Bridge Research at the AASHO Road Test

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The AASHO Road Test includes 16 single-lane, single-span highway test bridges located in the regular traffic lanes of loops C and D, the heaviest traffic loops. Eight steel I-beam bridges, four designed to the yield point stress of the steel and four to 27,000 psi, are included, along with four conventional and four prestressed concrete bridges. This report summarizes the construction of the bridges, completed in 1957, the construction control program, instrumentation for the bridges, and plans for the research programs before, during and after the regular test traffic phase of the road test.

● THE NEED to protect investments in existing bridges against the increasing traffic loads and the desire to achieve further economies in the increasing volume of new construction led to the idea of investigating bridge performance under a large number of applications of overstress. The test road sponsored by the American Association of State Highway Officials presented an excellent opportunity for such a study under controlled traffic conditions.

After early discussions in the AASHO Committee on Bridges and Structures, the Highway Research Board Committee on Bridges developed the basic concepts for the research program. The program was reviewed by the working committee in charge of planning the test road at its July 1952 meeting. On the recommendation of the working committee, the chairman of the Committee on Bridges appointed a subcommittee to plan the bridge investigation and to design the test structures. The resulting designs, including eight steel and eight concrete bridges, became a part of the AASHO Road Test.

The investigation has two principal objectives: (a) to determine the behavior of certain short-span highway bridges under repeated applications of overstress; and (b) to determine the dynamic effects of moving vehicles on the short-span highway bridges.

The first objective deals with the fatigue life of structures subjected to repeated high stresses and with the manner in which distress occurs. Observations of cumulative effects of the repeated overstress and correlation of the observed behavior with the available information are the principal means for reaching this objective.

The second objective is concerned with the behavior under a range of loads. It involves primarily the correlation of observed dynamic effects with those predicted by mathematical analyses. Deflection and strain data obtained from the test bridges should provide an experimental check on the assumptions of the analyses.

The test bridges are located on the test road loops C and D (Fig. 1) subjected to the heaviest truck loads. There are 16 bridges placed in groups of four on straight tangents outside the pavement test sections (Fig. 2). Each location contains four simple span 1-lane bridges. The bridges at two locations are made with steel beams; at one location, with prestressed concrete beams; and at one location, with reinforced concrete beams.

The cost of the bridge research at the AASHO Road Test is estimated to be $470,000, including the construction contracts and the direct expenditures for research.

DESIGN FEATURES

Typical bridge cross-sections are shown in Figure 3. Each bridge consists of three simply supported beams on a 50-ft span and a reinforced concrete slab 6½ in. thick and 15 ft wide. The slab is separated from the adjacent bridges and the back wall of the abutment by 1-in. clear space. The slab is provided with a 12- by 12-in. timber guard bolted to the outside edge.

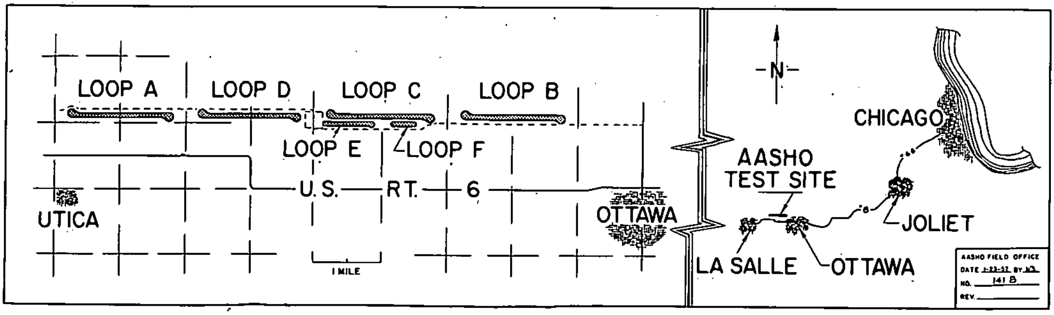


Figure 1. Location of AASHO Test Road.

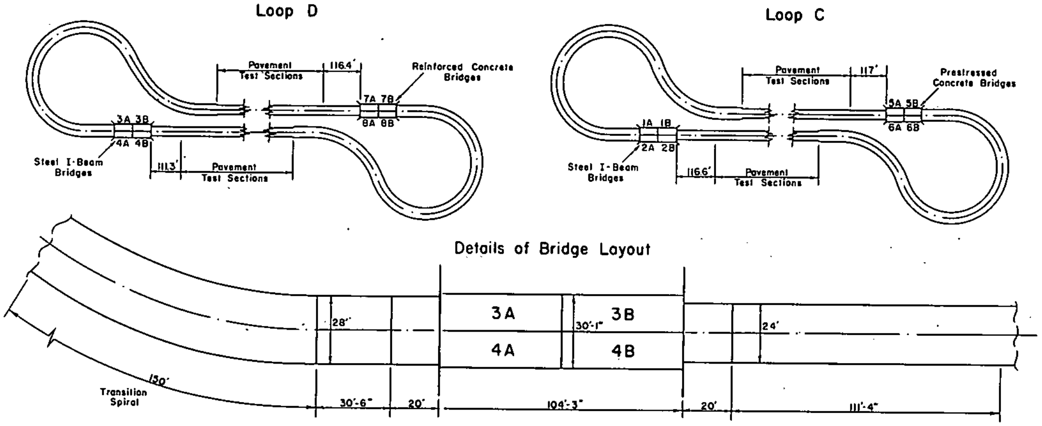


Figure 2. Bridge locations.

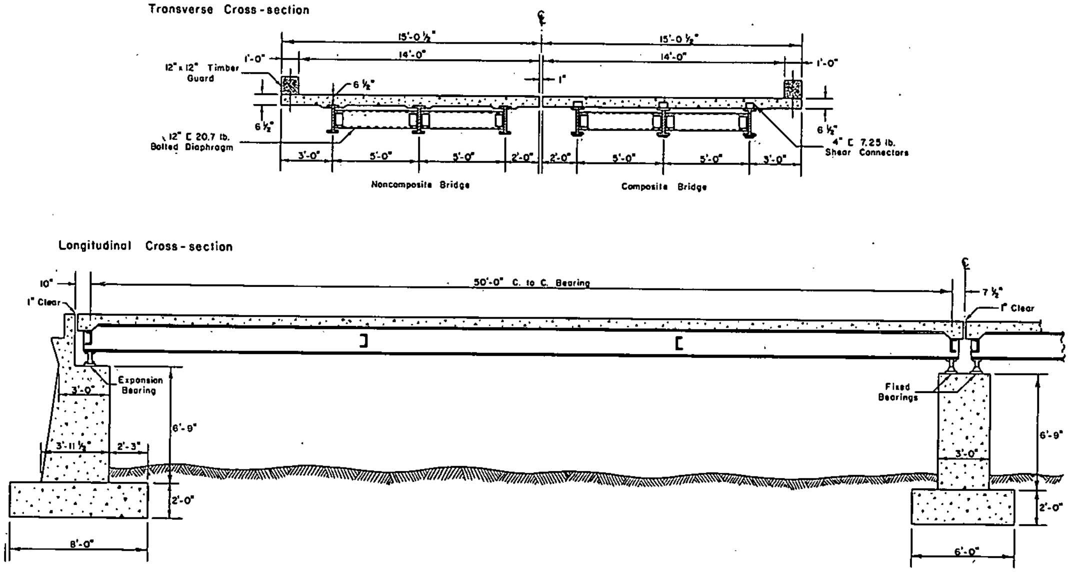
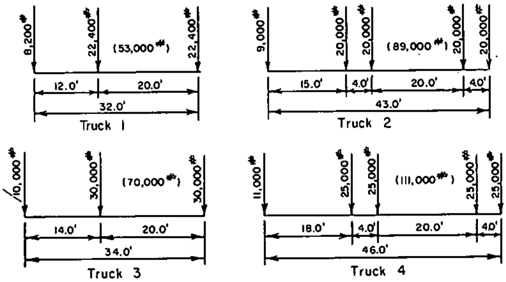


Figure 3. Cross-sections of steel bridges.

Criteria for Design

The design of the test bridges was based on two basic requirements: (a) the project is limited to the study of the flexural behavior of the principal load carrying members, that is, of beams; (b) the beams are to be subjected to the selected stress level on each passage of the test vehicle.

To obtain the chosen stresses in the tests, it was essential to base the designs of beams on actual moments caused by the test vehicle rather than on conventional moments obtained by the usual design procedures given in the AASHO standard specifications for highway bridges. On the other hand, the designs of the slabs, web reinforcement, and miscellaneous details were based on more or less conventional analyses.



Loads shown are design axle loads in pounds

Figure 4. Diagrams of design trucks.

