	0.75			28	62		-217	
"	1,2,3,4	0.833		36					
"	1,2,3	0.90	24						230
"	5,6	1.00					21		
Max.			64	74	66	138	53	-478	430

24" C.B. @ 100# Carbon Steel.
S.M. = 248.9   Web 0.468"   Flange 12"
Ratio Span/Depth = 18.2
Max. stress: Pos. mom. 12 × 430,000/248.9 = 20,700 #/in²
Neg. mom. 12 × 478,000/248.9 = 23,000 #/in²

At center support, 24" C.B. is reinforced on the bottom flange by a 12" × 7/16" plate 4'-9½" long.

New c.g. – 29.43 × 0 = 0
5.25 × 12.22" = 64.1
34.68 × 1.85" = 64.1

		I	Ad²	I New c.g.
24" C.B. @ 100#		2987	101	3088
12" × 7/16" pl.			565	565
			Gross I =	3653

For neg. mom. – Max. tension = 12 × 478,000 × 13.85/3653 = 21,800 #/in²
Max. compression = 12 × 478,000 × 10.59/3653 = 16,600 #/in²

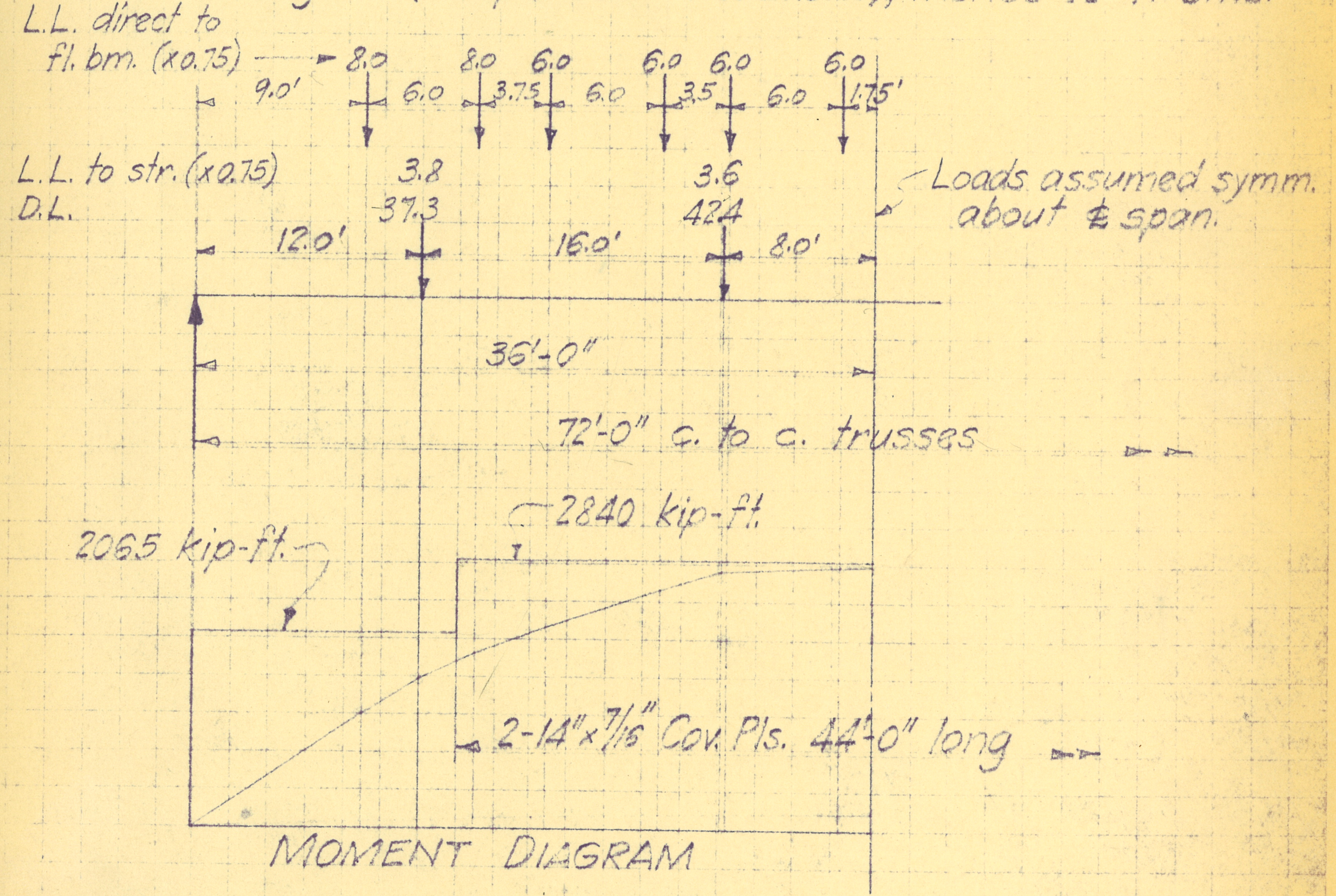
Upper Deck Floor Beams for 288' Spans on Yerba Buena Island.

D.L. Fl. Bm. = 280 #/ft.

L.L. - H13⅓ on each outside lane, H10 on 4 inside lanes.

6 lanes loaded. C = 0.75

One row of rear wheels direct to fl. bm. Other wheels to stringers (simple beam reactions), thence to fl. bms.



	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	80	1635 1816
Uniform	10	181
L.L.	47	975
Total	137	2791

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 x 7/16	29.31	22.31	10,965	8,350			
4 Ls 6 x 4 x 11/16	25.60	20.10	27,390	21,505			
	54.91		38,355	29,855	1135	825	2065
2 Cov. 14 x 7/16 x 44'-0	12.25	10.50	14,135	12,115			
	67.16		52,490	41,970	1535	1227	2840

Max. compression = 12 × 2,791,000 / 1535 = 21,800 #/in.^{2}

Max. tension = 12 × 2,791,000 / 1227 = 27,300 #/in.^{2}

Silicon Steel.

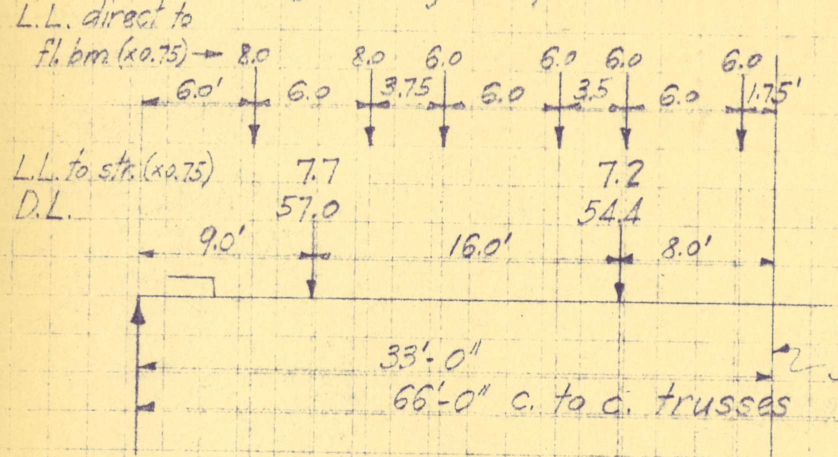
Upper Deck Floor Beams for Cantilever Structure - 48' Panels.

D.L. Fl. Bm. = 285#/ft.

L.L. - H13⅓ on each outside lane, H10 on 4 inner lanes.

6 lanes loaded. C = 0.75

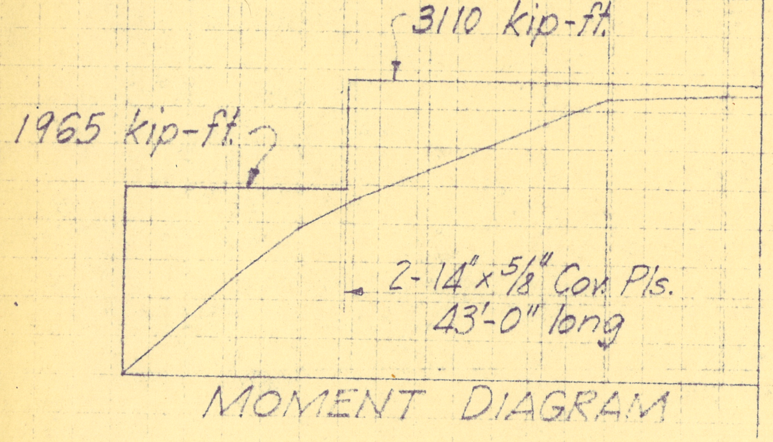
One row of rear wheels directly above fl. bm. Other wheels to stringers (by simple beam reactions), thence to fl. brms.



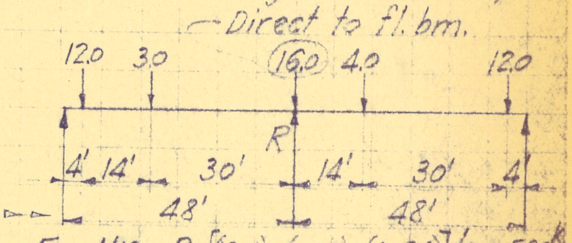
L.L. to stringers:

Outside stringer - $0.75(H13\tfrac{1}{3} + H10 \times \tfrac{6.25}{16}) = H12.92$

Interior stringer - $0.75(H10 + H10 \times \tfrac{9.75}{16}) = H12.08$



Fl. bm. reactions (excl. rear wheels directly above fl. bm.):



For H10, $R = [(12\times8)+(3\times18)+(4\times34)]/48 = 5.96^k$

" H12.92, $R = 5.96 \times 1.292 = 7.7^k$.

" H12.08, $R = 5.96 \times 1.208 = 7.2^k$.

	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	112	1876
Uniform	10	155
L.L.	55	957
Total	177	2988

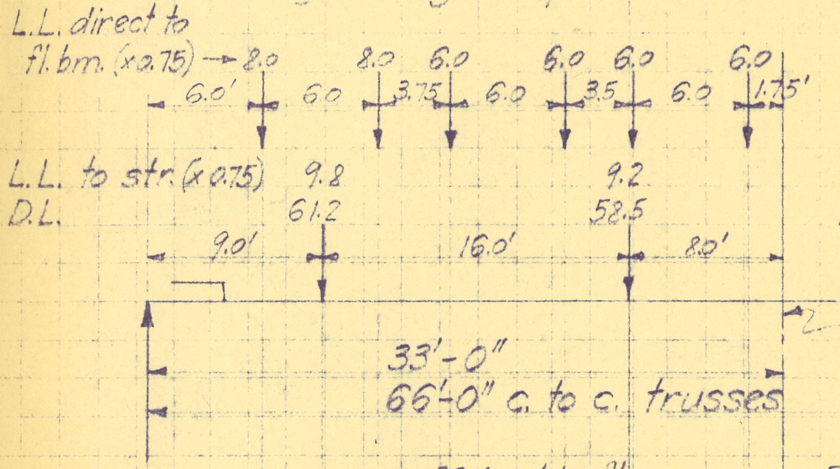
	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @28,000
1 Web 67 x 7/16	29.31	23.19	10,965	8,670			
4 Ls 6 x 4 x 5/8	23.44	18.44	25,125	19,760			
	52.75		36,090	28,430	1070	842	1965
2 Cov. 14 x 5/8 x 43'-0	17.50	15.00	20,300	17,400			
	70.25		56,390	45,830	1640	1333	3110

Max. compression = 12 x 2,988,000/1640 = 21,900#/in²

Max. tension = 12 x 2,988,000/1333 = 26,900#/in²

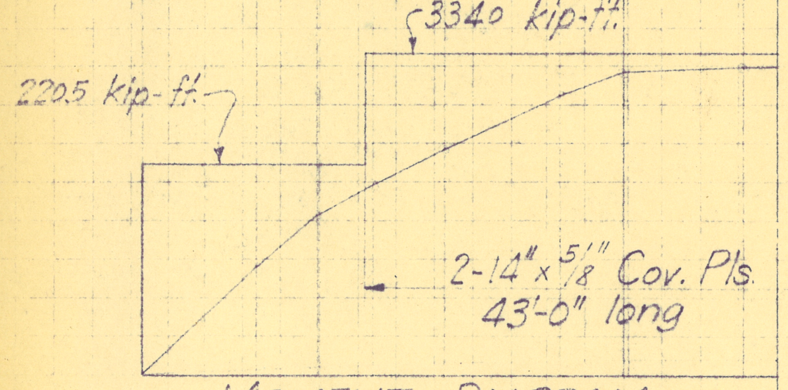
Silicon Steel.

Upper Deck Floor Beams for Cantilever Structure - At Panel Pts. LA4 & LC4.
D.L. Fl. Bm. = 300#/ft.
L.L. - H13⅓ on each outside lane, H10 on 4 inside lanes.
6 lanes loaded. C = 0.75
One row of rear wheels directly above fl. bm. Other wheels to stringers (by simple beam reactions), thence to fl. bms.



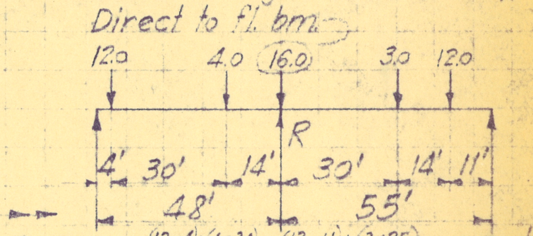
L.L. to outside stringer = H 12.92
" " interior " = H 12.08

Symm. about ℄ span.



MOMENT DIAGRAM

Fl. bm. reactions (excl. rear wheels directly above fl. bm.):



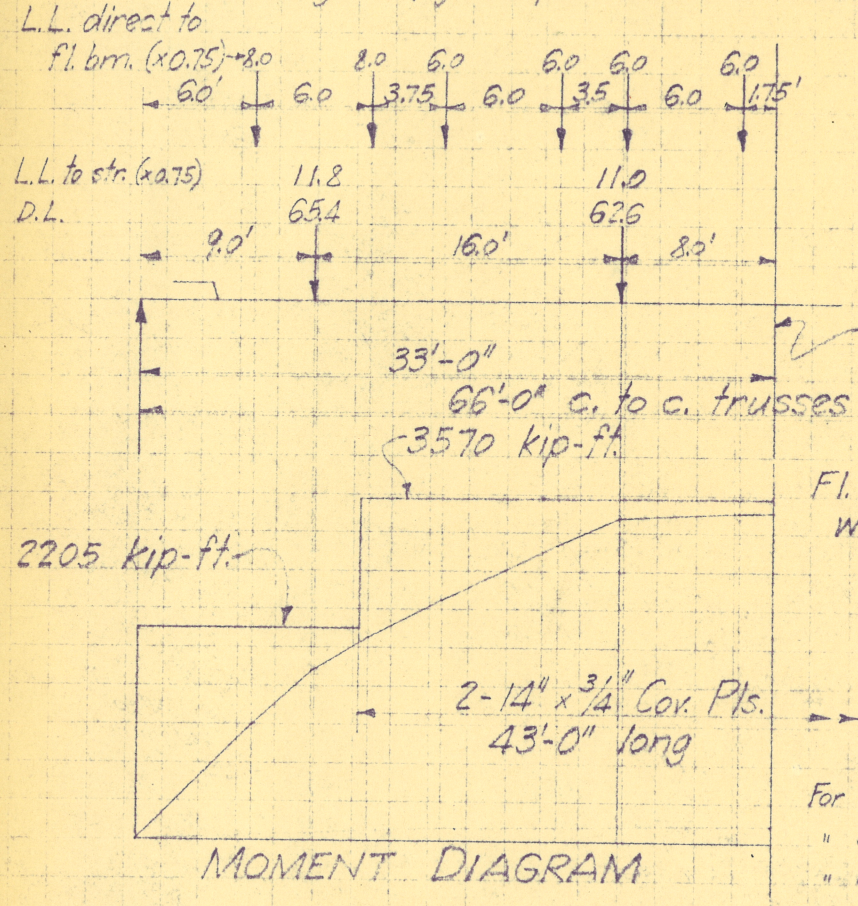
For H10, $R = \frac{(12\times4)+(4\times34)}{48} + \frac{(12\times11)+(3\times25)}{55} = 7.61^k$
" H12.92, $R = 7.61 \times 1.292 = 9.8^k$
" H12.08, $R = 7.61 \times 1.208 = 9.2^k$

	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	120	2013
Uniform	10	163
L.L.	59	1026
Total	189	3202

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 x 7/16	29.31	23.19	10,965	8,670			
4 Ls 6 x 4 x 3/4	27.76	21.76	29,660	23,240			
	57.07		40,625	31,910	1204	945	2205
2 Cov. 14 x 5/8 x 43'-0	17.50	15.00	20,300	17,400			
	74.57		60,925	49,310	1770	1434	3340

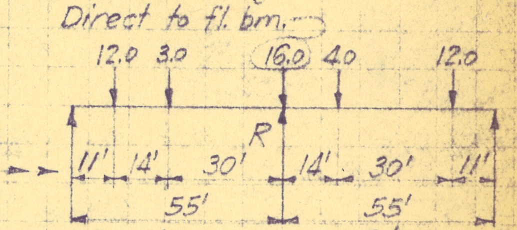
Max. compression = 12 x 3,202,000 / 1770 = 21,700 #/in.²
Max. tension = 12 x 3,202,000 / 1434 = 26,800 #/in.²
Silicon Steel.

