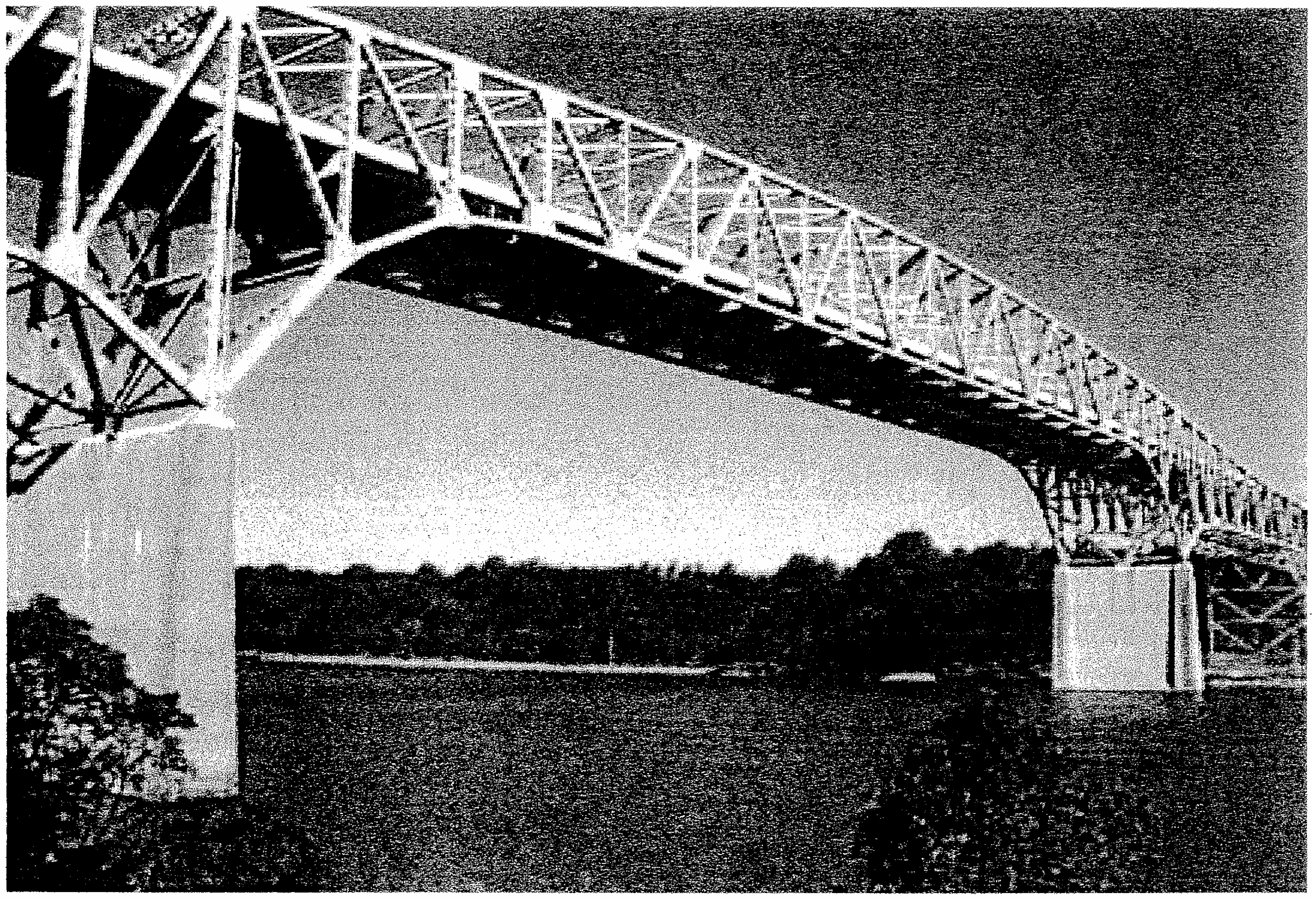
- **Name: Jim Chu**
- **Phone: 215-656-6793**
- **Company: USACE**
- **E Mail: chien-ming.chu@usace.army.mil**

Summit Bridge Fatigue Study

By Jim CHU Structural Engineer
USACE Philadelphia District



1. Study Purpose

To determine the fatigue life of the main structural members of the Summit Bridge trusses.