Four different types of trucks were used in the design (Fig. 4). The axle loads and spacings shown in the figure represent approximately the properties of the actual test vehicles (1, 2). Trucks of types 1 and 2 will operate on loop C; trucks of types 3 and 4 will operate on loop D. The tandem axle vehicles will operate on the outside lanes and the single axle vehicles on the inside lanes.

Beams. The design criteria for beams are summarized in Table 1. The factors for distribution of the static moment to the slab and the individual beams were obtained from an elastic analysis. The exact properties of the actual test vehicles are not yet available. Minor differences in the front axle loads and in the spacing of axles are expected. The rear axle load for truck 4 was changed from 25,000 to 24,000 lb. Table 1 includes the distribution factors for the center beam moment only, because calculations have shown that the stresses in the center beam governed the design. The impact factors were estimated on the basis of theoretical studies of the effect of smoothly rolling loads. In addition to the effect of smoothly rolling load, the so-called roll effect was

TABLE 1

DESIGN CRITERIA FOR BEAMS

Bridge		Design Truck	Distribution Factor,[a] %	Impact Factor, %	Composite Action,[b] %	Governing Design Stress	
No.	Type					Location	Allowable Value, psi
1A	Steel, noncomposite	1	30.0	10	10	Bottom fiber	27,000
1B	Steel, noncomposite	1	29.4	10	10.	Bottom fiber	35,000
2A	Steel, noncomposite	2	29.3	10	10	Bottom fiber	35,000
2B	Steel, composite	2	32.6	10	100	Bottom fiber	35,000
3A	Steel, noncomposite	3	30.6	10	10	Bottom fiber	27,000
3B	Steel, composite	3	33.0	10	100	Bottom fiber	27,000
4A, 4B	Steel, noncomposite	4	30.4	10	10	Bottom fiber	35,000
5A	Prestressed concrete, post-tensioned	2	32.2	8	100	Bottom fiber	800
5B	Prestressed concrete, post-tensioned	2	33.3	8	100	Bottom fiber	300
6A	Prestressed concrete, pretensioned	1	33.3	2	100	Bottom fiber	800
6B	Prestressed concrete, pretensioned	1	32.9	2	100	Bottom fiber	300
7A, 7B	Reinforced concrete	4	32.9	4	100	Tension steel	40,000
8A, 8B	Reinforced concrete	3	32.9	0	100	Tension steel	30,000

[a] Ratio of design moment for center beam to total static moment.

[b] Interaction between slab and beam; partial interaction taken into account by proportional decrease of effective slab width.

considered in the design of edge beams. The roll effect should not be present for the center girder since the trucks will straddle the center beam.

Two of the steel bridges and all concrete bridges were designed for complete interaction between the slab and the beams. In the remaining six steel bridges 10 percent composite action was assumed to account for the effects of friction between the slab and the steel beam. This partial interaction was taken into account by proportional reduction of the effective slab width.

The design of steel beams was based on the moment of inertia method. Two stress levels were chosen for the steel structures: tension of 27,000 and 35,000 psi. The first was chosen as a high stress level which is not likely to result in fatigue failures. The second may lead to fatigue failures especially in bridges with tension cover plates.

The design of prestressed concrete beams was based on the moment of inertia of uncracked sections. Tensile stress of 300 or 800 psi was the governing factor; the designs followed the BPR Criteria (3) in all other aspects. It is expected that the higher tensile stress will cause cracking of concrete on the first application of load so that the tests should furnish information on the fatigue behavior of cracked prestressed concrete beams. . The lower stress level will permit a study of the effect of repeated loading on cracking of prestressed concrete beams.

TABLE 2

DESIGN CRITERIA FOR SLABS

Bridge Type	Design Truck	Moment M/PL[a]	Distribution Factor, ft	Impact Factor, %	Allowable Stress, psi	
					Concrete	Steel
Steel	4	±0.256	0.36L + 2.58	30	1,200	18,000
Prestressed and reinforced concrete	4	±0.200	0.36L + 2.58	30	1,200	18,000

[a] For design of transverse reinforcement.

The reinforced concrete beams were designed by the straight line, cracked section theory for tension stresses of 30,000 or 40,000 psi in the steel. The effect of repeated loading on the crack width and spacing, and the fatigue behavior of the reinforcing steel are of primary interest.

Slabs. Slabs for all bridges were designed of the same thickness. The reinforcement for each type of bridge—steel bridges, prestressed concrete bridges and reinforced concrete bridges—was designed for the heaviest trucks. The moment coefficients (Table 2) include an allowance for the deflections of beams. The distribution factor, impact factor and allowable stresses follow the AASHO specifications (4).

Web Reinforcement. The design of web reinforcement was based on the nominal shearing stress. The spacing of stirrups was computed from

$$s = \frac{A_s \text{ x } f_s}{v^1 \text{ x } b} \tag{1a}$$

and

$$s = \frac{A_s \text{ x } f_y}{v_u^1 \text{ x } b} \tag{1b}$$

in which s = spacing of stirrups;
A_s = area of stirrups;
b = beam width;
f_s = allowable stress = 20,000 psi; and
f_y = yield point of stirrups = 44,000 psi.

The nominal shearing stresses for the design of web reinforcement were computed from the following:

$$v^1 = \frac{V_{LL} + V_{DL}}{b\,j\,d} - 150 \tag{2a}$$

or

$$v_u^i = \frac{k\ V_{LL} + V_{DL}}{b\ j\ d} - 200 \qquad (2b)$$

The numerical factor k is the overload factor shown in Table 6.

Shear Connectors. The shear connectors for the composite steel bridges were designed according to the 1956 revisions of the AASHO specifications. The factor of safety in the specifications is based on the allowable stress of 18,000 psi. It was necessary, therefore, to modify the equations for the factor of safety as follows (5):

$$F.S. = 1.45 \frac{f_y}{f_s} (1 + C_{mi}\, C_{ms}) - C_{mi} \qquad (3)$$

in which f_y = yield point of beam steel = 33,000 psi but not less than f_s;
f_s = design stress; and
$C_{mi} C_{ms}$ = coefficients explained in the AASHO specifications.

Ultimate Moment Capacities. Ultimate moment capacities were computed for center beams of all bridges. These moments were used in calculations of the overload factors.

For noncomposite steel bridges, the slab and beam were assumed to deform independently. The stresses in the steel beam were taken equal to the yield point value f_y = 33,000 psi and the computation of the moment capacity was based on the fully plastic stress distribution. The capacity of the slab was computed for the yield point stress of reinforcement f_y = 44,000 psi and the concrete strength f'_c = 4,000 psi (6).

Full composite action was assumed for the composite steel bridges. The yield point of the structural steel was taken as 33,000 psi and the strength of concrete as 4,000 psi in the computations of the ultimate moment capacity (7).

Equations for the ultimate moment capacity (3) were used for prestressed beams. The calculations were based on the strength of prestressing steel f'_s = 250,000 psi. Complete interaction between the slab and the beam was assumed.

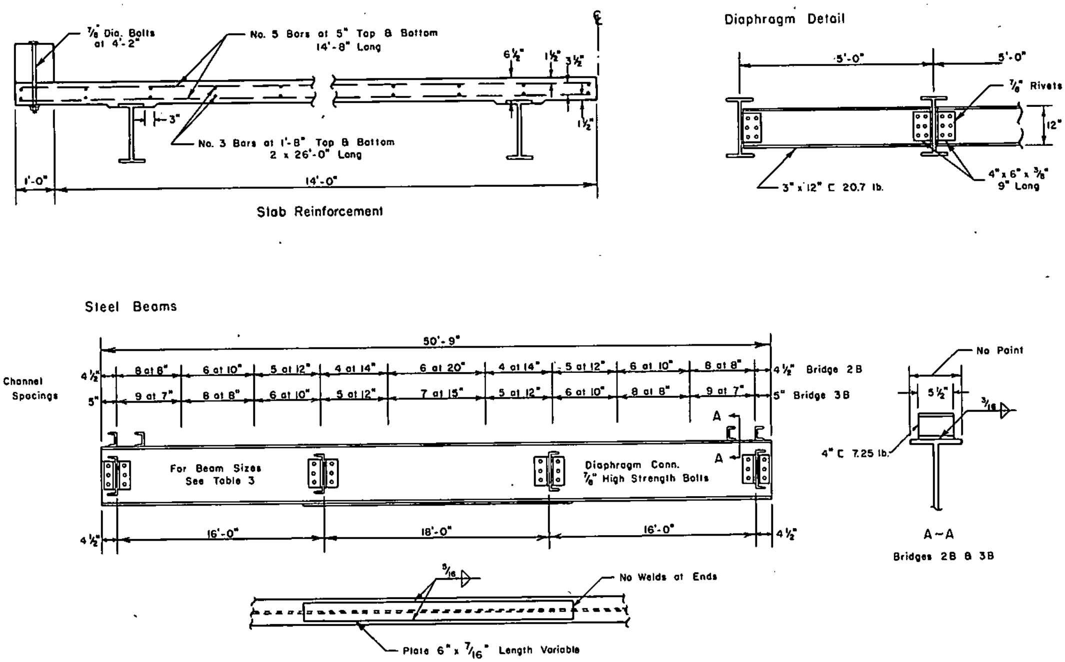


Figure 5. Details of steel bridges.