Upper Deck Floor Beams for Cantilever Structure - 55' Panels.
D.L. Fl. Bm. = 310 #/ft.
L.L. - H13⅓ on each outside lane, H10 on 4 inside lanes.
6 lanes loaded. C = 0.75
One row of rear wheels directly over fl. bm. Other wheels to stringers (by simple beam reactions), thence to fl. bms.



L.L. to outside stringer = H 12.92
" " interior " = H 12.08

Fl. bm. reactions (excl. rear wheels directly above fl. bm.):



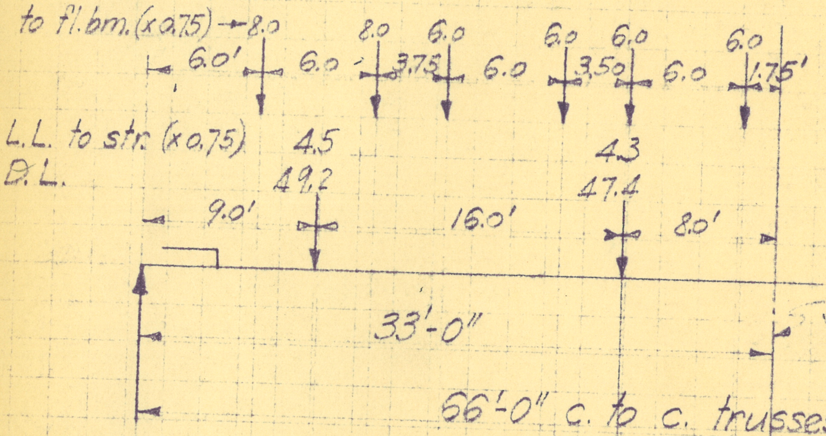
For H10, R = [(12×22)+(3×25)+(4×41)]/55 = 9.15[k]
" H12.92, R = 9.15 × 1.292 = 11.8[k]
" H12.08, R = 9.15 × 1.208 = 11.0[k]

	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	128	2154
Uniform	10	169
L.L.	63	1091
Total	201	3414

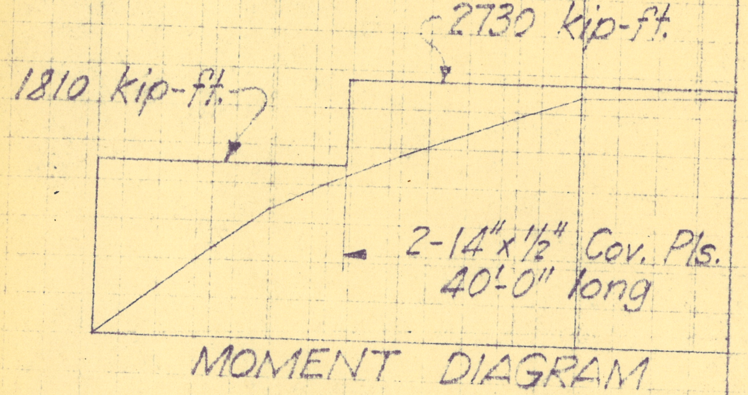
	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sec.@28,000
1 Web 67 × 7/16	29.31	23.19	10,965	8,670			
4 Ls 6 × 4 × 3/4	27.76	21.76	29,660	23,240			
	57.07		40,625	31,910	1204	945	2205
2 Cov. 14 × 3/4 × 43'-0	21.00	18.00	24,455	20,960			
	78.07		65,080	52,870	1885	1530	3570

Max. compression = 12 × 3,414,000 / 1885 = 21,700 #/in.²
Max. tension = 12 × 3,414,000 / 1530 = 26,800 #/in.²
Silicon Steel.

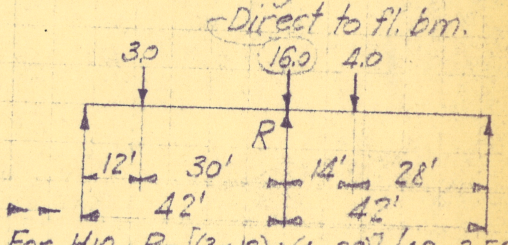
Upper Deck Floor Beams for 504' Spans
D.L. Fl. Bm. = 260#/ft.
L.L. - H13⅓ on each outside lane, H10 on 4 inside lanes.
6 lanes loaded. C = 0.75
One row of rear wheels directly above fl. bm. Other wheels to stringers (by simple beam reactions), thence to fl. bms.



L.L. to outside stringer = H 12.92
" " interior " = H 12.08



Fl. bm. reactions (excl. rear wheels directly above fl. bm):



For H10, $R = [(3 \times 12) + (4 \times 28)]/42 = 3.52^k$
" H12.92, $R = 3.52 \times 1.292 = 4.5^k$
" H12.08, $R = 3.52 \times 1.208 = 4.3^k$

	Shear (kips)	Moment (kip-ft)
D.L. - Concentrated	97	1627
Uniform	9	142
L.L.	49	856
Total	155	2625

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 x 7/16	29.31	21.87	10,965	8,180			
4Ls 6x4x9/16	21.24	16.74	22,795	17,970			
	50.55		33,760	26,150	1000	775	1810
2 Cov. 14x½x40'-0	14.00	12.00	16,180	13,870			
	64.55		49,940	40,020	1460	1170	2730

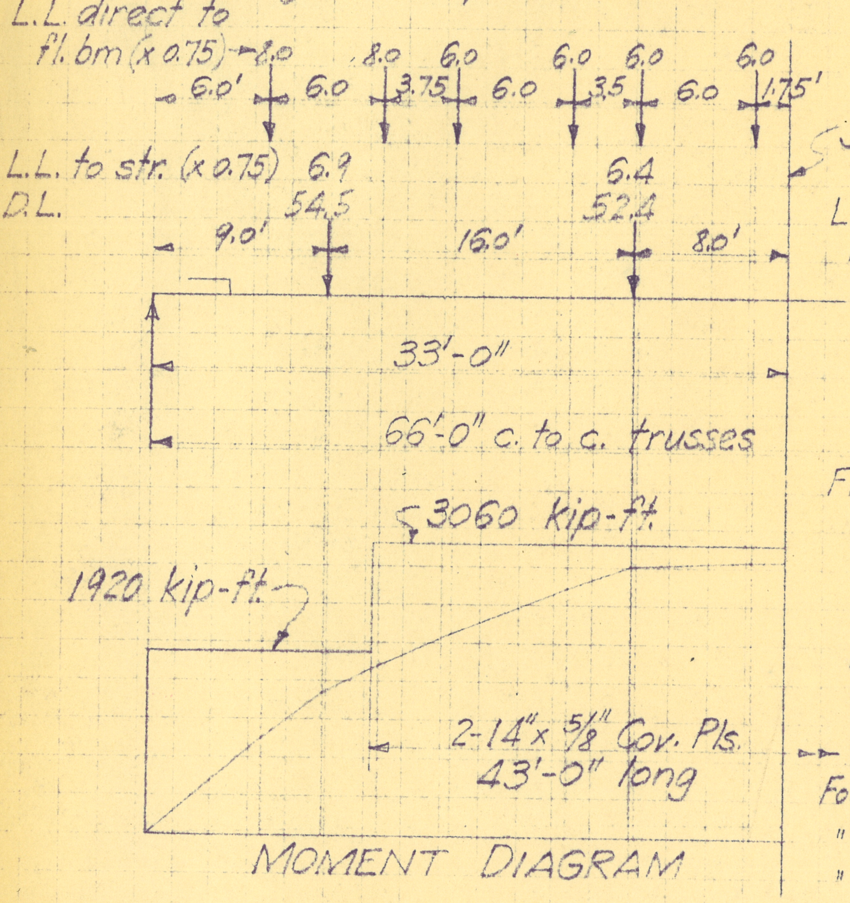
Max. compression $= 12 \times 2{,}625{,}000/1460 = 21{,}600$ #/in.²
Max. tension $= 12 \times 2{,}625{,}000/1170 = 26{,}900$ #/in.²
Silicon Steel.

Upper Deck Floor Beam at Bent E9W

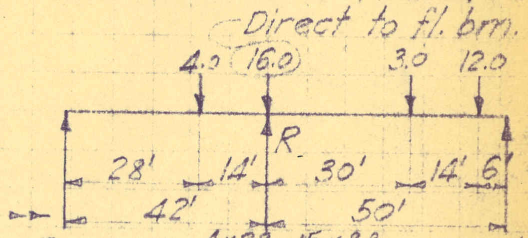
D.L. Fl. Bm. = 280#/ft.

L.L. - H13⅓ on each outside lane, H10 on 4 inside lanes.
6 lanes loaded. C = 0.75

One row of rear wheels direct to fl. bm. Other wheels to stringers (simple beam reactions), thence to fl. bms.



Fl. bm. reactions (excl. rear wheels direct to fl. bm.):



For H10, $R = \frac{4 \times 28}{42} + \frac{15 \times 8.8}{50} = 5.31^k$

" H12.92, $R = 5.31 \times 1.292 = 6.9^k$

" H12.08, $R = 5.31 \times 1.208 = 6.4^k$

	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	107	1800
Uniform	9	153
L.L.	53	930
Total	169	2883

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28000
1 Web 67 x 7/16	29.31	21.44	10,965	8,020			
4 Ls 6 x 4 x 5/8	23.44	18.44	25,125	19,760			
	52.75		36,090	27,780	1070	823	1920
2 Cov. 14 x 5/8 x 43'-0	17.50	15.00	20,300	17,400			
	70.25		56,390	45,180	1640	1314	3060

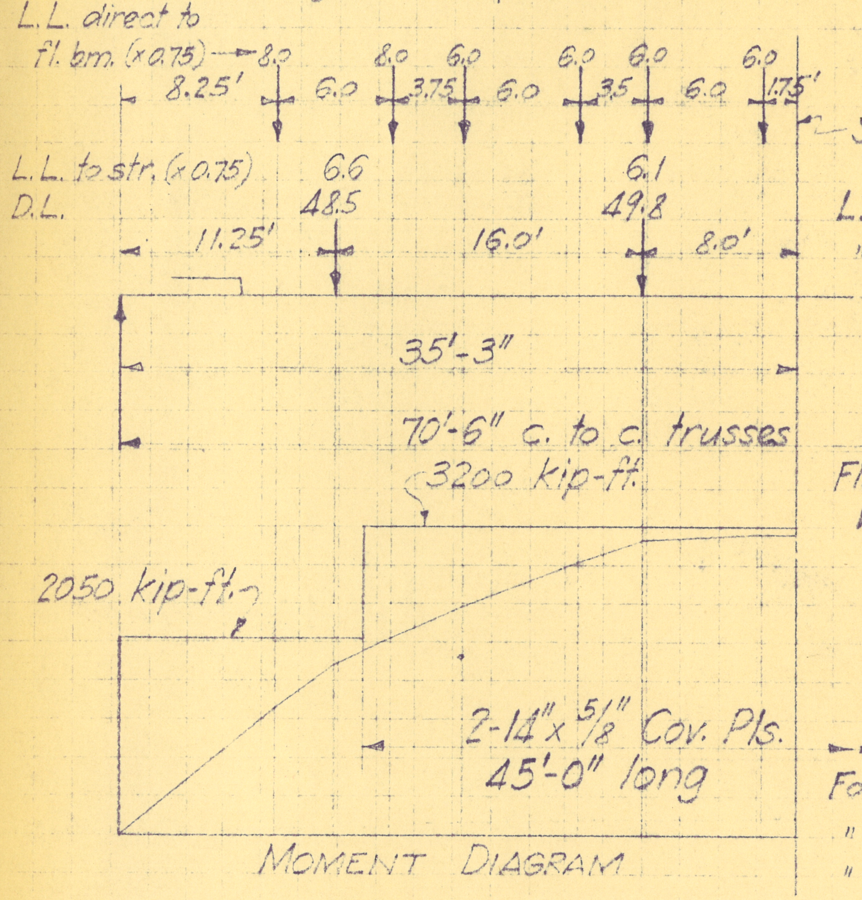
Max. compression = 12 x 2,883,000 / 1640 = 21,100#/in.²

Max. tension = 12 x 2,883,000 / 1314 = 26,300#/in.²

Silicon Steel.

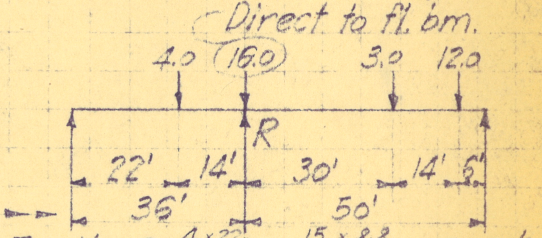
Upper Deck Floor Beam at Bent E9E

D.L. Fl. Bm. = 300#/ft. (incl. brackets)
L.L. - H13⅓ on each outside lane, H10 on 4 inside lanes.
6 lanes loaded. C = 0.75
One row of rear wheels direct to fl. bm. Other wheels to stringers (simple beam reactions), thence to fl. bms.



L.L. to outside stringer = H 12.92
" " interior " = H 12.08

Fl. bm. reactions (excl. rear wheels direct to fl. bm.):



For H10, $R = \frac{4 \times 22}{36} + \frac{15 \times 8.8}{50} = 5.08^k$
" H12.92, $R = 5.08 \times 1.292 = 6.6^k$
" H 12.08, $R = 5.08 \times 1.208 = 6.1^k$

	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	98	1903
Uniform	11	186
L.L.	53	1039
Total	162	3128

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 x 7/16	29.31	21.87	10,965	8,180			
4 Ls 6 x 4 x 11/16	25.60	20.10	27,390	21,505			
	54.91		38,355	29,685	1135	880	2050
2 Cov. 14 x 5/8 x 45'-0	17.50	15.00	20,300	17,400			
	72.41		58,655	47,085	1708	1370	3200

Max. compression = 12 x 3,128,000 / 1708 = 22,000 #/in.²
Max. tension = 12 x 3,128,000 / 1370 = 27,400 #/in.²
Silicon Steel.

STATE OF CALIFORNIA—DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE

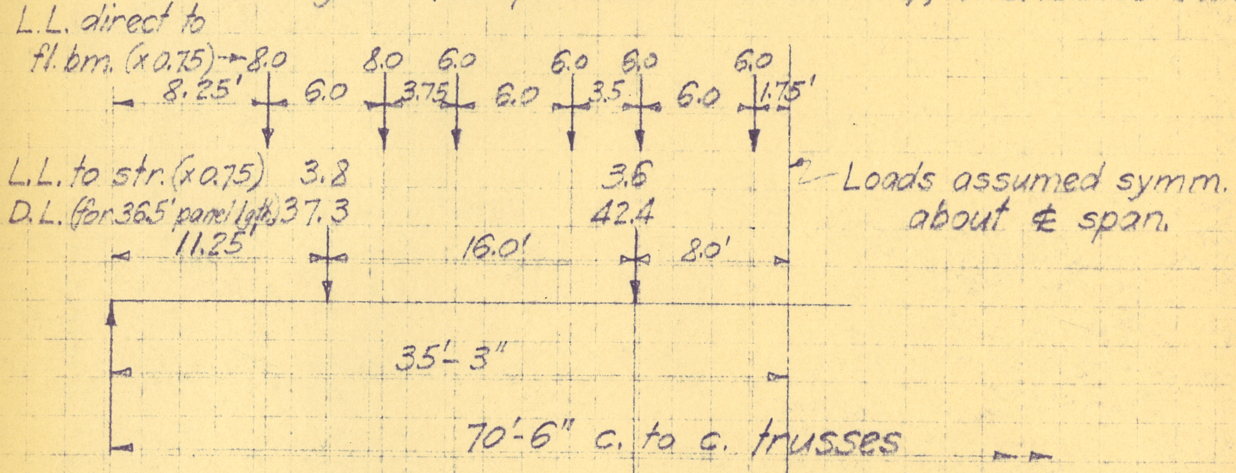
Upper Deck Floor Beams for 288' Spans E9-E10 and E10-E11.

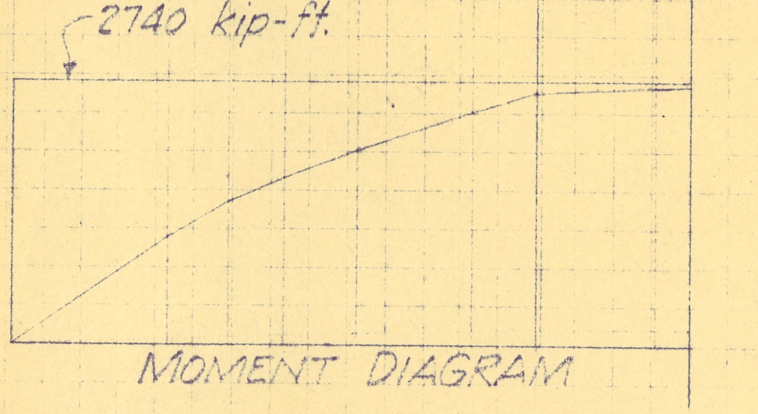
D.L. Fl. Bm. = 280#/ft.