2. Structural Description

- Four(4) lanes high level steel bridge
- Total length 2058 ft (See Fig. 1)
- Two(2) 250 ft deck truss span
- One(1) 1200 ft anchor cantilever through truss span
- Four(4) stringer spans total length 358 ft
- AADT volume 27,690 (2003 Del. DOT data)

2.1 Deck Truss

- 250 ft long simply supported truss (Fig.1).
- Ten(10) panels with each panel 25’ long.
- Floor beams are rest on top chord panel points. (Fig. 2)
- All truss members sees only axial load.
- All except two truss members are wide flange shape

2.2 Cantilever Through Truss

- Two(2) 150’ cantilever spans, two(2) 300’ anchor spans, one(1) 300’ suspended span. (Fig.1)
- Forty(40) panels with each panel 30’ long.
- Floor beam is supported at each vertical member (Fig. 4)
- All members sees only axial load.
- All members are riveted built up box section (Fig. 3)

3. Study Procedure

- In accordance with the AASHTO (2003) LRFR manual for highway bridges.
- Infinite life check by Analytical method
- Check again by field measurement method for failed members
- If both methods are failed then finite life calculation is necessary.

3.1 Analytical Method

- Two dimensional truss models.(Fig.5&6)
- Assume pure truss behavior. (only axial load)
- Assume truck load in one lane. (shoulder lane)

3.1.1 Model Geometry and Boundary Conditions

- All member info. obtained from special load program 'SMTBRM' user's manual
- Deck Truss (Fig. 5):

  a. Simply supported

  b. Calculation only need for half of truss

  c. Load concentrate apply at top panel pt.

3.1.1 Model Geometry and Boundary Condition (Cont'd)

- Through Truss (Fig. 6):
  a. Half truss modeled and analyzed
  b. truss supported by pin at node L10 and roller at node L0
  c. suspended span supported by pin at node L15
  d. load applied at each vertical member (Fig.4)

3.1.2 Loading

- Dead loads-
  1. Wt. of truss member, wt. of floor system steel, wt. of slab and wearing surface, wt. of parapet.
  2. Applied concentrately at each top panel pt.
  3. Cross-sections of deck& through truss. see Fig. 2&4

3.1.2 Loading (Cont'd)

- Live loads- Based on AASHTO LRFD 2004 spec.

  1. AASHTO Paragraph 3.6.1.4- Fatigue truck (see Fig.7)
  2. AASHTO Paragraph 3.6.1.4.2-The single lane ADTT is for shoulder lane.

3.1.2 Loading (Cont'd)

- Live load (Cont'd)

  3. AASHTO Paragraph 3.6.1.4.3- distribution factor DF is equal to the support reaction due to a unit load located at truck location. (see Fig. 8)
  4. AASHTO Paragraph 3.6.2.1- add 15% to impact load.

3.1.3 Member forces and stress range

- Dead load forces and stresses- See Table 1
- Live load forces-
  1. Assume truck load as single point load.
  2. Add impact and multiply by proper DF.
  3. Find Max. and Min. Influence line coef.
  4. Use net cross section area
  5. See Table 2,3.1,3.2,3.3

3.1.3 Member Forces and Stress Range (Cont'd)

- Live load stress range Sr- Sum of Max. tension and compression stress
- Live load stress range tension component St
- Dead load compression stress Sc
- See Table 4,5.1,5.2,5.3