The ultimate moment capacity of reinforced concrete T-beams was computed for the yield point of reinforcement f_y = 44,000 psi and concrete strength f'_c = 3,000 psi. The same equations were used as for the slabs of noncomposite steel bridges.

TABLE 3

BEAMS AND COVER PLATES[a] FOR STEEL BRIDGES

Bridge	Beam Size	Length of Cover Plate	Bridge	Beam Size	Length of Cover Plate
1A	18WF55	20 ft 6 in.	1B	18WF50	0
2A	18WF55	0	2B	18WF50	14 ft 0 in.
3A	21WF62	0	3B	18WF60	18 ft 6 in.
4A	18WF60	19 ft 0 in.	4B	18WF60	19 ft 0 in.

[a] All cover plates are 6 x 7/16 in.

Steel Bridges

The details of the steel bridges are shown in Figures 3 and 5; additional data, in Tables 3 and 4. The roadway is made of a concrete slab with no crown and placed at a 0.2 percent longitudinal slope. The reinforcement of the slab (Fig. 5) is the same for all steel bridges. In noncomposite bridges 3-in. concrete haunches provide lateral support for the top flange of the steel beams. In composite bridges the bottom of the slab is flush with the top surface of the I-beams throughout the full width.

TABLE 4

VARIABLE DIMENSIONS OF BEARING SHOES

Bridge Type	A	B	C	R	X
Steel	7½ in.	9½ in.	1 ft 4 in.	5¾ in.	7/8 in. ϕ SF bolts
Prestressed concrete	1 ft 5 in.	9 in.	2 ft 2 in.	5¼ in.	1 x 3/8 in. straps
Reinforced concrete	11½ in.	9 in.	1 ft 8½ in.	5¼ in.	1 x 3/8 in. straps

The slab is supported on three steel beams spaced at 5 ft. In five bridges a steel cover plate is welded on the tension flange. No cover plate was necessary on the compression flange because of the 10 percent composite action assumed to exist between the concrete slab and the steel beam. Beams for bridge 1B had a 3-in. camber at midspan and beams for all remaining bridges had a 2-in. camber. The surface of all beams was treated with one coat of red lead paint except for the top surface of the composite beams which was left as rolled. In addition, the top surfaces of the I-beams for noncomposite bridges were covered with two coats of bond-preventing agent.

The slab is connected to the beams by flexible channel shear connectors welded to the top flange of the I-beam with continuous transverse welds. The steel bridges are provided with diaphrams near the third points and at the ends.

The beams are supported on steel bearings shown in Figure 6 and described in Table 4. In each bridge the fixed bearing is placed on the center pier and the expansion rocker on the end abutment. A 7- by 16- by ⅛-in. fabreeka pad provides for distribution of the load from the bearing to the substructure. The bearing is fastened to the substructure with two swedge bolts of 1¼-in. diameter set in cement grout.

The center pier and end abutments are identical for all bridge structures. They rest on spread footings. The dimensions of the substructures (Fig. 3) were dictated in part by the necessity of access to the underside of bridges.

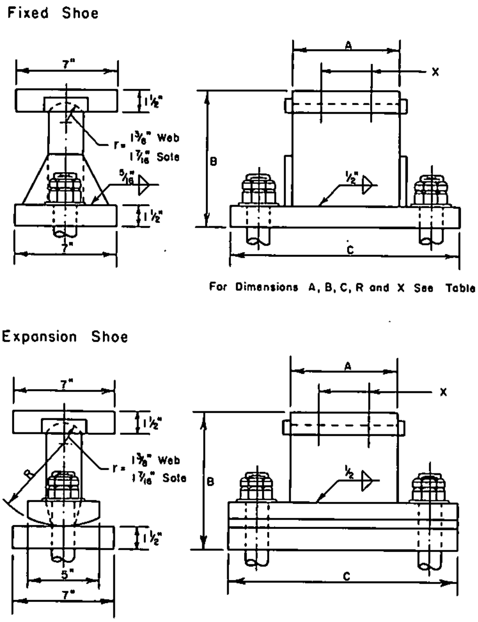


Figure 6. Details of bearing shoes.

Prestressed Concrete Bridges

The details of prestressed concrete bridges are shown in Figures 7, 8, and 9. The dimensions and slope of the slab are the same as for steel bridges. The reinforcement is shown in Figure 7.

The slab rests on three prestressed concrete I-beams spaced at 4 ft 8 in. and imbedded approximately 1 in. in the slab. The post-tensioned beams for bridges 5A and 5B are reinforced with parallel wire cables. Each cable is made of ten 0.192-in. diameter wires and a flexible metal sheathing. The cables are anchored with Freyssinet cone anchorages. The pretensioned beams for bridges 6A and 6B are reinforced with 3/8-in. 7-wire strands anchored by bond. The web reinforcement consisting of two No. 3 vertical stirrups is the same in all prestressed concrete beams. Each beam is provided with end blocks.

Recessed keys in the beams and extensions of stirrups provide connection between the slab and the beam. Cast-in-place diaphrams reinforced with three No. 6 tension bars and No. 3 closed stirrups placed at 10 in. are provided at each end of the bridge.

The beams rest on bearing shoes (Fig. 6 and Table 4). The bearing shoes are supported on substructures in a manner identical with that for steel bridges.

Reinforced Concrete Bridges

The details of the reinforced concrete bridges are shown in Figures 10 and 11. The slab and beams were cast monolithically. The slab reinforcement (Fig. 10) is identical for all four concrete bridges.

The beams are spaced at 4 ft 8 in. The tension reinforcement of the beams is placed in two layers. The beams are reinforced with No. 3 vertical U-Stirrups except in the center 21 ft 2 in. where no web reinforcement is provided.

The diaphrams, bearing shoes and substructures for reinforced concrete bridges are the same as for prestressed concrete bridges.

Design Stresses

The design stresses for the steel bridges are summarized in Table 5. Two values are given at each location: the dead load stress representing the minimum stress; and

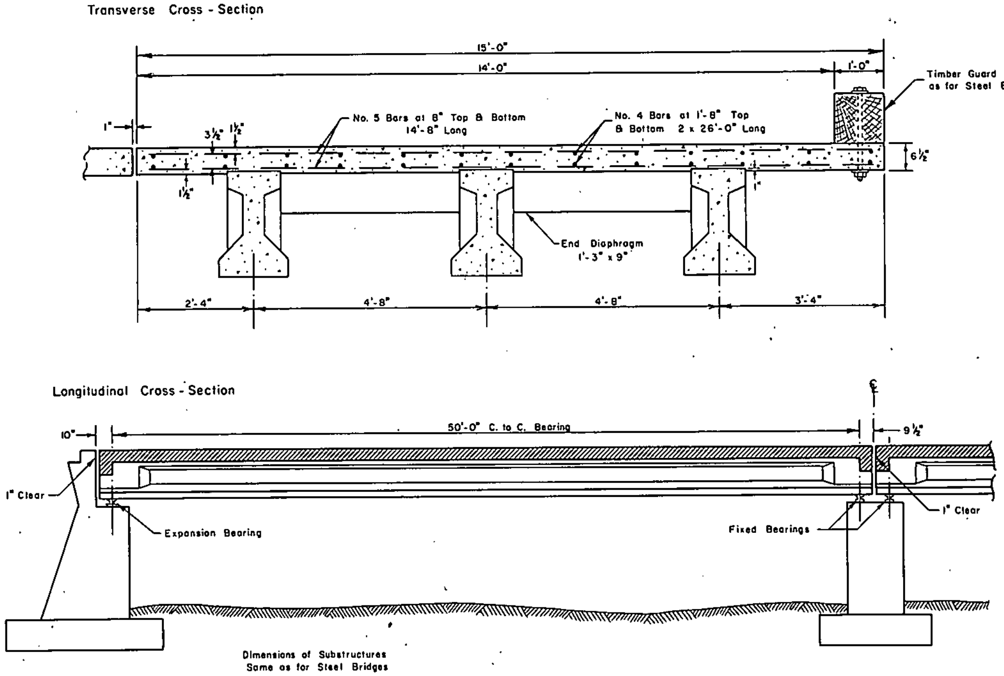


Figure 7. Cross-sections of prestressed concrete bridges.