L.L. - H13⅓ on each outside lane, H10 on 4 inside lanes.

6 lanes loaded. C = 0.75

One row of rear wheels direct to fl. bm. Other wheels to stringers (simple beam reactions), thence to fl. bms.





MOMENT DIAGRAM

	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	80	1575
Uniform	10	174
L.L.	47	940
Total	137	2689

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 x 7/16	29.31	21.87	10,965	8,180			
4 Ls 6 x 6 x 3/4	33.76	30.76	34,620	31,540			
	63.07		45,585	39,720	1350	1175	2740

Max. compression = 12 x 2,689,000 / 1350 = 23,900 #/in.²

Max. tension = 12 x 2,689,000 / 1175 = 27,400 #/in.²

Silicon Steel.

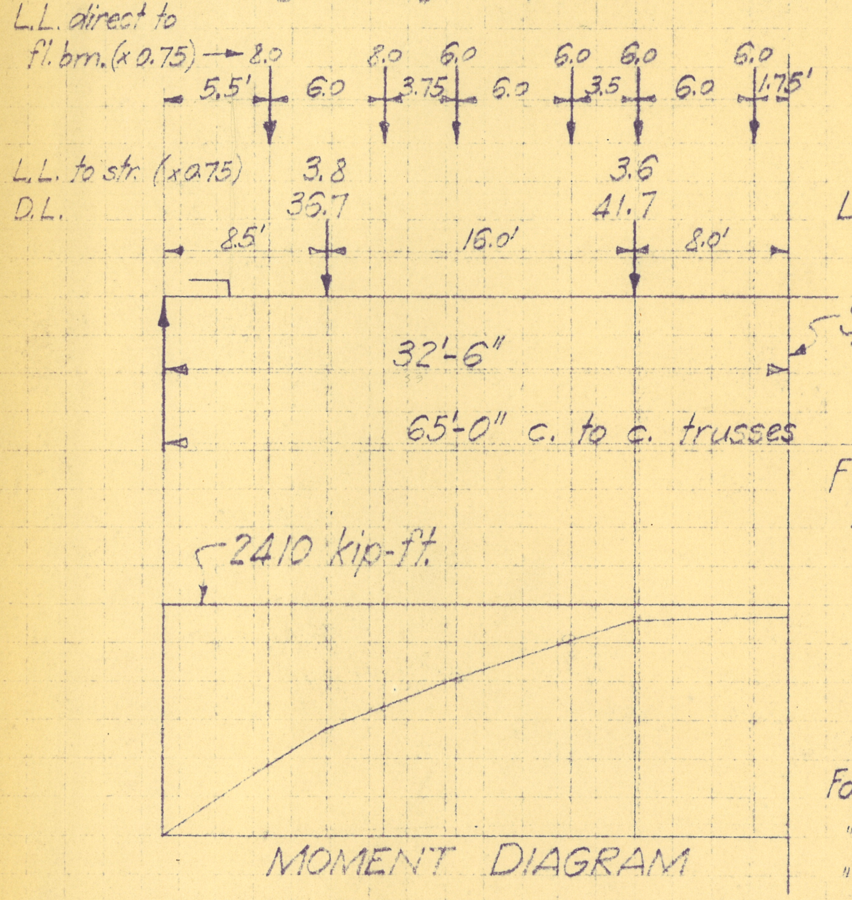
Upper Deck Floor Beams for 288' Spans E11 to E23

D.L. Fl. Bm. = 255 #/ft.

L.L. - H13⅓ on each outside lane, H10 on 4 inside lanes.

6 lanes loaded. C = 0.75

One row of rear wheels directly above fl. bm. Other wheels to stringers (by simple beam reactions), thence to fl. bms.

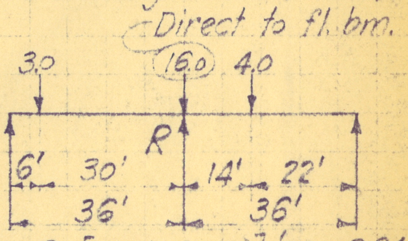


L.L. to outside stringer = H 12.92

" " interior " = H 12.08

Symm. about ℄ span.

Fl. bm. reactions (excl. rear wheels directly above fl. bm):



For H10, R = [(3 x 6) + (4 x 22)]/36 = 2.94 k.

" H12.92, R = 2.94 x 1.292 = 3.8

" H12.08, R = 2.94 x 1.208 = 3.6

	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	78	1333
Uniform	8	135
L.L.	47	810
Total	133	2278

	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 67 x 7/16	29.31	22.31	10,965	8,350			
4 Ls 6 x 4 x 3/4	27.76	24.76	29,660	26,450			
	57.07	47.07	40,625	34,800	1204	1031	2410

Max. compression = 12 x 2,278,000 / 1204 = 22,700 #/in.²

Max. tension = 12 x 2,278,000 / 1031 = 26,500 #/in.²

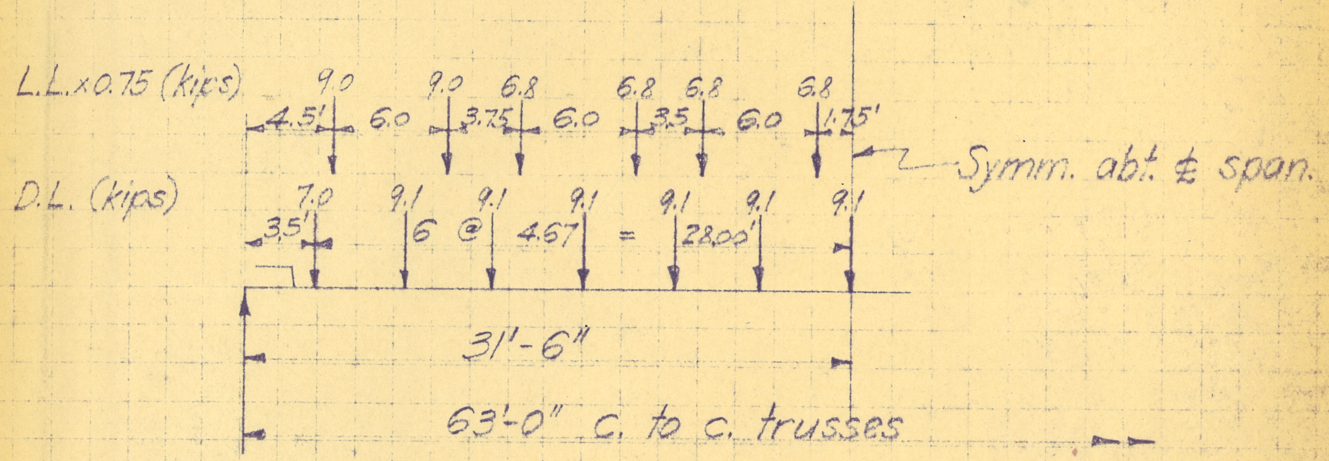
Silicon Steel.

Girder Spans E23-E33 - Intermediate Upper Deck Floor Beams

D.L. Fl. Bm. = 215 #/ft.

Live Load: H13⅓ on each outside lane, H10 on 4 inside lanes.

6 lanes loaded. C = 0.75



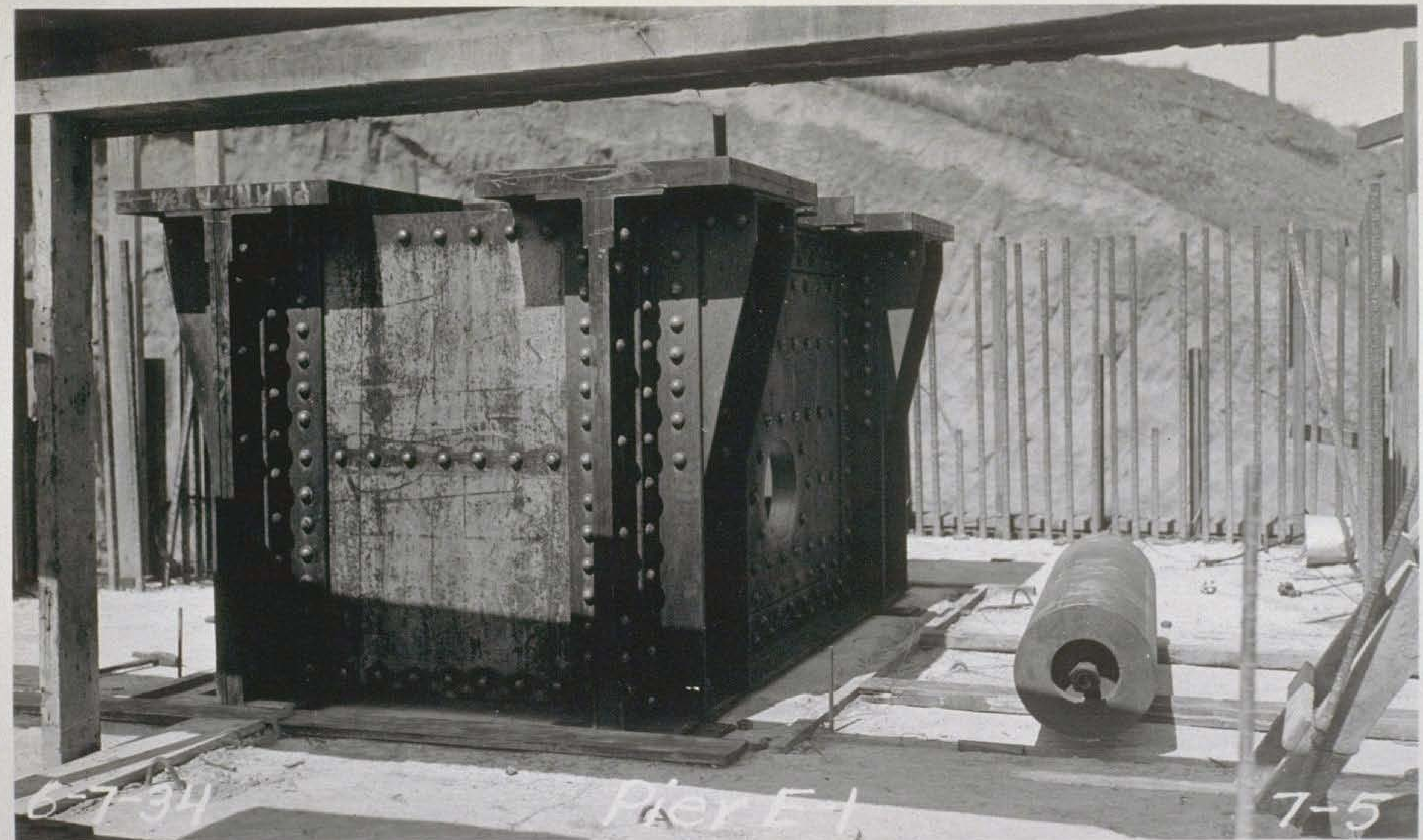
	Shear (kips)	Moment (kip-ft.)
D.L. - Concentrated	57	965
Uniform	7	107
L.L.	45	734
Total	109	1806

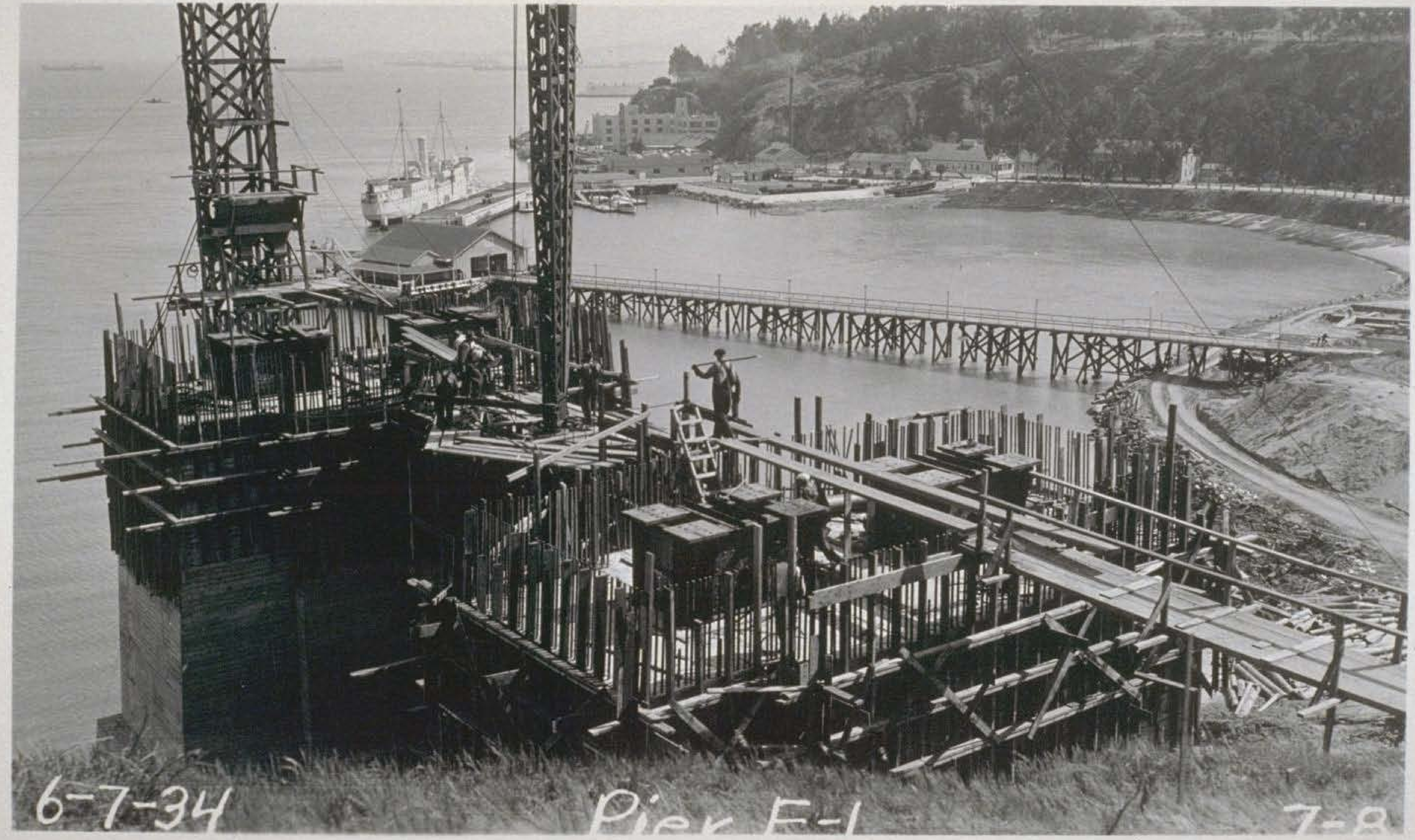
	Gross Area	Net Area	Gross I	Net I	Section Modulus Gross	Section Modulus Net	Resisting Mom. Net sect. @ 28,000
1 Web 66 × 7/16	28.87	23.19	10,480	8,420			
4 Ls 6 × 4 × 1/2	19.00	17.00	19,800	17,720			
	47.87		30,280	26,140	913	786	1835

Max. compression = 12 × 1,806,000 / 913 = 23,800 #/in.²

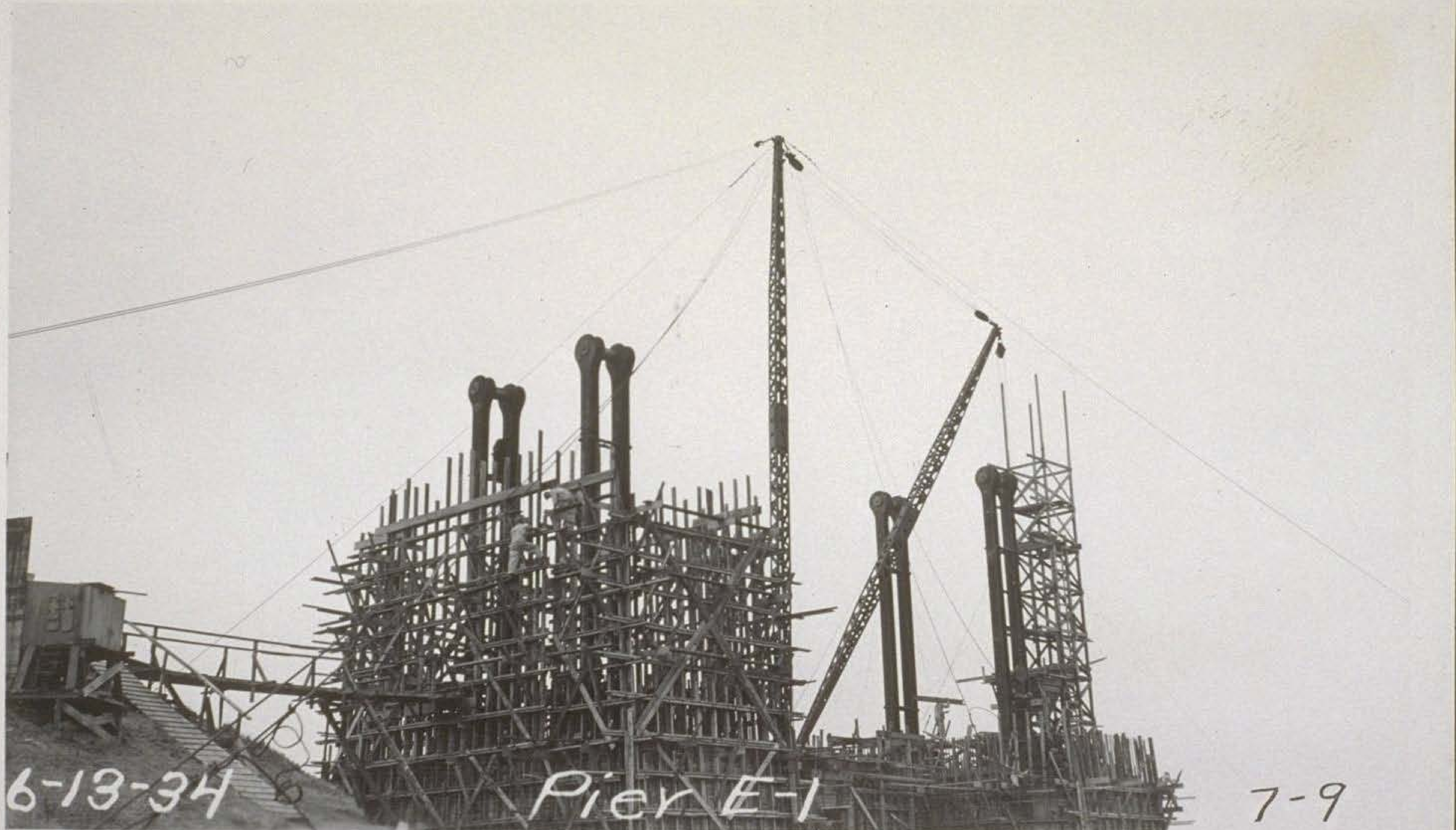
Max. tension = 12 × 1,806,000 / 786 = 27,500 #/in.²

Silicon Steel.