3.1.4 Infinite-Life Check

- Fatigue Category-
  1. AASHTO LRFR (2003) section 7.2.1 defines rivet connection as Category C
  2. Bower(1994) states rivet with tack weld reduced to Category E
- Infinite-life Check- AASHTO LRFR 7.2.4
  a. $2Rs(0.75Sr) < F_{TH}$ or
  b. $2Rs(0.75St) < Sc$

3.1.4 Infinite-Life Check (Cont'd)

where,

Rs: stress uncertainty factor, AASHTO LRFR
Table 7.1, 1 for simplified analysis

Sr: unfactored life load stress range

F_{TH}: fatigue threshold, AASHTO LRFD 2004
Table 6.6.1.2.5-3, 4.5 for Category E

St : unfactored life load tension portion of Sr

Sc : unfactored dead load compression stress

3.1.4 Infinite-Life Check (Cont’d)

- The factor of 2 is for max. possible stress for entire life of bridge, LRFR sect. 7.2.2.2
- Results shown in Table 4,5.1,5.2,5.3
- Fracture Critical Members (FCM) are members with dead load tensile stress.
- Four(4) members failed infinite life check
- Will check again by field measured effective stress range

3.2 Field Measurement Method

- Analytical method is conservative due to:
  1. assume pure truss member (bending effect neglected)
  2. 2-D model (ignored floor beam and cross brace effect)
  3. Fatigue truck is assumed load, and in shoulder lane only.

3.2 Field Measurement Method (Cont'd)

- Field measured effective stress expect lower
- Four(4) members with finite life and six(6) members with high stress to be tested by Structural Testing Inc. (STI)
- Results shown in Table 6
- Consider infinite life if

  $2f_{eff}$ or $2\ R_s\ f < F_{TH}$

  where,

3.2 Field Measurement Method (Cont'd)

Rs: stress uncertainty factor AASHTO LRFR Table 7.1, 0.85 for measured stress

f : measured effective stress range

- All members pass infinite-life check

4. Comparison of Analytical and Field Measured Stress Range

- AASHTO LRFR section 7.2.2 The effective stress range shall be estimated as

  $f_{eff} = Rs\ f$

where,

Rs: stress uncertainty factor, AASHTO LRFR Table 7.1, 0.85 for field measured method,1.0 for simplified analysis method

4. Comparison of Analytical and Field Measured Results (Cont'd)

f : measured effective stress range; or
0.75 of calculated stress range (Sr)

- Sr recalculated to remove conservatism (truck load three point load instead of one point load)
- Result listed in Table 6

5. Conclusion and Recommendation

- Fatigue problem does not exist for the Summit Bridge trusses. All truss members has infinite fatigue life.
- Calculated effective stress range is about 10% to 90% higher than measured effective stress range for Summit Bridge truss members.
- No need to remove all un-cracked tack welds. However, cracked tack weld shall be removed as identified.

Table 1

Table 1. Dead Load Stress					
Deck Truss		Through Truss			
Member	Stress (ksi)	Member	Stress (ksi)	Member	Stress
L0L2	13.4	L0L2	0.7	U1U3	1.3
L2L4	18.1	L2L4	-5.6	U3U5	12.6
L4L6	17.9	L4L6	-14.1	U5U7	16
U1U3	-14.9	L6L7	-15.7	U7U8	17
U3U5	-15.4	L7L8	-16.7	U8U9	17.7
L0U0	-3.4	L8L9	-17.2	U9U10	18
L2U2	-6.4	L9L10	-17.2	U10U11	18.6
L4U4	-6.6	L10L11	-17.3	U11U12	18.6
L0U1	-14	L11L12	-17.5	U12U13	18.7
U1L2	17.6	L12L13	-17.5	U13U15	17.6
L2U3	-9.8	L13L14	-17.6	U16U18	-17
U3L4	12.2	L15L17	15.4	U18U20	-17.1
L4U5	-4	L17L19	18.1		
		L19L20	18.4		
		L0U0	-3.18	L0U1	-1.8
		L1U1	6.4	U1L2	-4.9
		L2U2	-4.4	L2U3	13.9
		L3U3	6.4	U3L4	-13.7
		L4U4	-4.7	L4U5	17.4
		L5U5	6.6	U5L6	-14.8
		L6U6	-5.4	L6U7	18.3
		L7U7	-12.9	L7U8	18.5
		L8U8	-13.8	L8U9	17.6
		L9U9	-12.4	L9U10	-9.2
		L10U10	13.9	U10L11	-13.5
		L11U11	-10.7	U11L12	12.3
		L12U12	-16.9	U12L13	18.5
		L13U13	-16.6	U13L14	18.5
		L15U15	19.5	L14U15	-14.8
		L16U16	4.4	L15U16	-15.3
		L18U18	6.6	U16L17	18.3
		L20U20	6.8	L17U18	-13.6
				U18L19	12.2
				L19U20	-3.1