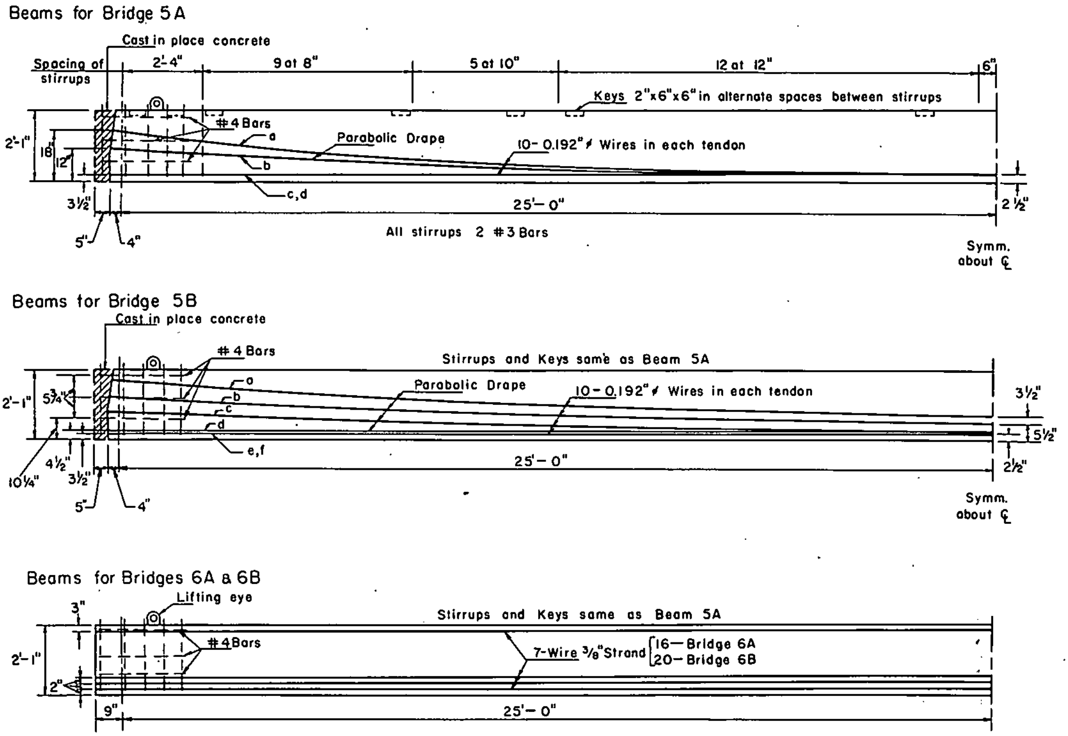


Figure 8. Reinforcement of prestressed beams.

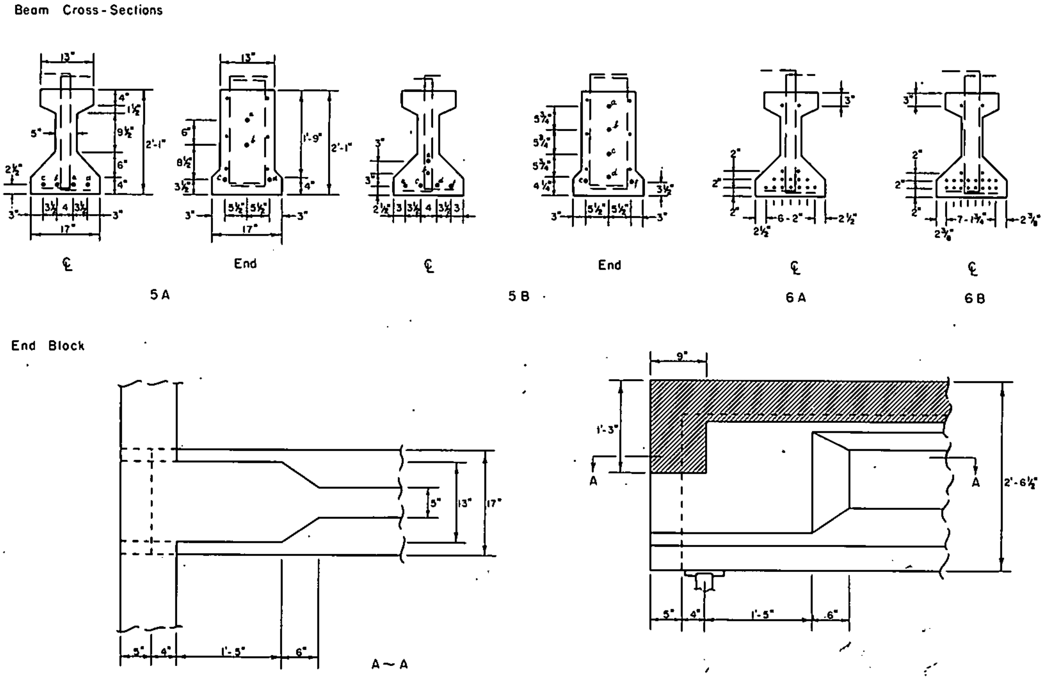


Figure 9. Details of prestressed concrete bridges.

the total stress (including dead load, live load and impact) which represents the maximum stress. The difference between the dead load and total stress represents the fluctuation of stress to which the bridges will be subjected under the test traffic. Bridges 4A and 4B will be subjected to the most severe stress conditions.

The design stresses for concrete bridges are summarized in Table 6. For prestressed concrete bridges both initial and final stress values are shown. The final stresses for prestressed bridges include an estimate of the effects of creep of concrete

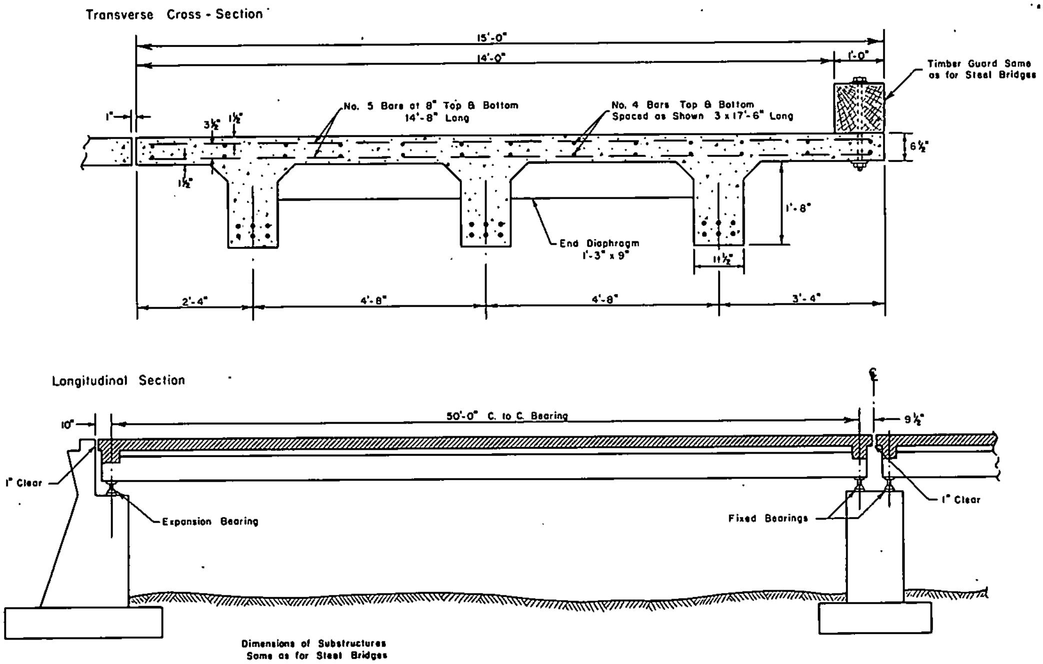


Figure 10. Cross-sections of reinforced concrete bridges.