6-7-34
Pier E-1
7-5



3


6-13-34
Pier E-1
7-9


8-3-34
Piers E-21 & E-22
7-15

8

8-10-34 Falsework Piling 7-22

10


8-14-34
Deck Span
7-32

12

14


9-13-34
Ft. Span E-22
7-73

25


10-3-34
288 Ft. Spans
7-100

31


10-17-34
288 Ft. Spans
7-135


10-19-34 288 Ft. Span E-18 7-139

40


11-7-34
288 Ft. Span E-16
7-168

52

11-9-34 Concrete Dock 7-173

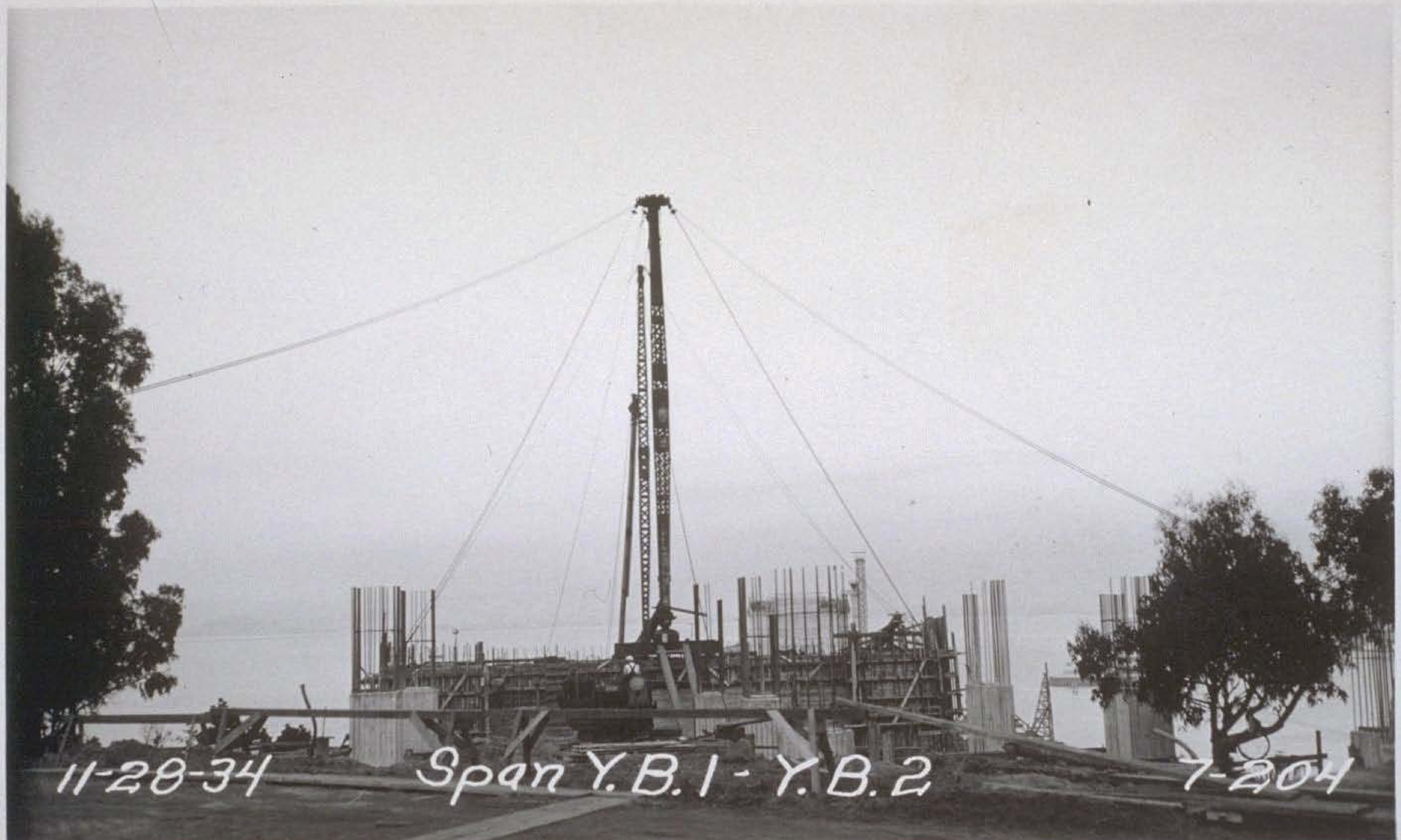

11-13-34 Steel Dock 7-175


11-22-34
Spans Y.B.1-E-1
7-192


Spans Y.B.1-E-1
11-22-34
7-194

63


11-23-34
288 Ft. Spans
7-203


11-28-34
Span Y.B.1 - Y.B.2
7-204


11-30-34
288 Ft. Spans
7-210

69

72

13


12-7-34 Concrete Plant 7-239


Concrete Plant
12-7-34
7-248

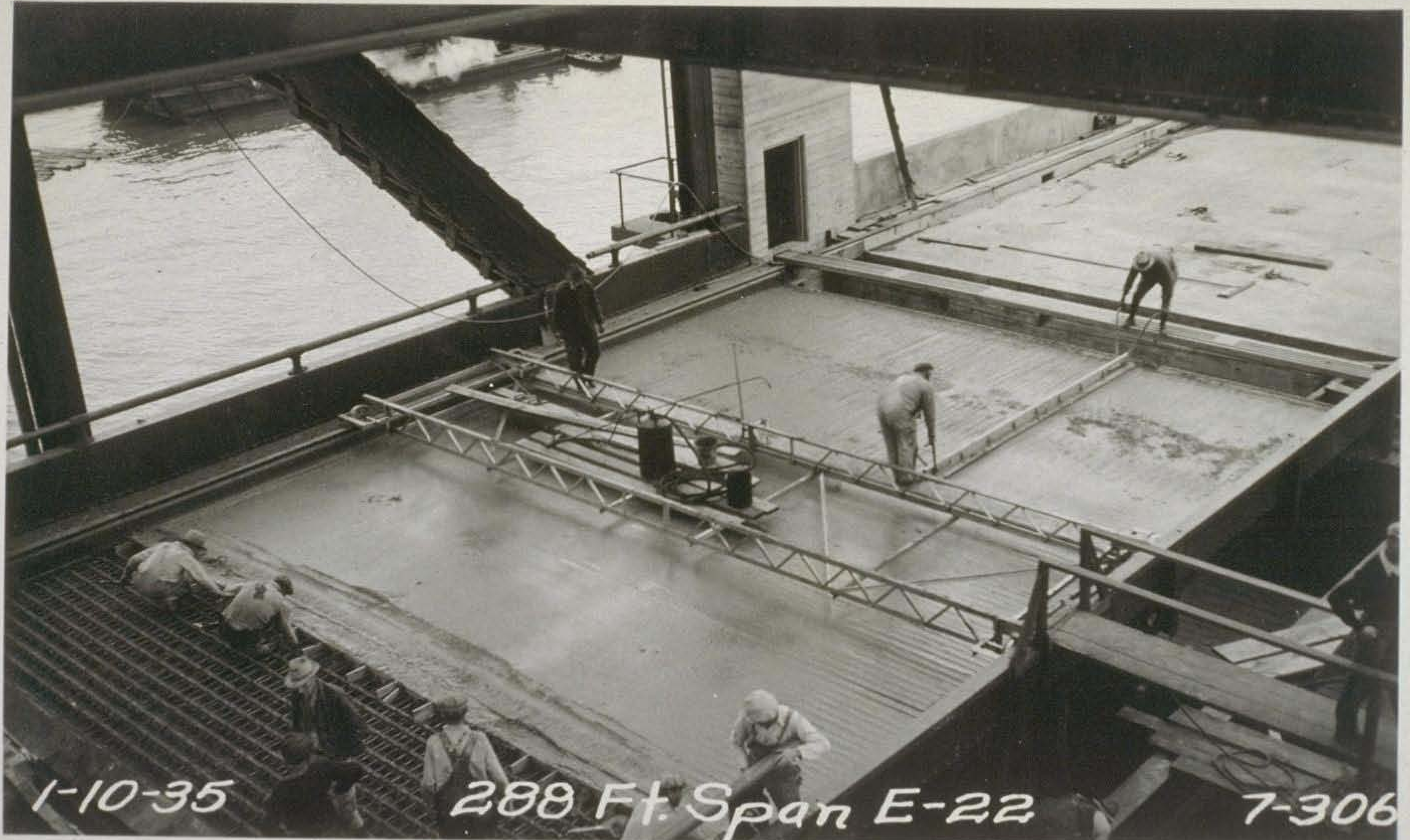

12-11-34 Span Y.B.1 7-250


12-19-34 Span Y.B.1 7-271


1-8-35
288 Ft. Span E-22
T-284

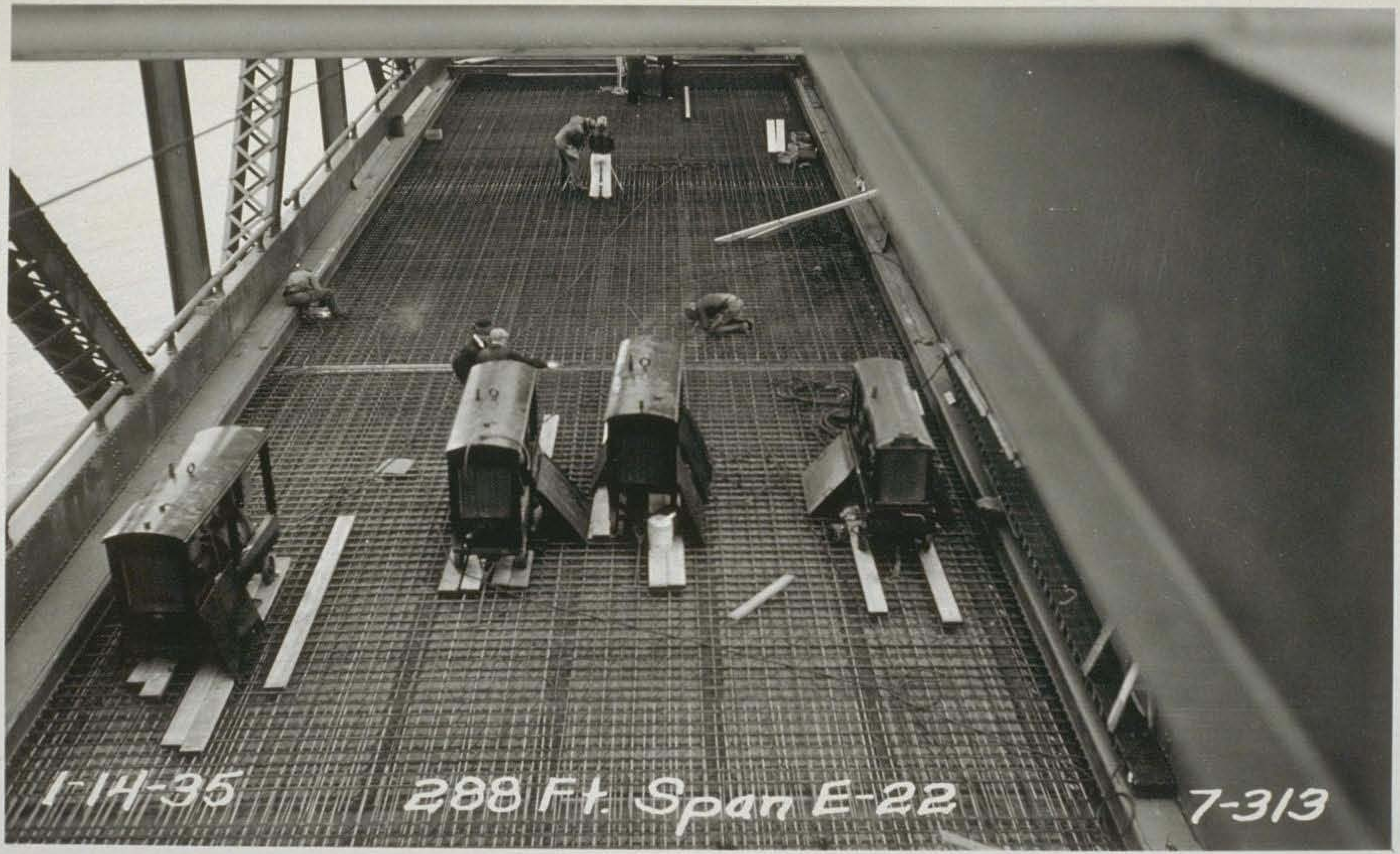

1-10-35
288 Ft. Span E-22
7-297

92



93

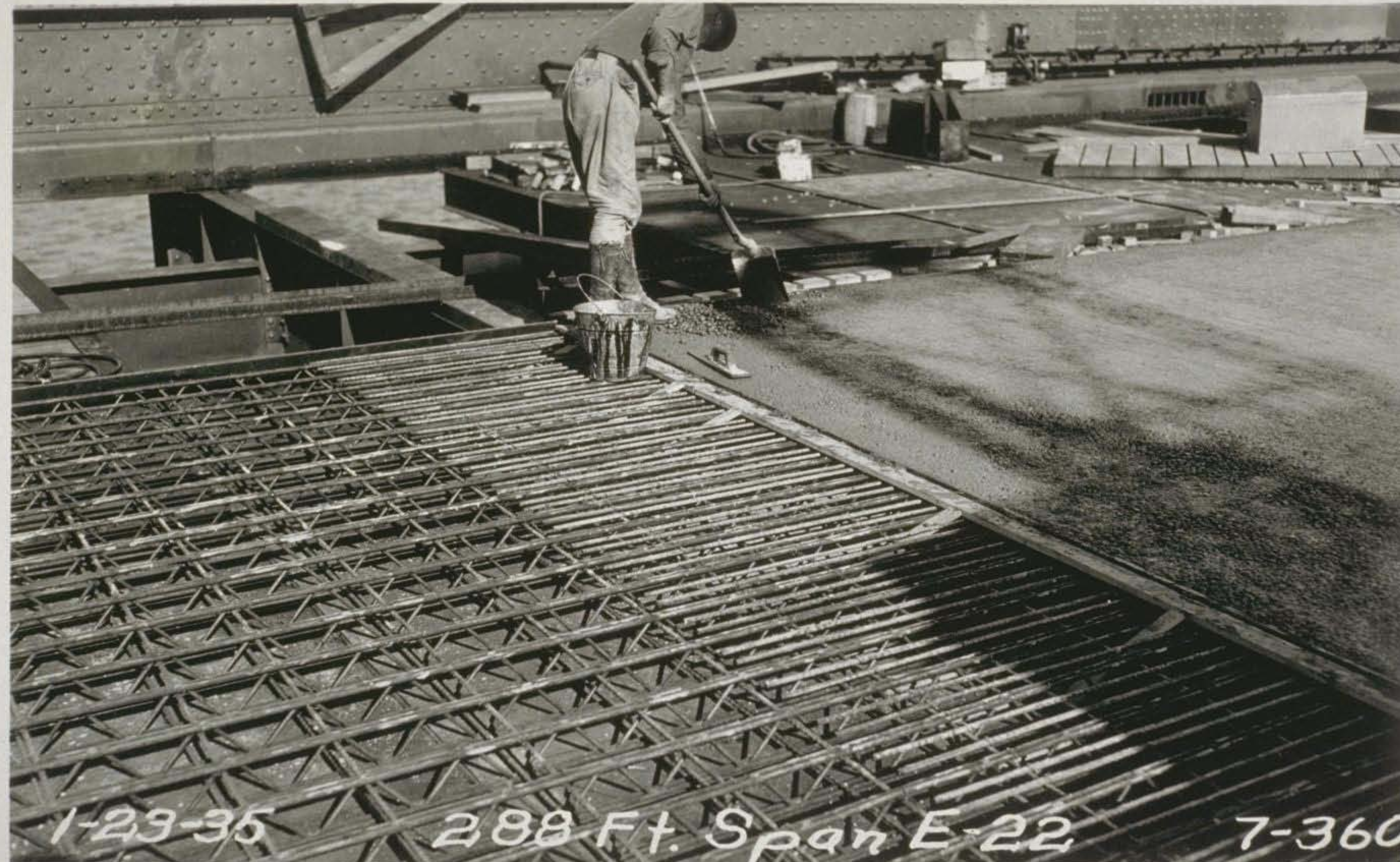