Table 2

Table 2. Member Forces: Deck Truss			
Member	Max. Axial LL+I (kips)	Min. Axial F LL+I (kips)	Net Area (in^2)
L0L2	67.3	0	39.91
L2L4	157	0	69.7
L4L6	187	0	84.4
U1U3	0	-120	64.4
U3U5	0	-180	94.1
L0U0	0	-100	21.5
L2U2	0	-100	21.5
L4U4	0	-100	21.5
L0U1	0	-113	64.16
U1L2	100	-13	39.91
L2U3	25	-88	46.04
U3L4	75	-38	25.49
L4U5	50	-63	25.49

Table 3.1

Table 3.1 Member Forces: Through Truss			
Member	Max. Axial LL+I (kips)	Min. Axial F LL+I (kips)	Net Area (in ^{2})
L0L2	51	-28	51.88
L2L4	113	-65	51.88
L4L6	122	-122	73.62
L6L7	89	-148	130.12
L7L8	61	-153	152.72
L8L9	31	-152	163.36
L9L10	0	-149	208.51
L10L11	0	-196	273.01
L11L12	0	-182	231.49
L12L13	0	-161	187.51
L13L14	0	-109	115.51
L15L17	43	0	41.71
L17L19	94	0	78.48
L19L20	109	0	89.78
U1U3	55	-89	51.88
U3U5	103	-123	53.01
U5U7	137	-110	102.11
U7U8	150	-90	130.36
U8U9	155	-62	155.81
U9U10	153	-31	176.38
U10U11	158	0	188.55
U11U12	160	0	175.72
U12U13	110	0	109.55
U13U15	52	0	50.18
U16U18	0	-65	65.24
U18U20	0	-106	92.24

Table 3.2

Table 3.2 Member Forces: Through Truss			
Member	Max. Axial Force LL+I (kips)	Min. Axial Force LL+I (kips)	Net Area (in^2)
L0U0	0	-73	31.54
L1U1	73	0	27.21
L2U2	0	-73	38.82
L3U3	73	0	27.21
L4U4	0	-73	36.5
L5U5	73	0	27.31
L6U6	0.1	-73	32.79
L7U7	6.6	-63	70.17
L8U8	1.7	-69	68.22
L9U9	0.3	-73	75.88
L10U10	130	-73	95.39
L11U11	0	-73	47.75
L12U12	0	-73	100.94
L13U13	0	-83	104.19
L15U15	73	0	61.73
L16U16	73	0	40.16
L18U18	73	0	27.59
L20U20	73	0	27.68

Table 3.3

Table 3.3 Member Forces: Through Truss			
Member	Max. Axial Force LL+I (kips)	Min. Axial Force LL+I (kips)	Net Area (in^2)
L0U1	47	-84	29.82
U1L2	70	-43	29.82
L2U3	43	-61	29.82
U3L4	43	-36	38.13
L4U5	46	-35	47.46
U5L6	20	-55	54.2
L6U7	65	-15	62.38
L7U8	75	-4	60.56
L8U9	79	-5	56.49
L9U10	76	-75	55.58
U10L11	49	-70	72.8
U11L12	63	-4	30.57
U12L13	84	0	103.62
U13L14	95	0	103.62
L14U15	0	-93	107
L15U16	0	-78	77.13
U16L17	66	-11	47.06
L17U18	21	-57	38.99
U18L19	49	-28	28.66
L19U20	37	-40	23.59