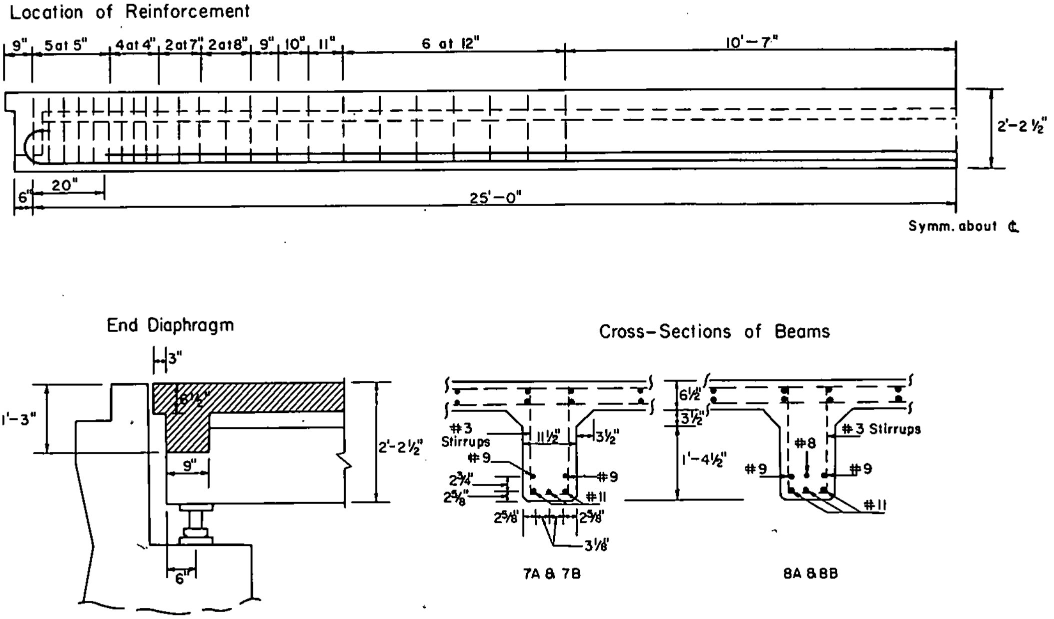


Figure 11. Details of reinforced concrete bridges.

TABLE 5

SUMMARY OF DESIGN STRESSES FOR STEEL BRIDGES

Bridge	Maximum Longitudinal Stress in Concrete, psi		Bottom Fiber Stresses in Steel Beams, psi						Overload Factor $\frac{M_u - M_{DL}}{M_{LL}}$
			At Theoretical End of Cover Plate[a]				Near Midspan		
			Unreinforced Beam		Reinforced Beam				
	DL[b]	Total[c]	DL	Total	DL	Total	DL	Total	
1A	0	-154[d]	15,420	27,025	11,370	20,060	13,250	23,000	1.67
1B	0	-176	-	-	-	-	21,090	34,800	1.04
2A	0	-240	-	-	-	-	17,220	35,010	0.99
2B	0	-680	18,400	35,000	13,510	26,000	14,060	26,800	2.47
3A	0	-180	-	-	-	-	13,610	27,330	1.61
3B	0	-550	14,660	26,940	11,310	20,950	12,470	22,800	3.54
4A, 4B	0	-275	14,500	34,735	11,225	28,430	12,185	28,430	1.01

[a] Each cover plate extends 1 ft beyond the theoretical end.
[b] Stress due to dead load.
[c] Stress due to dead load, live load and impact.
[d] Minus sign denotes compressive stress.

TABLE 6

SUMMARY OF DESIGN STRESSES FOR CONCRETE BRIDGES

Bridge		Maximum Longitudinal Concrete Stress Near Midspan, psi						Maximum Steel Stress Near Midspan, psi		Overload Factor $\frac{M_u - M_{DL}}{M_{LL}}$
		Top of				Bottom of Beam				
		Slab		Beam						
		DL[a]	Total[b]	DL	Total	DL	Total	DL	Total	
5A	Initial[c]	0		-230		-1,170		162,300		
	Final	0	-416[d]	-1,426	-1,610	-48	820	146,200	150,600	2.09
5B	Initial	0		-252		-2,025		176,200		
	Final	0	-530	-1,483	-1,742	-625	346	147,100	152,200	3.09
6A	Initial	0		-697		-1,051		172,700		
	Final	0	-317	-1,843	-2,025	147	828	144,400	148,100	2.16
6B	Initial	0		-565		-1,680		184,200		
	Final	0	-283	-1,745	-1,870	-293	310	147,300	150,000	3.64
7A, 7B		-800	-1,740					18,300	40,000	1.38
8A, 8B		-710	-1,318					16,700	30,900	2.25

[a] Includes the effects of prestress and dead load.
[b] Includes the effects of prestress, dead load, time, live load and impact.
[c] Stress before placing of the slab.
[d] Minus sign indicates compressive stress.

and relaxation of prestressing steel. The test traffic will start at least six months after the completion of the last bridge structure. Accordingly, the final stress values in Table 6 are the best indicator of the expected minimum and maximum stress levels at the beginning of the test traffic.

Tables 5 and 6 include overload factors for the center beam of every bridge expressed as the number of live loads required for failure by yielding of steel combined with crushing of concrete. The computed overload factor is equal to 1.0 for noncomposite steel bridges designed for $f_s = 35,000$ psi; the actual overload factor is slightly higher because some interaction may be expected to be present between the slab and the beam, and strain hardening may occur in the steel beam. The overload factor is in excess of 1.0 for all other bridges.

CONSTRUCTION

Progress of Construction

The work on the test bridges began in October 1956, with the excavations for substructures and placing of foundations for pier and abutments. The work on substructures was completed in the spring of 1957 and was followed by the erection of superstructures.

Construction of the superstructures began with the erection of the structural steel (Fig. 12). To satisfy the design assumptions, the top surfaces of the steel beams for noncomposite bridges were treated with two coats of a bond preventing agent. A mixture of 1 part graphite to 4.43 parts of linseed oil by weight was used for this purpose.

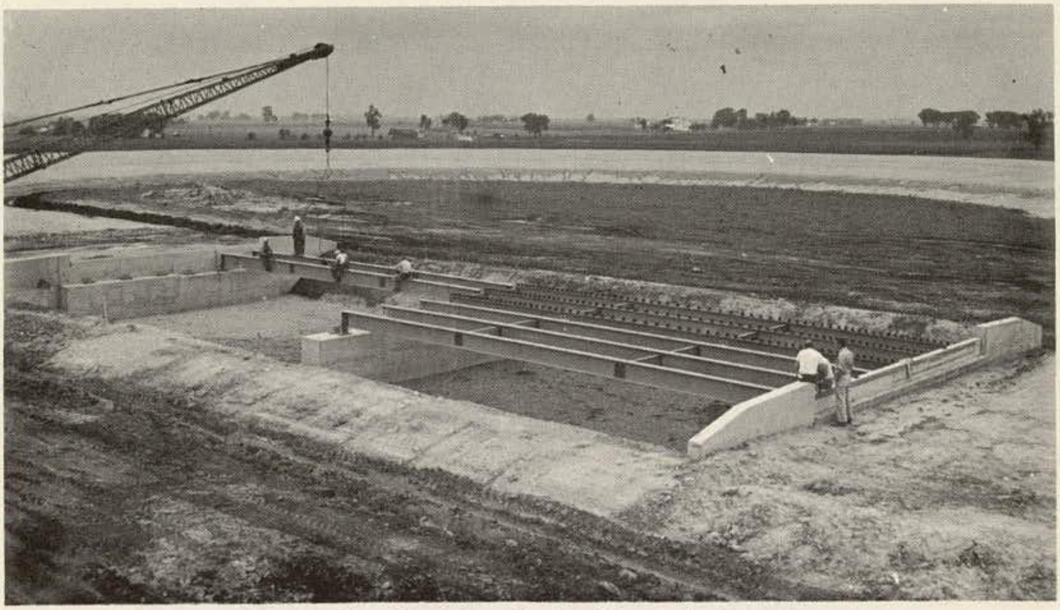


Figure 12. Erection of steel beams in Loop D.

The first coat was allowed to dry for 24 hours before application of the second coat and the second coat was applied at least three days before casting the concrete.

Plywood forms for the slabs of steel bridges were suspended from the beams independently for each bridge. All concrete slabs for steel bridges were cast in the first half of August.

The beams and slabs of each concrete bridge were cast in one operation. The formwork for each bridge was supported independently from the adjacent units. Concrete bridges were cast during August and the beginning of September.

The beams for the prestressed concrete bridges were manufactured in Springfield, Ill., and trucked to the bridge sites. The manufacture of the prestressed beams began in July but was discontinued because of difficulties with the prestressing equipment. Work was resumed at the end of September and completed by the end of November. The forms for the slabs, suspended from the prestressed beams independently for each bridge, were erected first for the bridges with pretensioned beams 6A and 6B. The slabs for these two bridges were cast at the end of November. Low temperatures prevented casting of the slabs for bridges 5A and 5B during the 1957 construction season.

Manufacture of Prestressed Beams

The prestressed concrete beams were cast in two sets of plywood forms erected on a fixed base. The pretensioned beams were made on a 150-ft prestressing bed permitting simultaneous manufacture of two beams. For each bridge, two outside beams were made simultaneously while the center beam was cast alone. Each post-tensioned beam was manufactured independently.