95


1-14-35
288 Ft. Span E-22
7-313

102

105


1-23-35
288 Ft. Span E-22
7-357


1-23-35
288 Ft. Span E-22
7-360

1-23-35 288 Ft. Span E-22 7-375

137

145


Traveler Derrick
3-11-35
7-511

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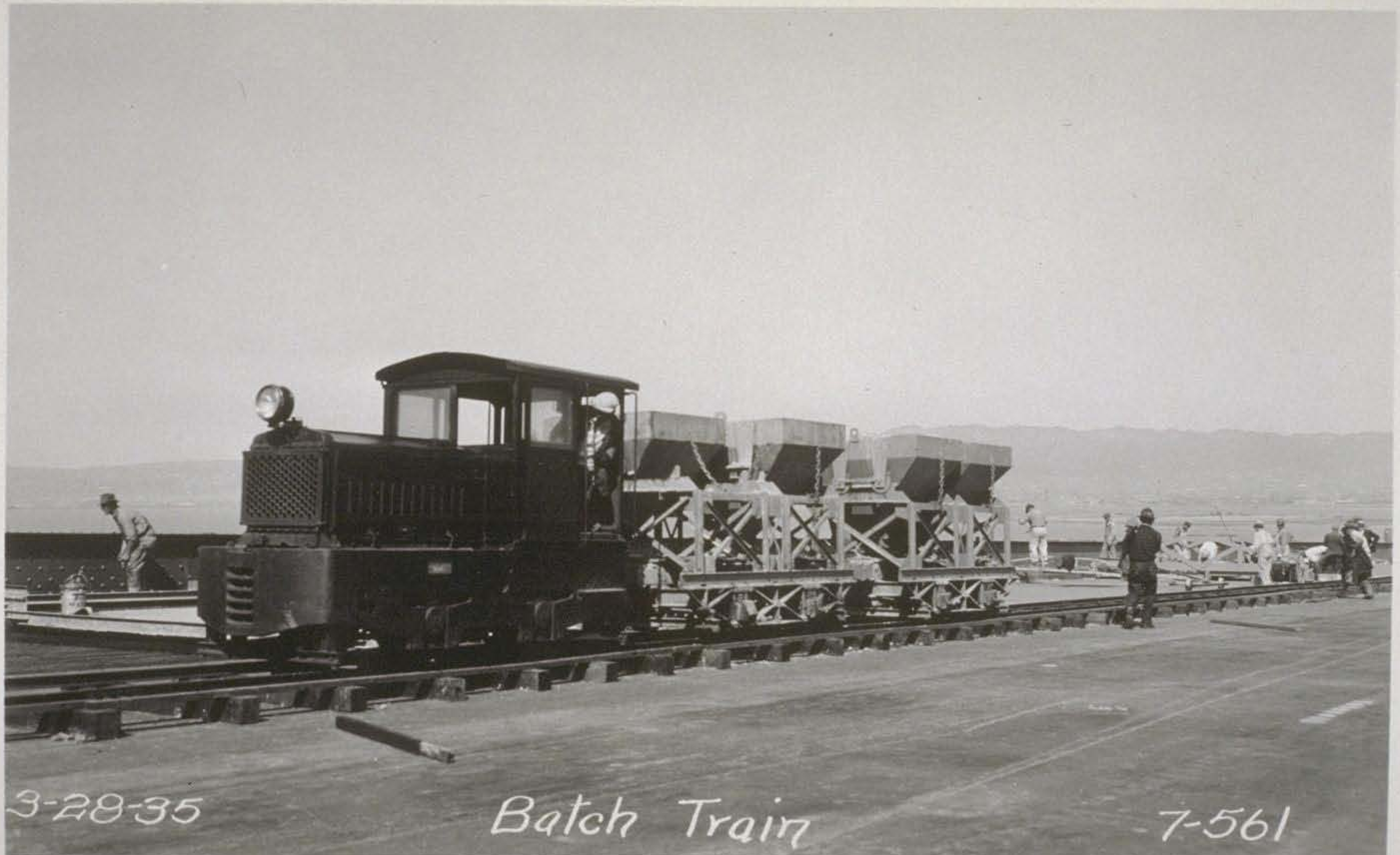

3-28-35 Batch Train 7-561

156

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3-28-35 Brooming Surface 7-563


3-28-35
Placing Tile
7-564

3-28-35 Vibrating Base Course 7-565

3-28-35
Vibrating Light Weight Concrete
7-567


3-28-35
Scraping Hole
7-568


3-28-35
Hammering Tile
7-569

3-28-35
Placing Base Course
7-570

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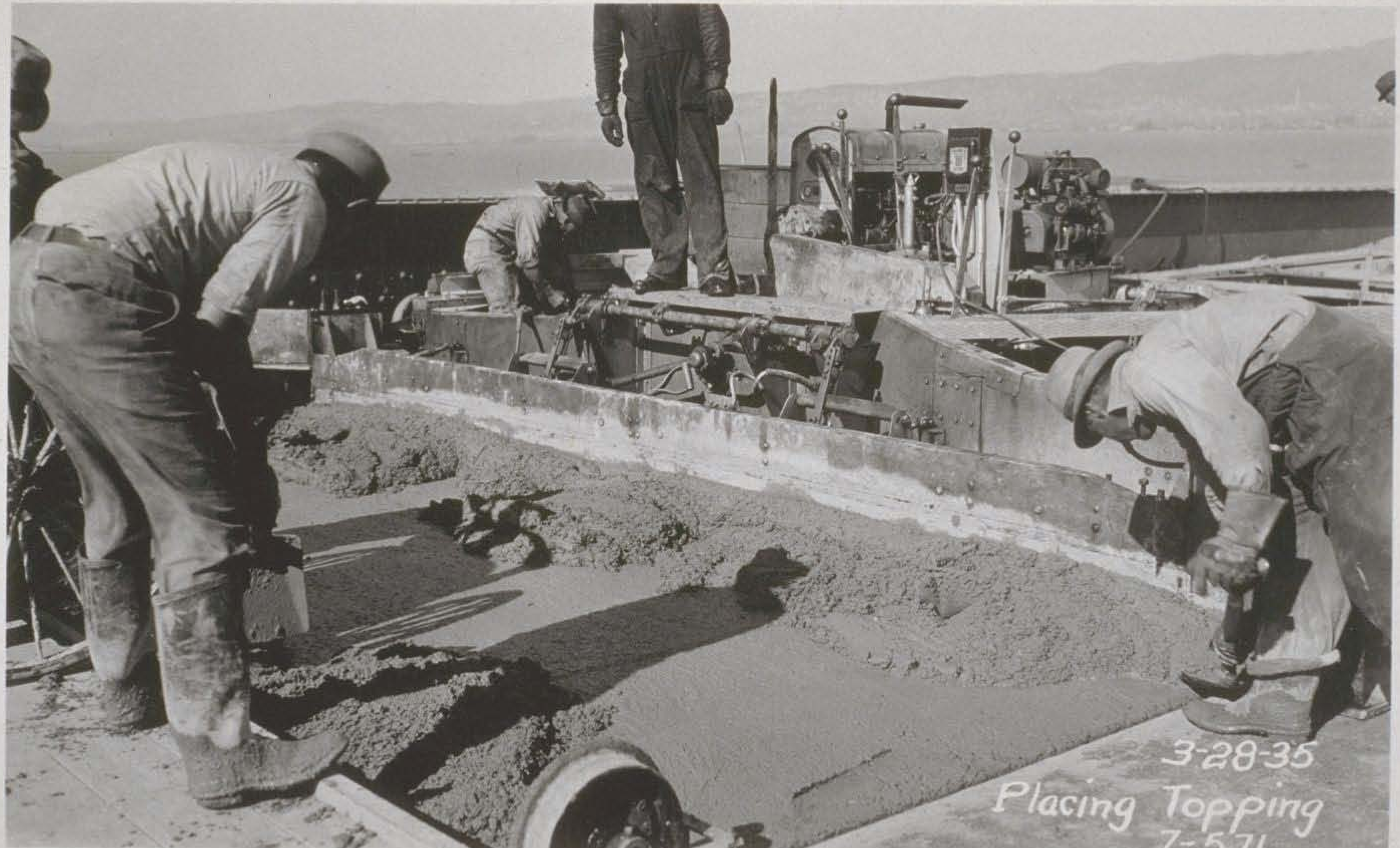

3-29-35 Span E-7 7-589

178


4-25-35
288 Ft. Span E-11
7-672


4-29-36
Grit Plant
7-694

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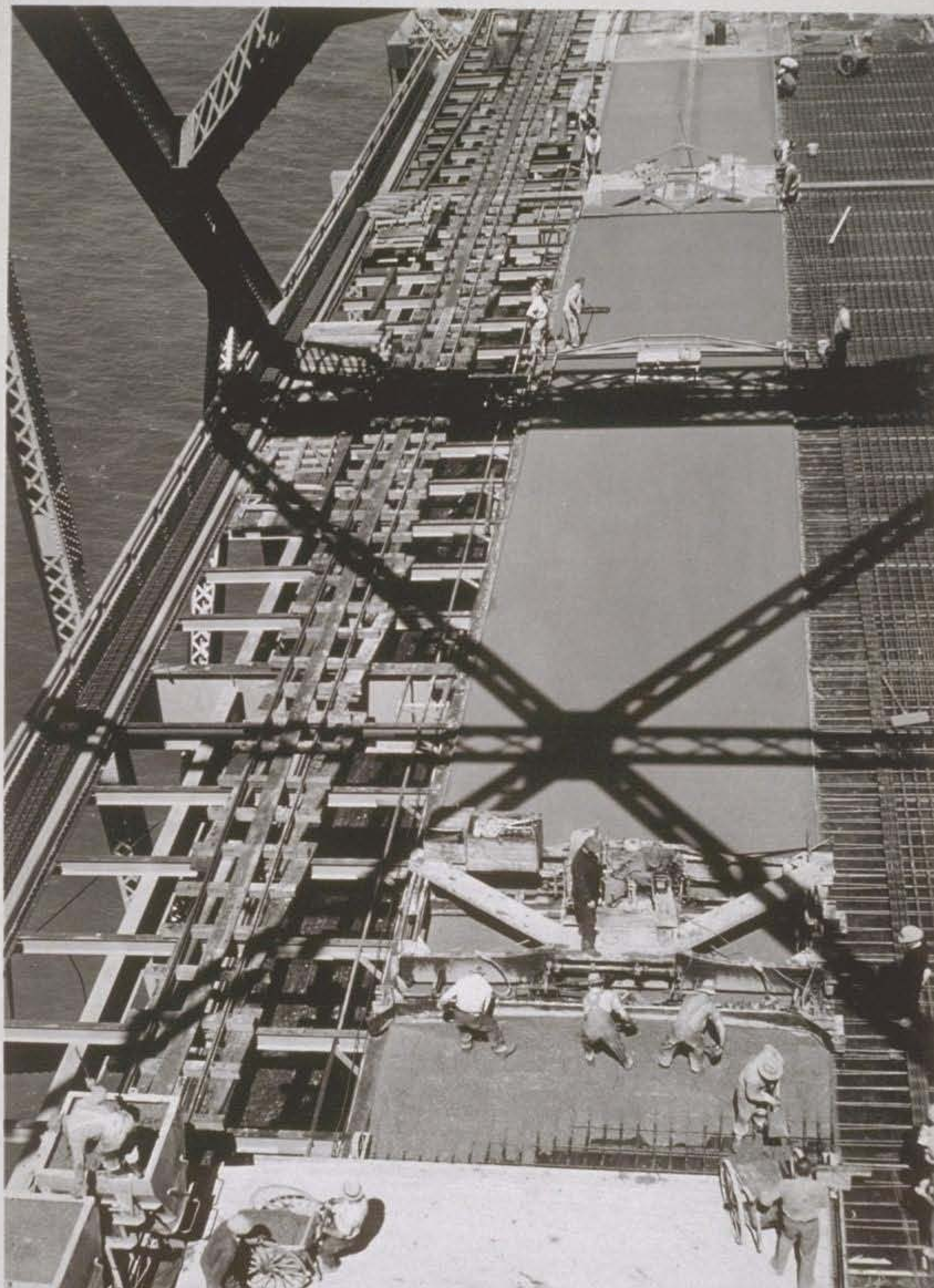
5-17-35
Span E-8
7-760