Table 4

Table 4 Member Stresses and Fatigue Life: DECK TRUSS						
Member	S_r (ksi)	S_t (ksi)	S_c (ksi)	Y_f (yrs)		
L0L2	1.69	1.69	0	infinite	2Rs(0.75Sr)<4.5	(FCM)
*L2L4	2.25	2.25	0	infinite	2Rs(0.75Sr)<4.5	(FCM)
*L4L6	2.21	2.21	0	infinite	2Rs(0.75Sr)<4.5	(FCM)
U1U3	1.86	0	-14.9	infinite	$S_c>2R_s(0.75S_t)$	
U3U5	1.91	0	-15.4	infinite	$S_c>2R_s(0.75S_t)$	
L0U0	4.65	0	-3.4	infinite	$S_c>2R_s(0.75S_t)$	
L2U2	4.65	0	-6.4	infinite	$S_c>2R_s(0.75S_t)$	
L4U4	4.65	0	-6.6	infinite	$S_c>2R_s(0.75S_t)$	
L0U1	1.76	0	-14	infinite	$S_c>2R_s(0.75S_t)$	
*U1L2	2.83	2.5	0	infinite	2Rs(0.75Sr)<4.5	(FCM)
L2U3	2.45	0.54	-9.8	infinite	$S_c>2R_s(0.75S_t)$	
*U3L4	4.43	2.94	0	finite		(FCM)
L4U5	4.43	1.96	-4	infinite	$S_c>2R_s(0.75S_t)$	

*Members(FCM) with highest stress range were selected for field stress measurement

Table 5.1

Table 5.1 Member Stress and Fatigue Life: THROUGH TRUSS						
Member	S_r (ksi)	S_t (ksi)	S_c (ksi)	Y_f (yrs)		
L0L2	1.55	0.99	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L2L4	3.45	2.2	-5.6	infinite	$S_c>2R_s(0.75S_t)$	
L4L6	3.33	1.67	-14.1	infinite	$S_c>2R_s(0.75S_t)$	
L6L7	1.84	0.69	-15.7	infinite	$S_c>2R_s(0.75S_t)$	
L7L8	1.43	0.4	-16.7	infinite	$S_c>2R_s(0.75S_t)$	
L8L9	1.33	0.2	-17.2	infinite	$S_c>2R_s(0.75S_t)$	
L9L10	0.72	0	-17.2	infinite	$S_c>2R_s(0.75S_t)$	
L10L11	0.72	0	-17.3	infinite	$S_c>2R_s(0.75S_t)$	
L11L12	0.8	0	-17.5	infinite	$S_c>2R_s(0.75S_t)$	
L12L13	0.87	0	-17.5	infinite	$S_c>2R_s(0.75S_t)$	
L13L14	0.95	0	-17.6	infinite	$S_c>2R_s(0.75S_t)$	
L15L17	1.03	1.03	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L17L19	1.21	1.21	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L19L20	1.23	1.23	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
*U1U3	2.79	1.07	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
*U3U5	4.31	1.95	0	finite	$2R_s(0.75S_r)<4.5$	(FCM)
*U5U7	2.44	1.35	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U7U8	1.85	1.16	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U8U9	1.39	1	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U9U10	1.04	0.88	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U10U11	0.85	0.85	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U11U12	0.92	0.92	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U12U13	1.01	1.01	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U13U15	1.04	1.04	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U16U18	1	0	-17	infinite	$S_c>2R_s(0.75S_t)$	
U18U20	1.17	0	-17.1	infinite	$S_c>2R_s(0.75S_t)$	