Concrete. Prestressed beams were made with type I portland cement furnished by one manufacturer. The aggregates were lake sand and crushed stone. The average fineness modulus of the sand was 2.67 and the maximum size of the crushed stone was 1 in. The sieve analysis for the sand and stone are given in Table 7. All concrete was made with air-entraining agent added at the mixing plant.

The concrete was designed for a nominal strength of 5,000 psi. The cement content, water content and mix proportions are given in Table 8. Approximately ¾ ounce of air-entraining agent were added per bag of cement; the amount was adjusted according to the control tests of air content. The air content varied from 3.1 to 5 percent. The average slump was 1½ in.

TABLE 7

GRADATION OF SAND AND STONE FOR PRESTRESSED BEAMS

Crushed Stone				Sand			
Sieve Size	Mean	% Retained Max	% Retained Min	Sieve Size	Mean	% Retained Max	% Retained Min
1½ in.	0.0	0	0	⅜ in.	0	0	0
1 in.	0.2	1	0	No. 4	3.2	6	2
¾ in.	19.8	33	11	No. 8	12.8	21	8
½ in.	61.0	65	54	No. 16	26.1	33	19
⅜ in.	81.9	90	75	No. 30	46.1	54	39
No. 4	97.3	99	96	No. 50	80.6	85	75
No. 8	98.0	100	94	No. 100	97.8	98	97
				No. 200	99.4	100	99

The concrete was mixed at the plant. Each beam and the corresponding control specimens were made from two batches. The concrete was compacted with internal vibrators. Control tests of slump and air content were made for every batch.

The beams and the corresponding control specimens were steam cured for 12 to 84 hours. The maximum steam temperature was 110 F.

Prestressing. Pretensioned beams were prestressed with 7-wire strand delivered in two coils. All three beams for one bridge were made with strand from the same coil. The acceptance tests of the strand used in beams for bridge 6A indicated an area of 0.0799 sq in and a tensile strength of 273,200 psi; the properties of the strand used in bridge 6B were 0.0799 sq in and 281,000 psi. The strands were stressed one at a time. The load on each strand was measured by a calibrated load cell, and the elongation, by a ruler. The stress was released three to five days after casting when the strength of concrete reached at least 4,000 psi.

The post-tensioned beams were prestressed with parallel wire cables delivered in two shipments. Cables from the second shipment were used only in one beam of bridge 5A. The acceptance tests indicated the following properties of the wire: first shipment —0.191-in. diameter, tensile strength 262,500 psi; second shipment—0.192-in. diameter, tensile strength 252,500 psi. The beams were stressed three to five days after casting except for one beam of bridge 6B cast in July and prestressed 97 days later. The minimum cylinder strength of concrete at the time of stressing was 4,000 psi. The prestressing was made with two double-acting Freyssinet jacks, one placed at each end of the beam. The load was measured by a calibrated pressure gage and the elongation by a ruler.

The friction in post-tensioned beams was determined by a trial procedure for each cable with the aid of the following:

$$F_t = 2(F_1 - \frac{aeE}{d}) \qquad (4)$$

in which F_t = total friction loss;
F_1 = observed tension at the jack;
a = cross-sectional area of the prestressing element;
e = observed elongation of the element at the jack when the force at the jack is F_1;
E = secant modulus of elasticity of the element for the stress F_1/a determined from the stress-strain diagram of the element (29.5 million psi); and
d = distance from the jack to the midspan of the beam.

A total force F_1 computed on the basis of an assumed friction loss was applied, the elongation e was measured and the friction loss computed from Eq. 4. The friction loss so computed was taken as a basis for recomputation of the force F_1 and the process was repeated until the assumed and computed friction losses were identical. The friction varied from 0.7 ksi for a straight cable to 20.0 ksi for a curved cable.

TABLE 8

CONCRETE MIX DATA

Nominal Strength, psi	Cement Content, sacks/cu yd	Water Content, gal/sack	Mix Proportions[a] (cement:sand:gravel)	Steel Punching, lb/sack
5,000	7.00	4.0	1 : 1.74 : 2.86	-
4,000	6.67	4.9	1 : 1.63 : 3.30	-
4,000	6.67	4.9	1 : 1.63 : 3.08	60.8
3,000	5.23	6.0	1 : 2.32 : 4.24	-

[a] Based on surface dry weight.

After the completion of post-tensioning all three beams for one bridge, the space between the steel sheathing and the wires in the cables was filled with neat cement grout made of type I portland cement and 5 gal water per bag. The grout was pumped from one end until continuous flow was observed at the other end. After plugging the free end, grouting was continued until refusal. Because of low temperatures, the beams were steam cured for 24 hours after grouting.

TABLE 9

RESULTS OF ACCEPTANCE TESTS OF STRUCTURAL STEEL

Bridge	Yield Point, ksi	Tensile Strength, ksi	Elongation, percent
1A	40.3	66.3	27.7
1B	38.2	65.6	30.7
2A	40.3	66.3	27.7
2B	38.2	65.6	30.7
3A[a]	(41.3	67.5	29.9
	40.7)	64.4	30.5
3B	39.9	66.4	30.5
4A	39.9	66.4	30.5
4B[a]	(39.9	66.4	30.5
	38.7)	64.8	30.0
All cover plates	38.1	63.9	31.5

[a] Beams 3A1 and 4B1 were made from the second heats listed.

Fabrication of Steel Beams

The steel beams were fabricated by a commercial manufacturer. I-beams for any one bridge were rolled from the same heat except for beams for bridges 3A and 4B which were rolled from two heats (Table 9). The cover plates for all bridges were made from one heat. The yield points determined from acceptance tests are listed in Table 9.

Reinforcing Bars

All concrete reinforcement other than the prestressing steel was made of intermediate grade deformed bars. The reinforcing bars for all slabs and for the reinforced concrete bridges were made from one heat. Physical properties of the steel determined from the acceptance tests are given in Table 10.

The physical properties of the reinforcing bars used in prestressed concrete beams are marked in Table 10. This steel was delivered in two shipments.

Cast-in-Place Concrete

All concrete cast on the bridge sites was made of type I portland cement from one manufacturer delivered in one shipment. The gravel was of 1-in. maximum size and the sand had a fineness modulus of 2.85. The gradations of the aggregates are given in Table 11. An air-entraining agent was added at the mixer.

The reinforced concrete bridges and the slabs for the prestressed concrete bridges were made from a 3,000 psi mix. The slab for bridge 1B was made from a 4,000 psi mix containing steel punchings added to increase the unit weight of concrete. The slab for bridge 2A was made from the same mix as the slab for bridge 1B but the steel punchings were omitted. The slabs for all remaining steel bridges were made from a 4,000 psi mix without steel punchings. The physical properties of all concrete mixes are given in Table 8.

All concrete was mixed on the site in approximately 1-cu yd batches. The concrete was placed from the midspan toward the bridge ends, simultaneously in both directions. It was compacted with internal vibrators at the slab edges and in the

TABLE 10

RESULTS OF ACCEPTANCE TESTS OF REINFORCING BARS

Bar Size	Actual Weight, lb/ft	Yield Point, ksi	Tensile Strength, ksi	Elongation, percent
3	0.377	57.9	83.6	20.0
4	0.675	56.7	87.3	18.0
5	1.034	46.6	75.3	19.0
6	1.504	50.4	83.9	18.0
8	2.688	55.6	82.5	22.0
9	3.240	53.8	82.0	21.0
11	5.230	49.6	79.3	24.0
3[a]		48.1	71.2	25.0
4[b]		47.9	82.0	19.0
		45.3	74.3	23.0

[a] Bars for prestressed concrete beams; all other bars were used in slabs and reinforced concrete beams.

[b] Furnished in two lots, and see a.

TABLE 11

GRADATION OF SAND AND GRAVEL FOR CAST-IN-PLACE CONCRETE

Gravel				Sand			
Sieve Size	Percent Retained				Percent Retained		
	Mean	Max	Min	Size	Mean	Max	Min
⅜ in.	0.0	0.0	0.0	1½ in.	0.0	0.0	0.0
No. 4	0.0	0.1	0.0	1 in.	18.1	25.0	15.0
No. 8	12.0	17.0	11.2	½ in.	74.4	79.2	70.8
No. 16	24.8	31.0	21.5	No. 4	99.7	99.8	99.5
No. 30	43.6	50.6	40.5				
No. 50	86.1	87.8	84.0				
No. 100	97.4	98.0	96.2				
No. 200	99.9	100.0	98.5				

Figure 13. Casting of concrete slabs for prestressed concrete bridges.

beams of reinforced concrete bridges, but hand rodding was used in the interior of the slabs. The finishing operations consisting of strike-off, floating, and two drags with burlap were carried out first on the middle third and then on the two outside thirds of the span. A general view of casting of concrete slabs is shown in Figure 13.