214


5-24-35
288 Ft. Span E-9
7-791

224

5-29-35 West Anchor Arm 1-795

224

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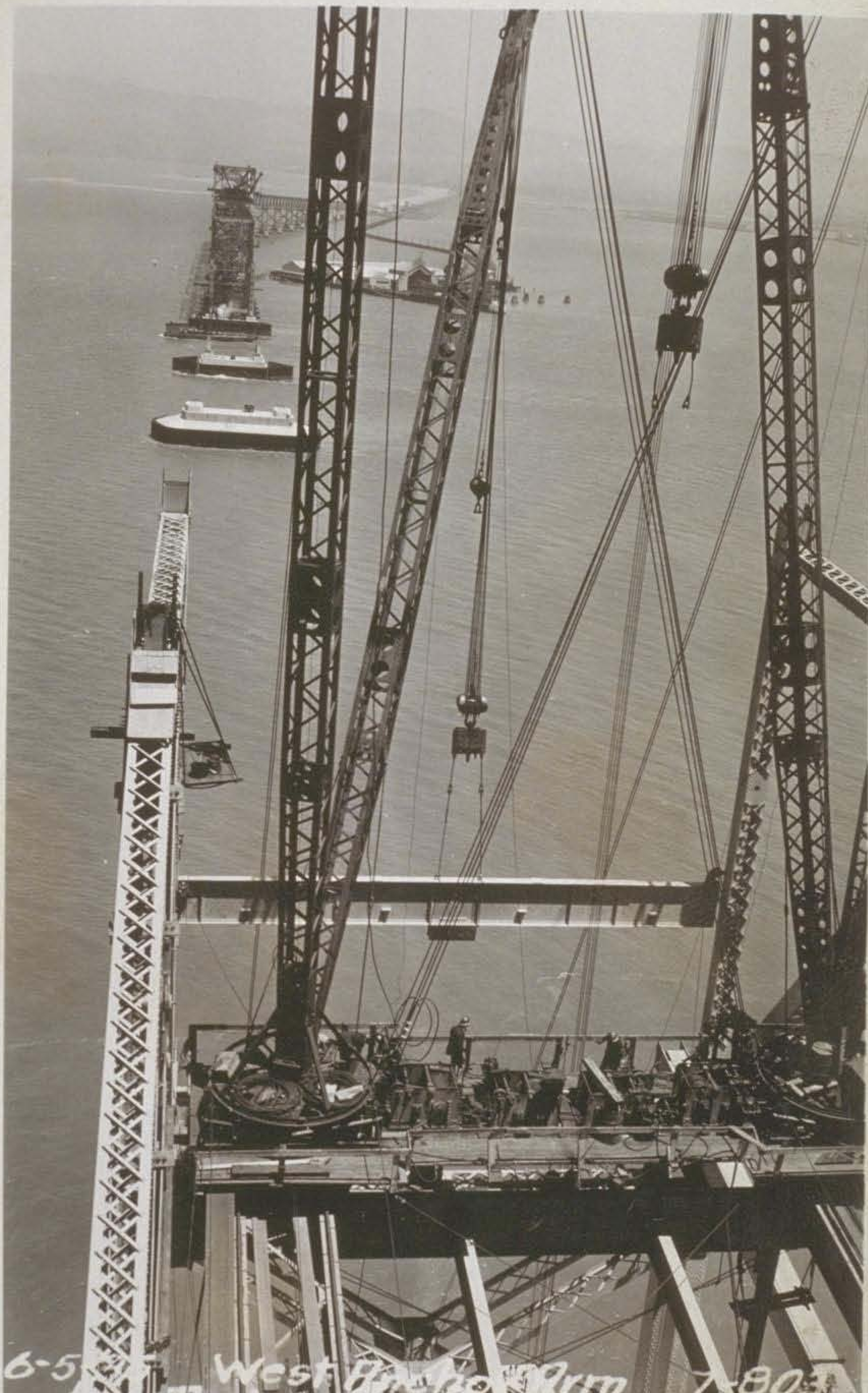
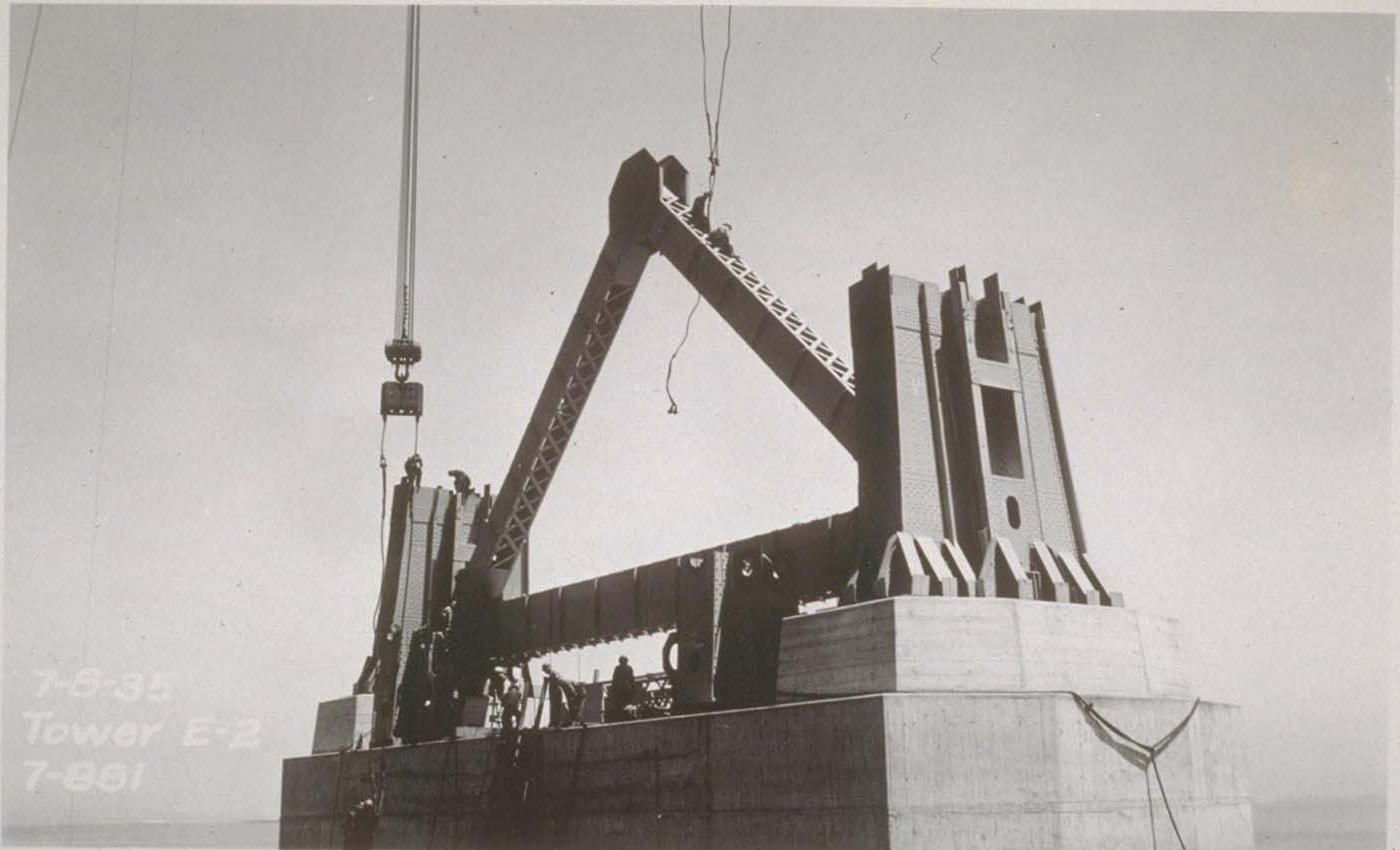
6-5-35 West Anchor Arm 7-797


6-5
West
Arm
7-803

230


6-21-35
Upper Deck Approach
7-843

250

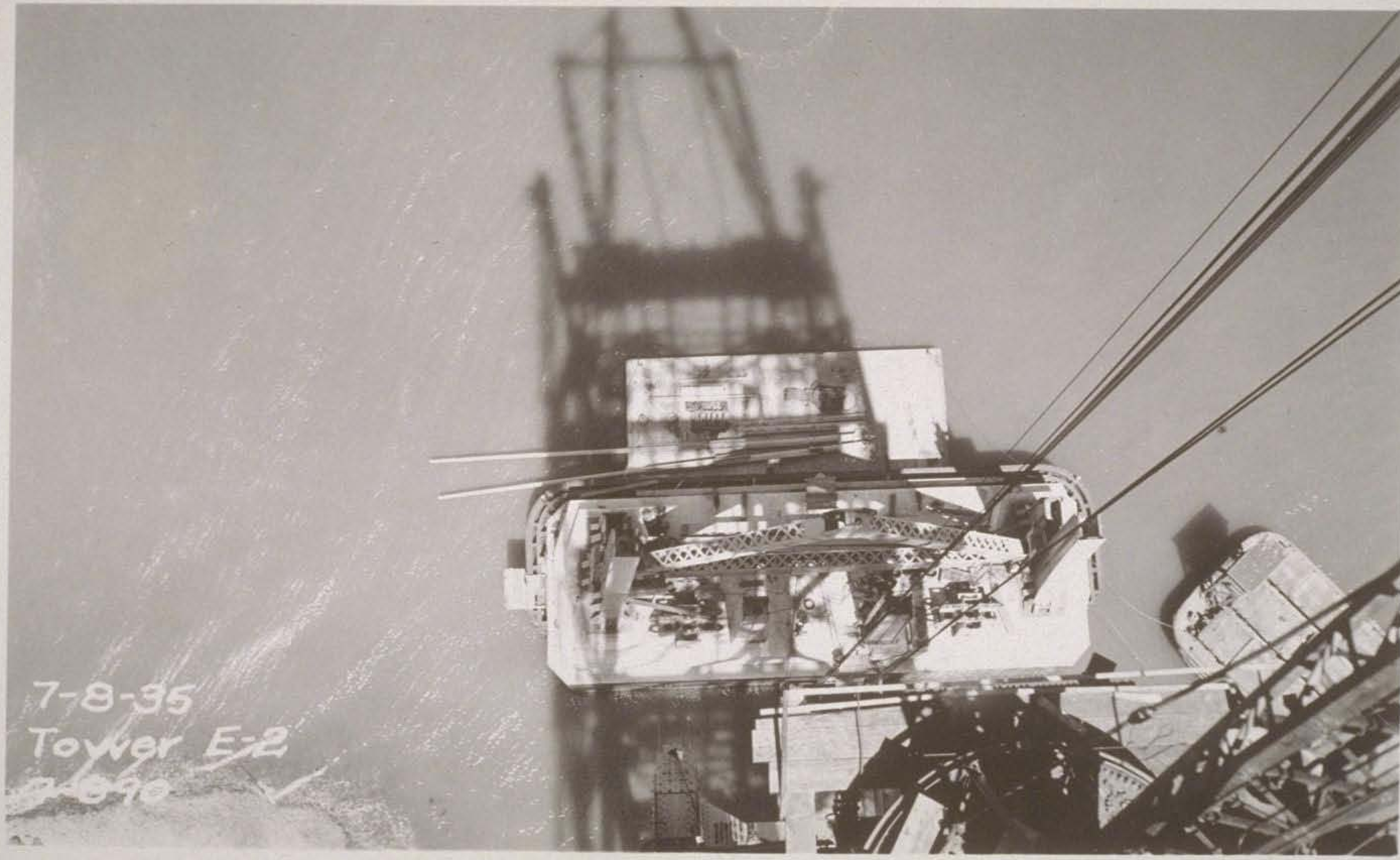


251

7-8-35 Falsework Bent-West Anchor Arm


7-8-35
West Anchor Arm
7-888

254




7-8-35
West Anchor Arm
7-891

256


7-11-35
West Anchor Arm
7-896


7-11-35
West Anchor Arm
7-898

262

263

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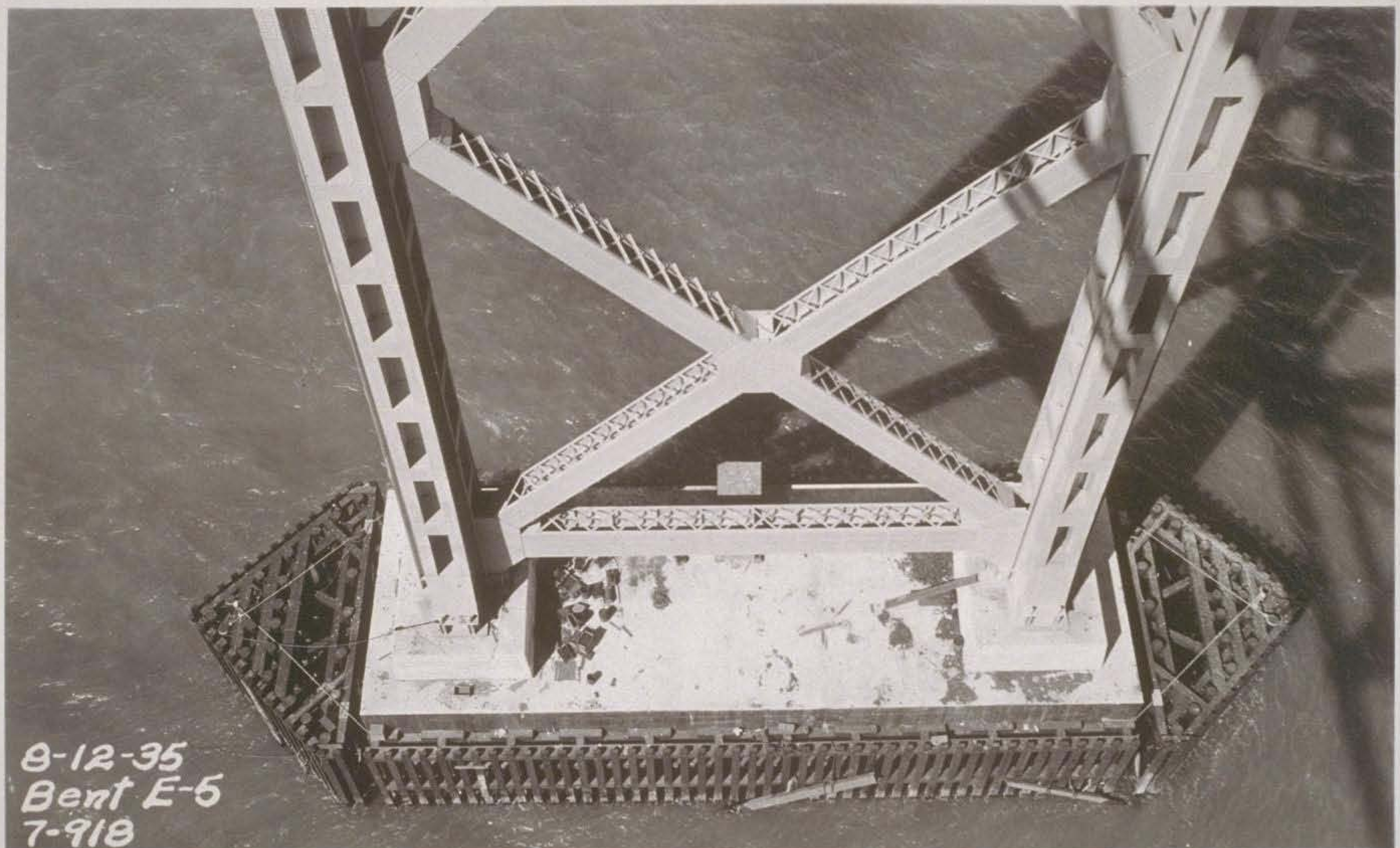
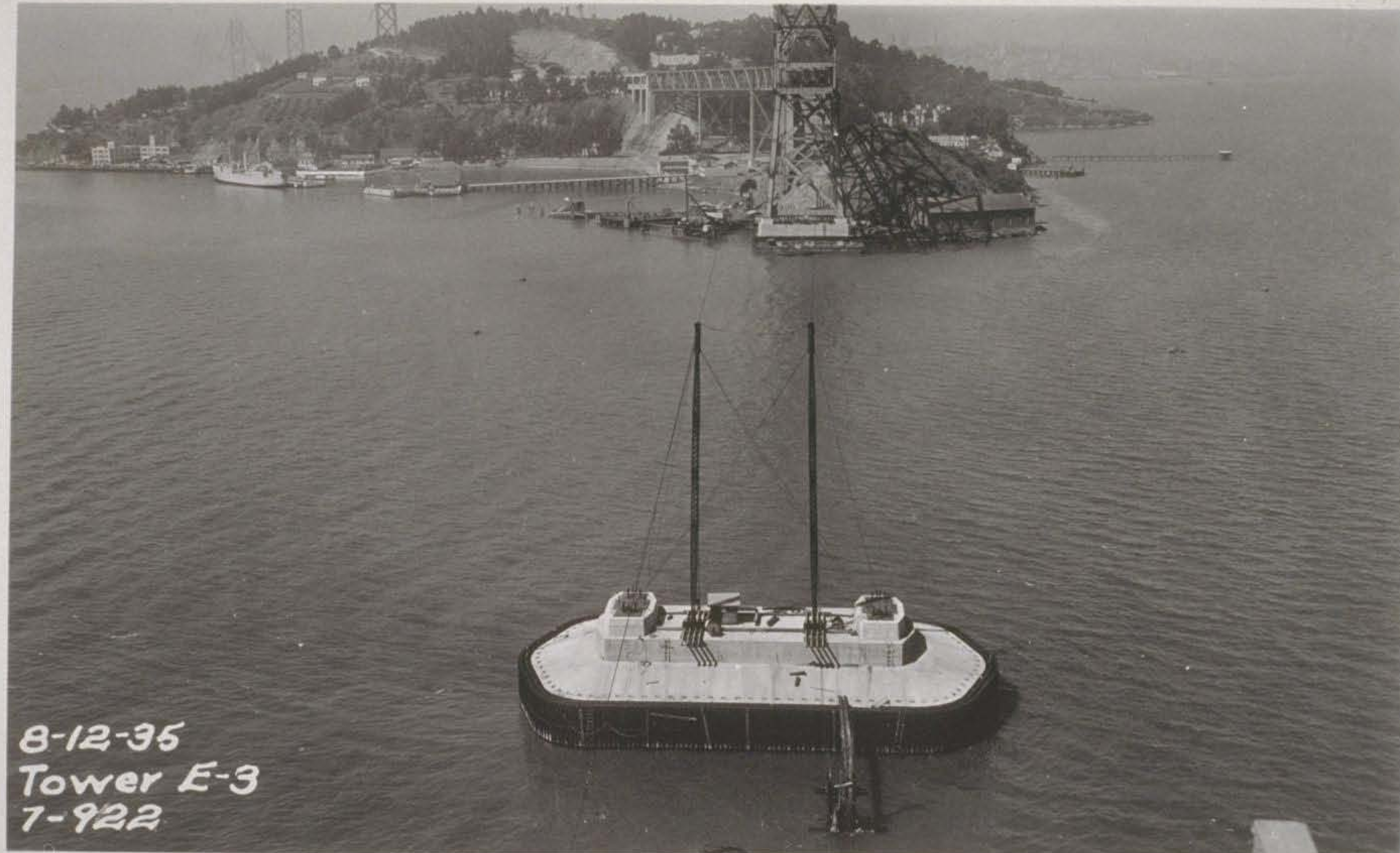
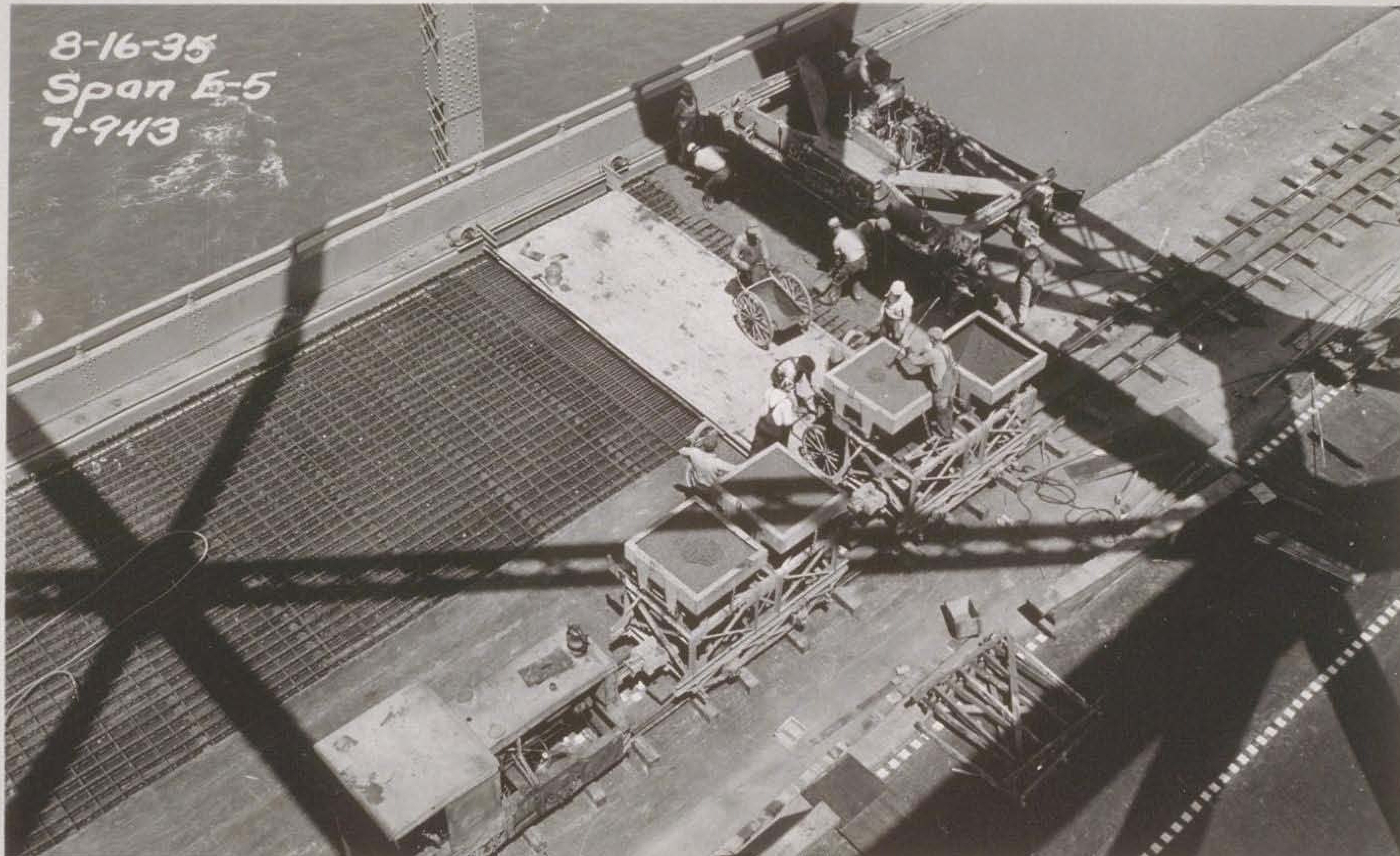