To assure uniformity, control tests of slump and air content were made from each batch placed into the beams of the reinforced concrete bridges, from the first three batches and every succeeding third batch going into the slab. The average slumps for the 3,000, 4,000 and 5,000 psi mixes were $3\frac{5}{8}$, $4\frac{1}{8}$ and $1\frac{5}{8}$ in.; the corresponding standard deviations were $1\frac{1}{8}$, $\frac{7}{8}$ and $\frac{1}{2}$ in. The average air contents for the three mixes were 4.3, 3.5, and 3.9 percent; the standard deviations were 0.7, 0.6 and 0.5 percent.

The concrete structures and the corresponding control specimens were moist cured for seven days. The slabs of prestressed bridges 6A and 6B were protected during the curing period against low temperatures with a layer of insulating material on the top surface and with heating units placed under the bridge. The forms for each structure were removed approximately 14 days after casting. The view of completed four bridges at one location is shown in Figure 14.

TESTS OF MATERIALS

Sampling

Numerous physical properties of materials actually incorporated in the structures will be required for the analyses of the test results. To make the evaluation of these physical properties possible, a comprehensive sampling was carried out during the construction. The sampling from the principal load-carrying members was particularly thorough to permit both the evaluation of the mean properties and an estimate of the possible deviations from the mean for each bridge. The types, sources and numbers of samples are listed in Table 12.

All concrete specimens were made from the same batches as, and were cured together with, the corresponding unit. Concrete specimens not yet tested are stored at the bridge sites. The steel specimens were cut from the materials placed into the bridges.

Tests of Concrete

The tests planned for the various types of specimens are also indicated in Table 12.

Figure 14. Completed reinforced concrete bridges.

TABLE 12

SAMPLES OF MATERIALS

Type of Specimen	Source of Specimen	No. per Unit	Total Number	Type of Tests
6- x 12-in. concrete cylinders	Prestressed concrete beams	18	216	Compressive strength
	Reinforced concrete beams	10-12	132	Stress-strain
	Slabs	18	288	Creep
6- x 6- x 30-in. concrete beams	Prestressed concrete beams	10	120	Modulus of rupture
6- x 6- x 64-in. concrete beams	Prestressed concrete beams	2	24	Flexural fatigue
3- x 3- x 11-in. concrete beams	5,000-psi concrete		4	Coefficient of thermal expansion
	4,000-psi concrete		4	
	3,000-psi concrete		4	
2-ft coupons from reinforcing bars	PCB—stirrups	2	24	Tensile yield point and strength
	PCB—end block bars	1	12	
	Slabs—transverse reinforcement	2	32	Stress-strain
	Slabs—longitudinal reinforcement	2	32	Fatigue
	RCB—longitudinal reinforcement	5-6	66	
	RCB—stirrups	2	24	
Samples of prestressing steel	Wire—2 ft long	20-30	150	Tensile strength
	Strand—10 ft long	8-10	54	Stress-strain
	Wire—50 ft long		2	Fatigue
	Strand—110 ft long		2	Relaxation
2-ft sections of structural steel	I-beams	1	24	Tensile yield point and strength
	Cover plates	1	15	
				Stress-strain
				Fatigue
				Residual stresses

The compression and modulus of rupture tests of concrete cylinders will be carried out at three ages: at 28 days, at the beginning of the test traffic, and at the conclusion of the bridge test. Additional cylinders from prestressed beams were tested immediately before and at stressing of the corresponding beam.

The determination of the time losses of stress in prestressed concrete members requires the knowledge of the creep characteristics of concrete. A series of creep and shrinkage tests involving twenty-four 6- by 12-in. cylinders was designed to determine such characteristics of the 5,000 psi concrete. Two cylinders from each bridge beam have been subjected to one of the following three stress levels: 0 psi, 1,000 psi or 2,000 psi. The cylinders were placed under the load and the creep observations began shortly after the stressing of the corresponding beam. A view of the test set-up is shown in Figure 15.

The tests of prestressed concrete bridges include a study of the effect of repeated loading on tensile cracking. Flexural fatigue tests of 6- by 6- by 64-in. plain concrete beams are planned for evaluation of the fatigue characteristics of concrete used in prestressed concrete beams.

Differential temperature changes in the length of various parts of the same bridge affect the stress conditions in the structure. Thus, the evaluation of the thermal coefficient of expansion of the three types of concrete used in the test bridges was considered desirable and was made part of the tests of materials.

Tests of Steel

It is planned to carry out the tensile tests of steel specimens before the beginning of the test traffic. This would make it possible to base preliminary calculations concerned with the behavior of bridges on the actual properties of materials.

The time losses of stress in prestressed concrete beams are a function of the relaxation properties of the prestressing steel. A series of eight relaxation tests of prestressing wire and strand will be carried out at two stress levels, 140,000 psi and 175,000 psi. Each specimen will be tested for at least 1,000 hours.

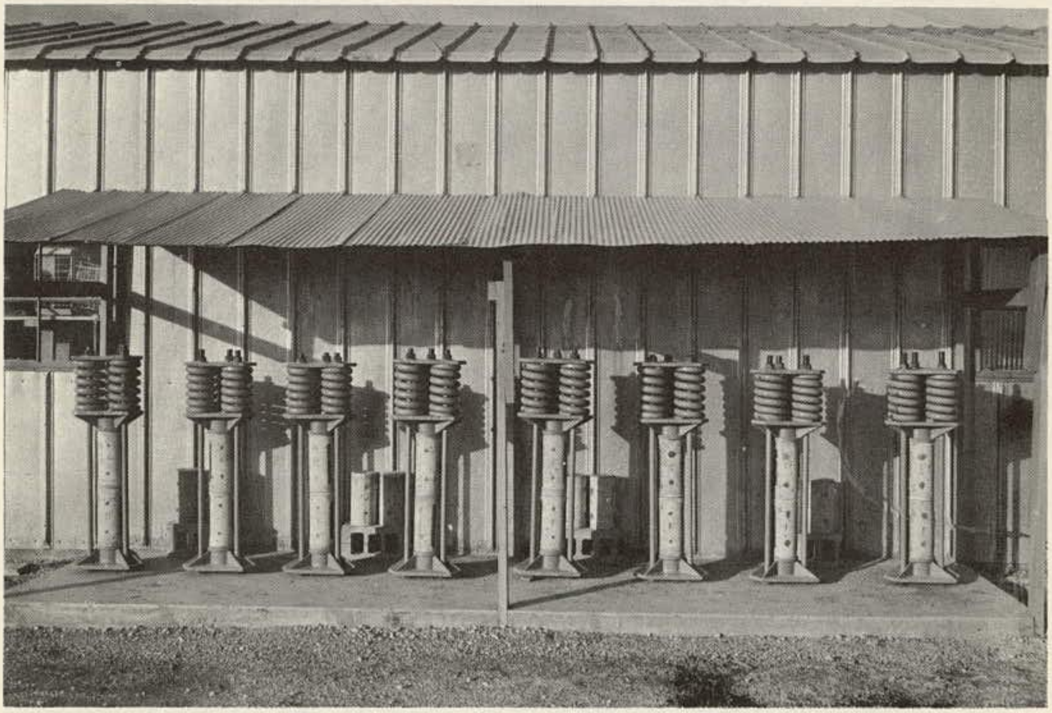


Figure 15. Investigation of creep characteristics of concrete.

The relaxation tests of wire and strand involve relatively short samples. Earlier experiments with wire have indicated no effect of the length of specimen on the results of relaxation tests. On the other hand, no data on the effect of length on the relaxation characteristics of strand are available. It is contemplated, therefore, to carry out control relaxation tests of two 100-ft samples of the strand.

The fatigue characteristics of the prestressing wire and strand, reinforcing bars, and of structural steel will be evaluated by direct tension tests. The specimens will be subjected to the stress levels and stress fluctuations similar to those encountered in the bridges.

The presence of the residual stresses in the steel beams may affect the fatigue behavior of the steel bridges. Residual stress measurements on 2-ft samples from the rolled I-beams are included in the program.

Special Study

One series of tests of materials was completed before the construction of superstructures. Its purpose was the selection of the bond breaking agent for coating the top surfaces of the I-beams for noncomposite steel bridges. The tests, involving ten specimens and four different treatments of the top flange, indicated a mixture of graphite and linseed oil as the most effective agent. Six specimens and the testing apparatus are shown in Figure 16.