8-12-35
Tower E-3
7-922

277


8-16-35
Span E-5
7-941


8-16-35
Span E-5
7-943

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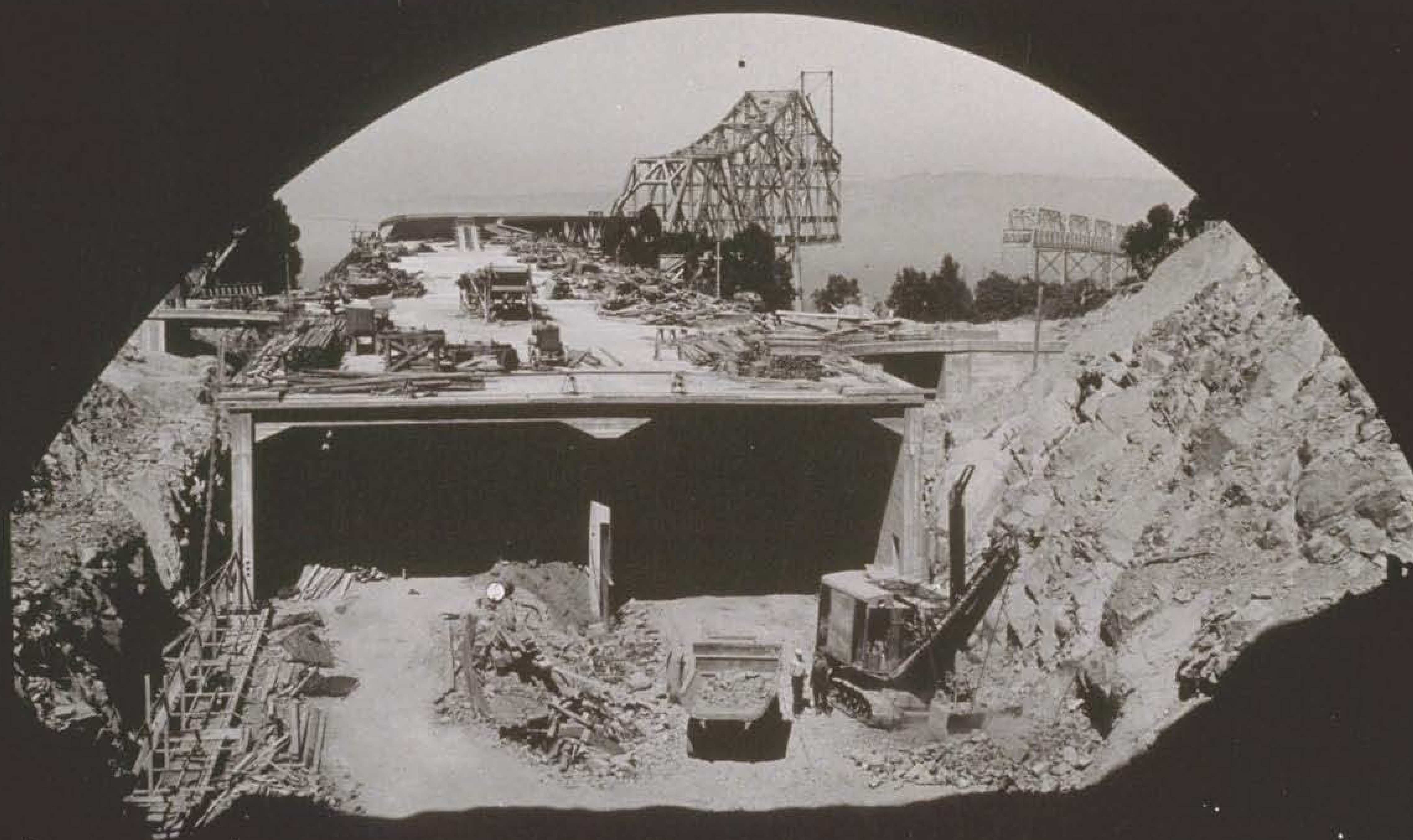
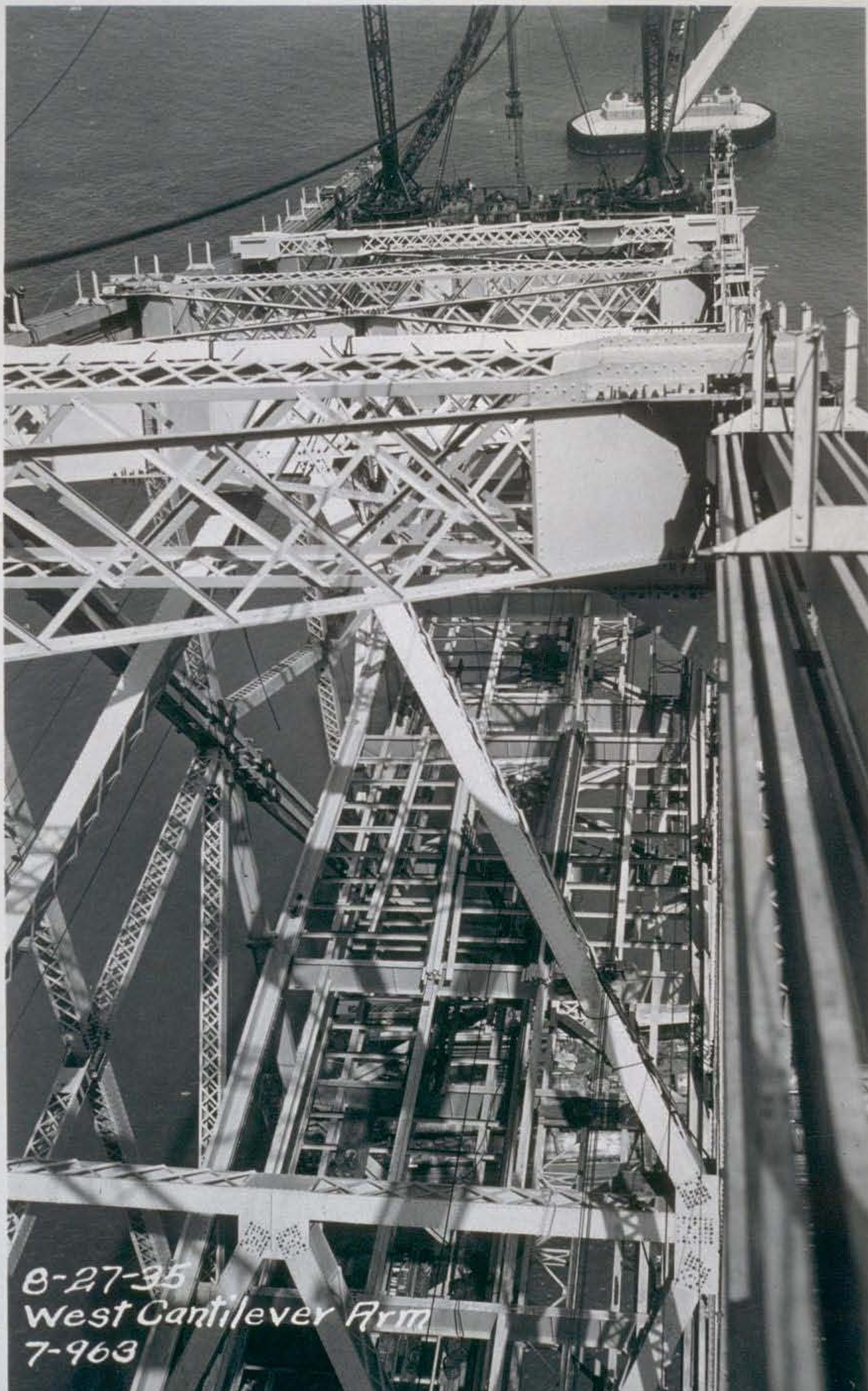
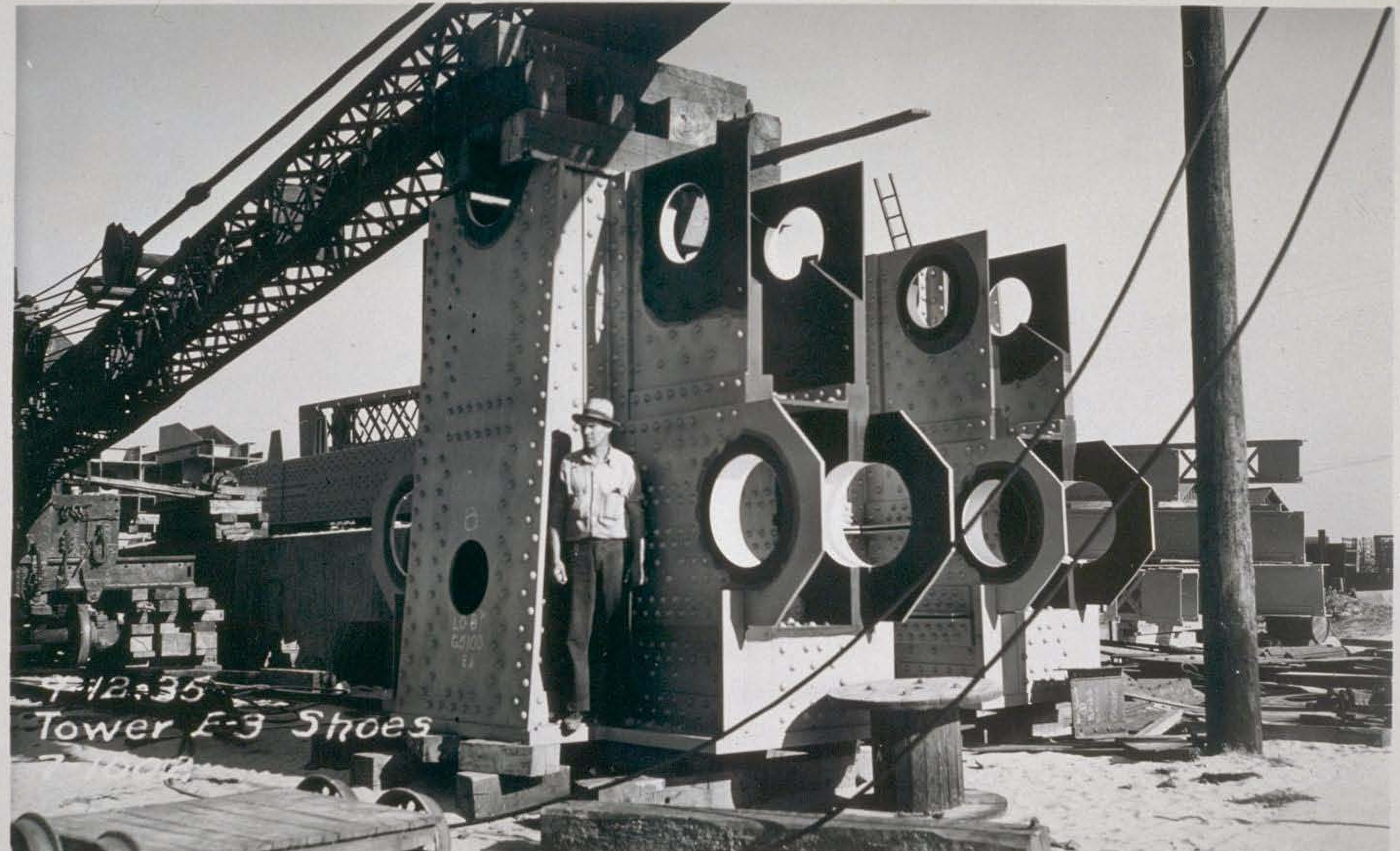