RESEARCH PROGRAMS

Pre-Traffic Studies

It is expected that the test traffic will begin in the fall of 1958. All but two bridges were completed during the 1957 construction season, and the last two units should be completed early in 1958. The time which will elapse between the completion of the structures and the beginning of the test traffic will allow for instrumentation of the bridge structures and for essential studies prior to the beginning of the principal programs.

The pre-traffic studies were designed primarily as an aid in planning the studies during the regular test traffic. The two most important preliminary studies include

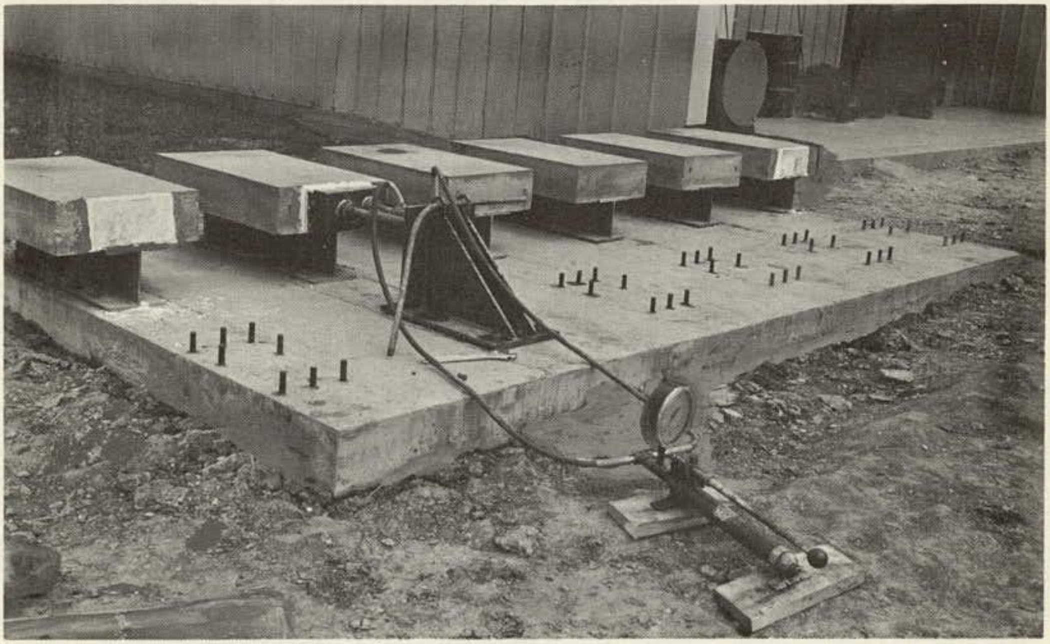


Figure 16. Tests of bond breaking agents.

(a) measurements of permanent stresses in bridge structures, and (b) preliminary analysis of the dynamic response of the bridges.

The measurements of the permanent stresses are necessary to determine the actual stress levels in the structures. Permanent stresses existing at the beginning of the test traffic and permanent cumulative stresses resulting from the test traffic add up to the minimum stress level on which the transient live load stresses are superimposed. The measurements of permanent stresses began during the construction and are now repeated at regular intervals.

The second objective of the bridge research, the determination of the dynamic effects of moving vehicles, requires special tests at varying intervals during the period of test traffic. A preliminary theoretical dynamic analysis is essential for selection of the most suitable structures, vehicle characteristics, speeds and locations.

Studies During Regular Test Traffic

Two years of regular test traffic are planned for the test road. The data collected during this period should provide the information essential for obtaining answers to the two principal objectives of the research program: the determination of the bridge behavior under repeated applications of overstress and the determination of the dynamic effects of moving vehicles.

Repeated Load Tests. Six vehicles with the same characteristics will operate on each traffic lane. The characteristics of the test vehicles on the lanes of loops C and D are described in Figure 4. The vehicles will operate 18 hours per day for six days during each week at a constant speed of 30 mph. As the complete loop is 3.15 miles long, about 600,000 vehicle passages over each bridge will accumulate during the two-year period.

The observations during the repeated load tests will be aimed primarily at determination of the maximum stress levels and deflections during the passage of the vehicle over the bridge. Such observations, together with the strain and deflection data for the unloaded condition, will provide information on the stress level and stress range, the two factors currently considered most significant in the determination of the fatigue behavior of structural materials.

The test of a bridge will be considered completed when the bridge fails or when the test traffic ends. In case of an early failure, the bridge will be rehabilitated to permit continuation of tests on other bridges and on the test pavements.

Dynamic Load Tests. To determine the dynamic effects, special runs of vehicles of various weights and at various speeds will be made on several of the test bridges at irregular intervals. The first of the special runs is planned immediately prior to the beginning of the test traffic.

The strain and deflection data obtained from the dynamic tests will be compared with the results of theoretical analyses carried out concurrently with tests. Each successive test will be planned around the needs indicated by the results of the preceding studies.

Post-Traffic Studies

The post-traffic studies will be concerned with the analysis and reporting of test data. Static, fatigue and dynamic analyses of the test bridges will be included. Approximately one year is set aside for this purpose.

It is expected that several test bridges will survive the regular test period. Tests to destruction of such structures under slowly moving vehicles heavier than those used in the regular test traffic or under static loads are under consideration.

INSTRUMENTATION AND MEASUREMENTS

Bridge Deformations and Conditions

The response of the bridge to a loading may be measured in terms of deformations. The strains and deflections are the most significant.

Both strains caused by moving vehicles (transient strains) and strains caused by dead loads and time effects (permanent strains) will be observed. The instrumentation for transient strains utilizes electric resistance strain gages as transducers. The gages are located primarily on the bottom surfaces of the beams at those locations where maximum stress response is expected. The strains will be recorded with oscillographs capable of instantaneous recording of the transducer responses. Equipment for simultaneous recording of the response of 48 transducers is available for this purpose. The permanent or cumulative strains are measured with mechanical strain gages at the midspan of each bridge beam. The recording is manual.

The transducers for observation of transient deflections are cantilever beams equipped with electric resistance strain gages. Deflection beams will be fastened to the bridge beams near midspan and at several additional locations. Recording of the deflection beam response will be made with the same equipment as that used for transient strains.

Permanent deflections are observed at midspan and the quarter points of the bridge beams. Special target scales in conjunction with a precise level are used for the observations of permanent deflections.

Additional measurements include, among others, crack patterns and crack width in the reinforced and prestressed concrete beams and slip lines on the steel beams.

The bridges and the approach slabs will be inspected at regular intervals. The inspection will include visual observations, measurements of transverse and longitudinal profiles of the bridge slab, and measurements of the elevation of substructures.

Characteristics of Test Traffic

An electronic scale and several tire pressure transducers are available to evaluate the static and dynamic properties of the test vehicles. The tire pressure transducers are transferable from truck to truck, thus permitting the recording of the actual wheel loads during the traffic runs.

The velocity of the vehicles will be checked occasionally by a fifth speed recording wheel. The number of load repetitions will be recorded continuously on each test loop with traffic counters. Automatic equipment is available for recording the transverse and longitudinal placement of vehicles on the bridges.

Environmental Conditions

The need for measurements of temperature, moisture and wind velocity in any field test is evident. Such measurements are in progress in the AASHO weather station located centrally on the test site. The station is equipped with automatic recording equipment.

Eight of the 16 bridges are equipped with 40 thermocouples located at various points on the beams and in the slabs. They permit observation of the distribution of temperature in the structure with an estimated accuracy of 1 F. As a differential temperature results in nonuniform changes in the stress conditions in the bridges, the observations of permanent stresses must be made while the temperature is essentially uniform throughout the bridge. The thermocouples will be used to determine suitable times for measurements of permanent stresses. In addition, the inclusion of the thermocouples in bridge structures will permit a study of the temperature stresses.

CONCLUSION

This report was written for the purpose of acquainting the technical public with the general aims and scope of the bridge research of the AASHO Road Test and to report on the two completed phases of the investigation—the design and construction of the test bridges.

The research programs, measurements and instrumentation are in the process of planning. Outlines presented on these phases will probably undergo a number of changes during the progress of the investigation and should, therefore, be considered as tentative.

The designs of the three types of bridges (that is, those with steel, prestressed concrete, or reinforced concrete beams) were based on different criteria, each aimed at answers peculiar to the type involved. Because of the differences in the design criteria, there is no basis for comparisons between the behavior of the steel, prestressed concrete, and reinforced concrete test structures.

The bridge research program is limited to 16 structures with a minimum amount of replication and of systematic variation of independent variables. Accordingly, each bridge must be considered an essentially separate case study expected to yield indications on how similar structures may behave under the repeated applications of high overstress. The investigation cannot be expected to provide final answers to the questions asked; nevertheless, the information obtained should prove extremely valuable in future advancements of bridge design through additional research and field studies.

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