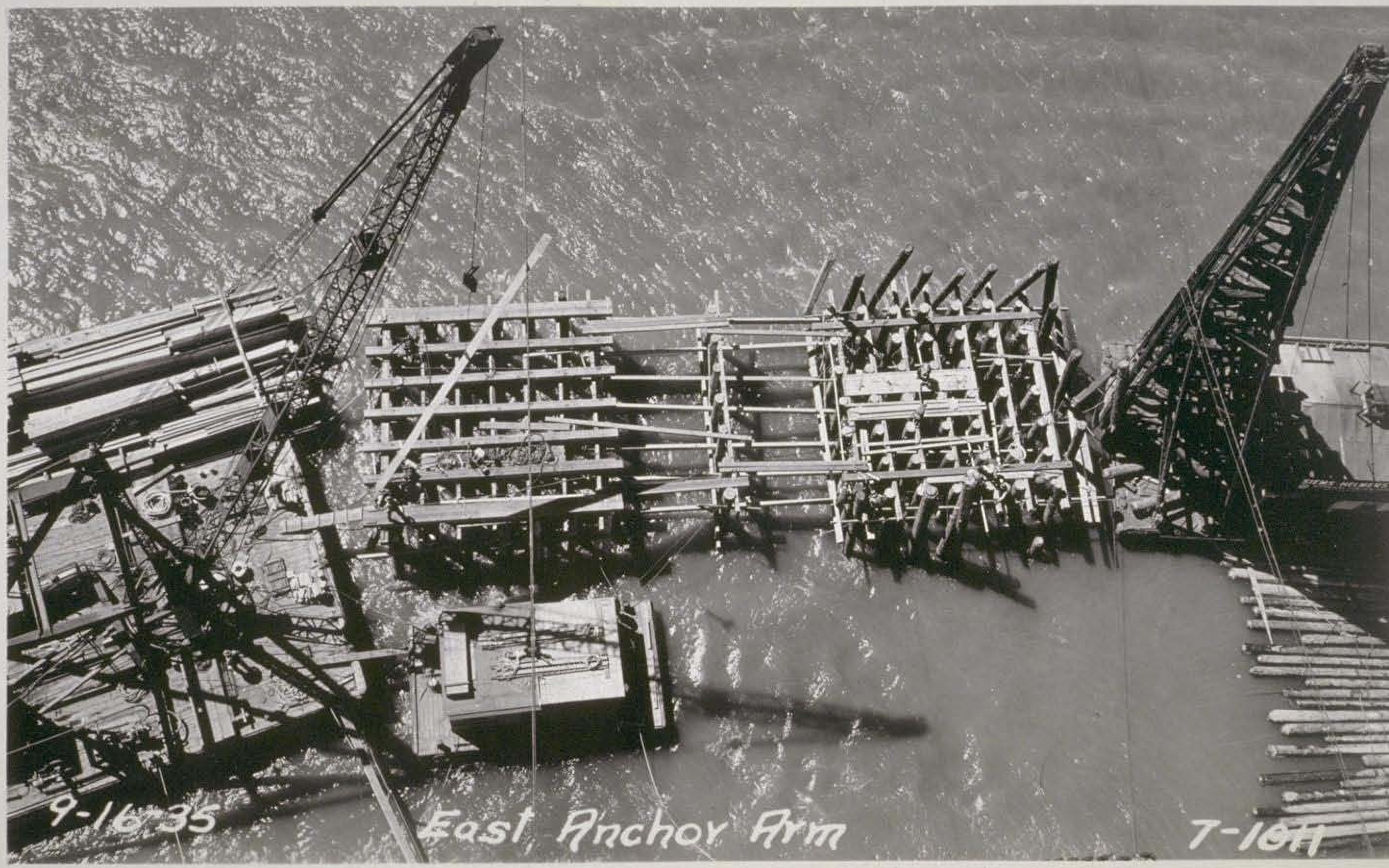
8-19-35 Cantilever Span 7-950


8-27-35
West Cantilever Arm
7-963


8-30-35
Span E-5
T-980

306




9-16-35
East Anchor Arm
7-1011

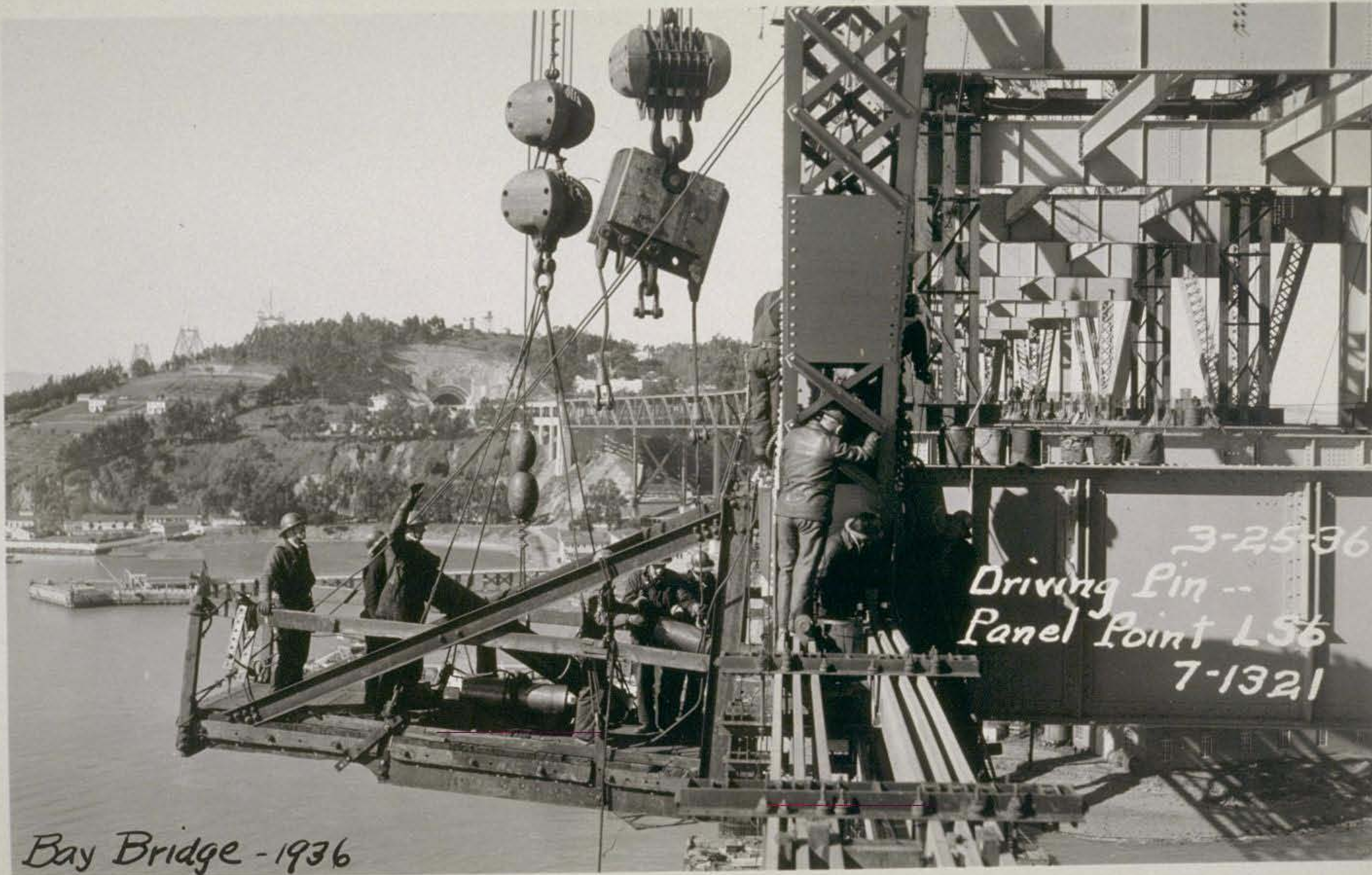

9-20-35
East Bay
7-1027

360

365

Bay Bridge - 1936

377




379
3-25-36 Pump and South Jack--West Arm 7-1333

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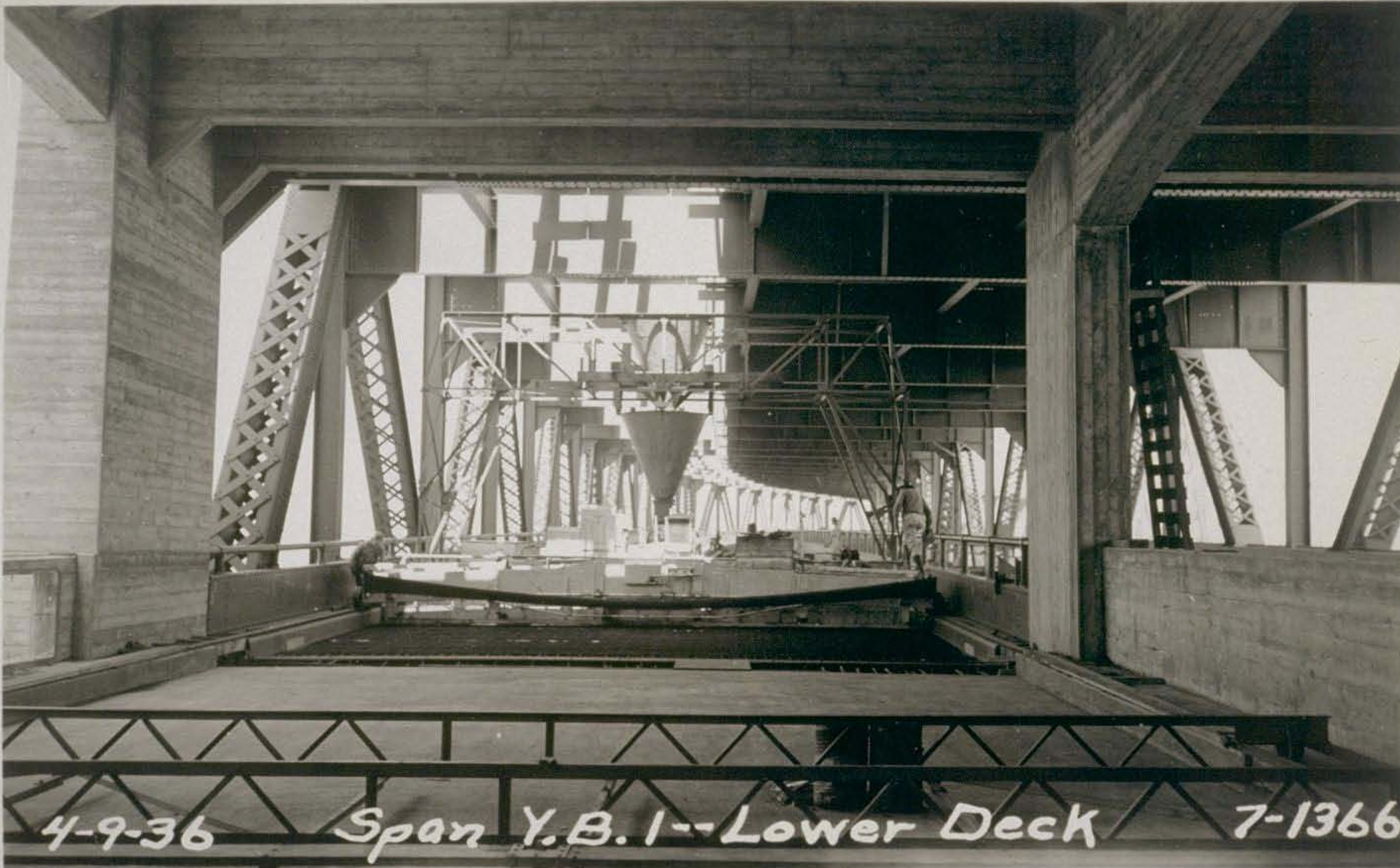
4-9-36 Span Y.B.1 -- Lower Deck 7-1366


4-9-36
Span Y.B. 1 --
Upper Deck
7-1367


4-9-36
Span Y.B. 4--
Upper Deck
7-1372

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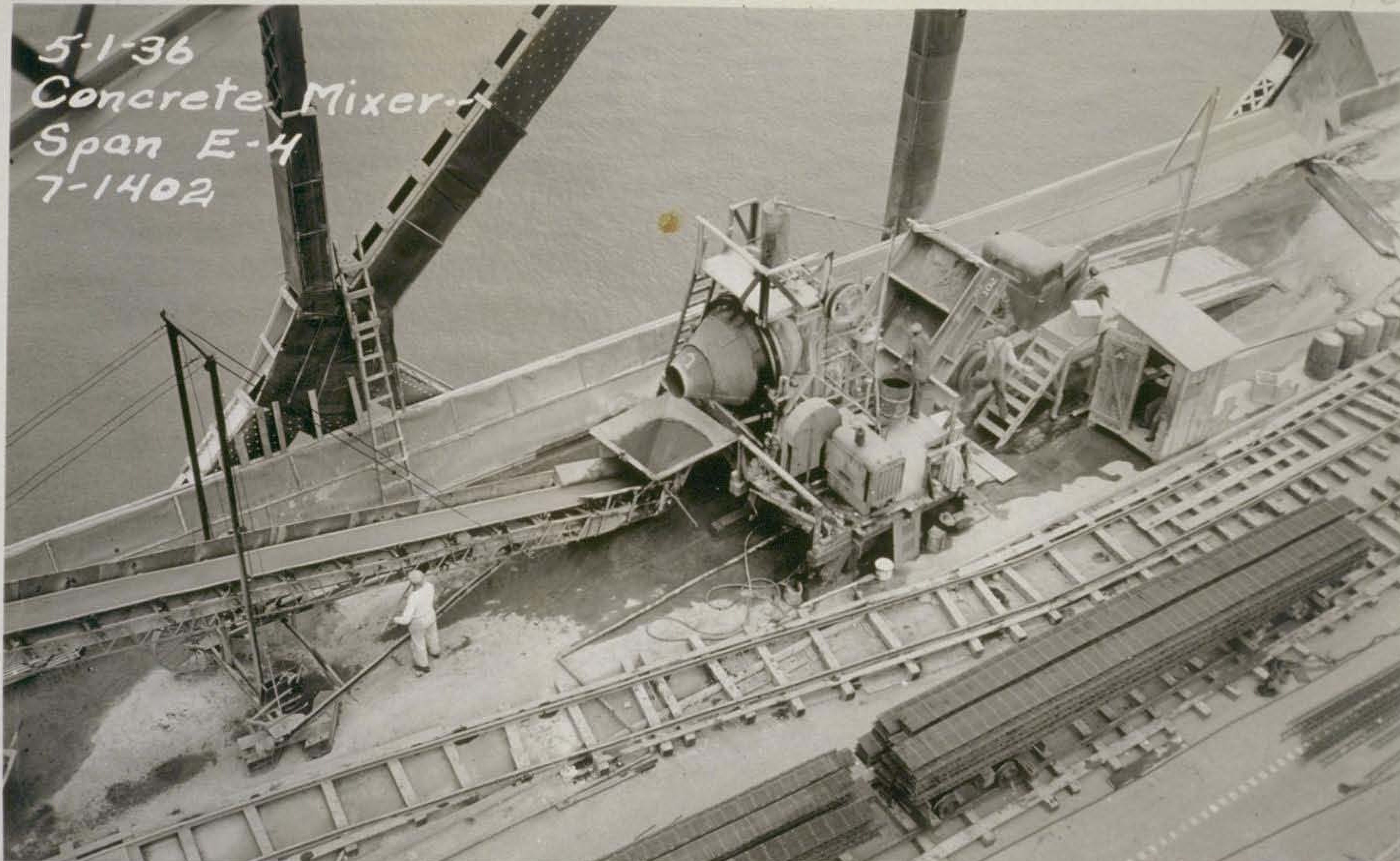
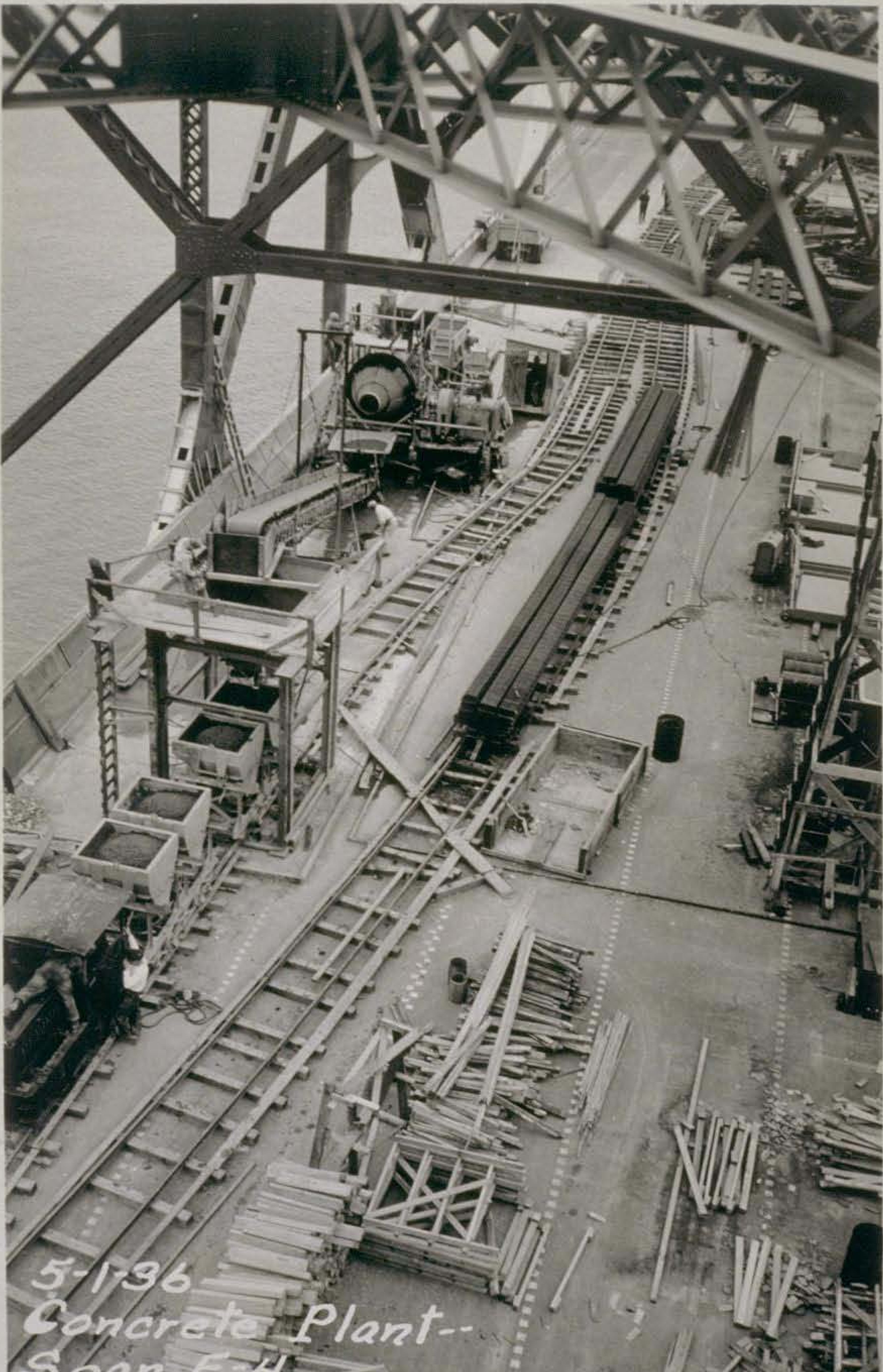



5-1-36
Hauling Train--Span E-4
7-1404
401


5-1-36
Concrete Plant--
Span E-H
7-1405

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5-27-36 Centilever Span-- "First Car" 7-1462