* FCM with highest stress range were selected for field stress measurement

Table 5.2

Table 5.2 Member Stress and Fatigue Life: THROUGH TRUSS						
Member	S_r (ksi)	S_t (ksi)	S_c (ksi)	Y_f (yrs)		
L0U0	2.33	0	-3.18	infinite	$S_c>2R_s(0.75S_t)$	
L1U1	2.71	2.71	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L2U2	1.89	0	-4.4	infinite	$S_c>2R_s(0.75S_t)$	
L3U3	2.71	2.71	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L4U4	2.03	0	-4.7	infinite	$S_c>2R_s(0.75S_t)$	
L5U5	2.7	2.7	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L6U6	2.24	0	-5.4	infinite	$S_c>2R_s(0.75S_t)$	
L7U7	1	0.1	-12.9	infinite	$S_c>2R_s(0.75S_t)$	
L8U8	1.05	0.03	-13.8	infinite	$S_c>2R_s(0.75S_t)$	
L9U9	0.97	0.004	-12.4	infinite	$S_c>2R_s(0.75S_t)$	
L10U10	2.15	1.37	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L11U11	1.55	0	-10.7	infinite	$S_c>2R_s(0.75S_t)$	
L12U12	0.72	0	-16.9	infinite	$S_c>2R_s(0.75S_t)$	
L13U13	0.81	0	-16.6	infinite	$S_c>2R_s(0.75S_t)$	
L15U15	1.2	1.2	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L16U16	1.84	1.84	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L18U18	2.67	2.67	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L20U20	2.67	2.67	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)

Table 5.3

Table 5.3 Member Stress and Fatigue Life: THROUGH TRUSS						
Member	S_r (ksi)	S_t (ksi)	S_c (ksi)	Y_f (yrs)		
*L0U1	4.41	1.57	-1.8	finite		
*U1L2	3.81	2.36	-4.9	infinite	$S_c>2R_s(0.75S_t)$	
*L2U3	3.52	1.47	0	finite		(FCM)
U3L4	2.09	1.15	-13.7	infinite	$S_c>2R_s(0.75S_t)$	
L4U5	1.73	0.99	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U5L6	1.41	0.37	-14.8	infinite	$S_c>2R_s(0.75S_t)$	
L6U7	1.29	1.05	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L7U8	1.32	1.25	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L8U9	1.49	1.4	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L9U10	2.73	1.39	-9.2	infinite	$S_c>2R_s(0.75S_t)$	
U10L11	1.64	0.68	-13.5	infinite	$S_c>2R_s(0.75S_t)$	
U11L12	2.23	2.09	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U12L13	0.83	0.83	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
U13L14	0.93	0.93	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L14U15	0.88	0	-14.8	infinite	$S_c>2R_s(0.75S_t)$	
L15U16	1.03	0	-15.3	infinite	$S_c>2R_s(0.75S_t)$	
U16L17	1.63	1.41	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L17U18	2	0.55	-13.6	infinite	$S_c>2R_s(0.75S_t)$	
U18L19	2.67	1.72	0	infinite	$2R_s(0.75S_r)<4.5$	(FCM)
L19U20	3.29	1.57	-3.1	infinite	$S_c>2R_s(0.75S_t)$	

*Members with highest stress range were selected for field stress measurement

Table 6

Table 6. Comparison of calculated and field measured effective stress			
Deck Truss			
Member	f_{eff} (ksi)-Calculated	f_{eff}(ksi)-Field measured	Ratio
L4L5	1.46	1.24	1.17
L3L4	1.57	0.81	1.93
U3L4	2.6	2.02	1.28
U1L2	1.78	1.58	1.13
Through Truss			
L0U1	2.99	1.377	2.17
U1L2	2.51	1.5	1.67
U3U4	2.96	1.53	1.93
U5U6	1.69	0.94	1.8
U2U3	1.92	1.34	1.43
L2U3	2.34	1.71	1.37

Fig. 1

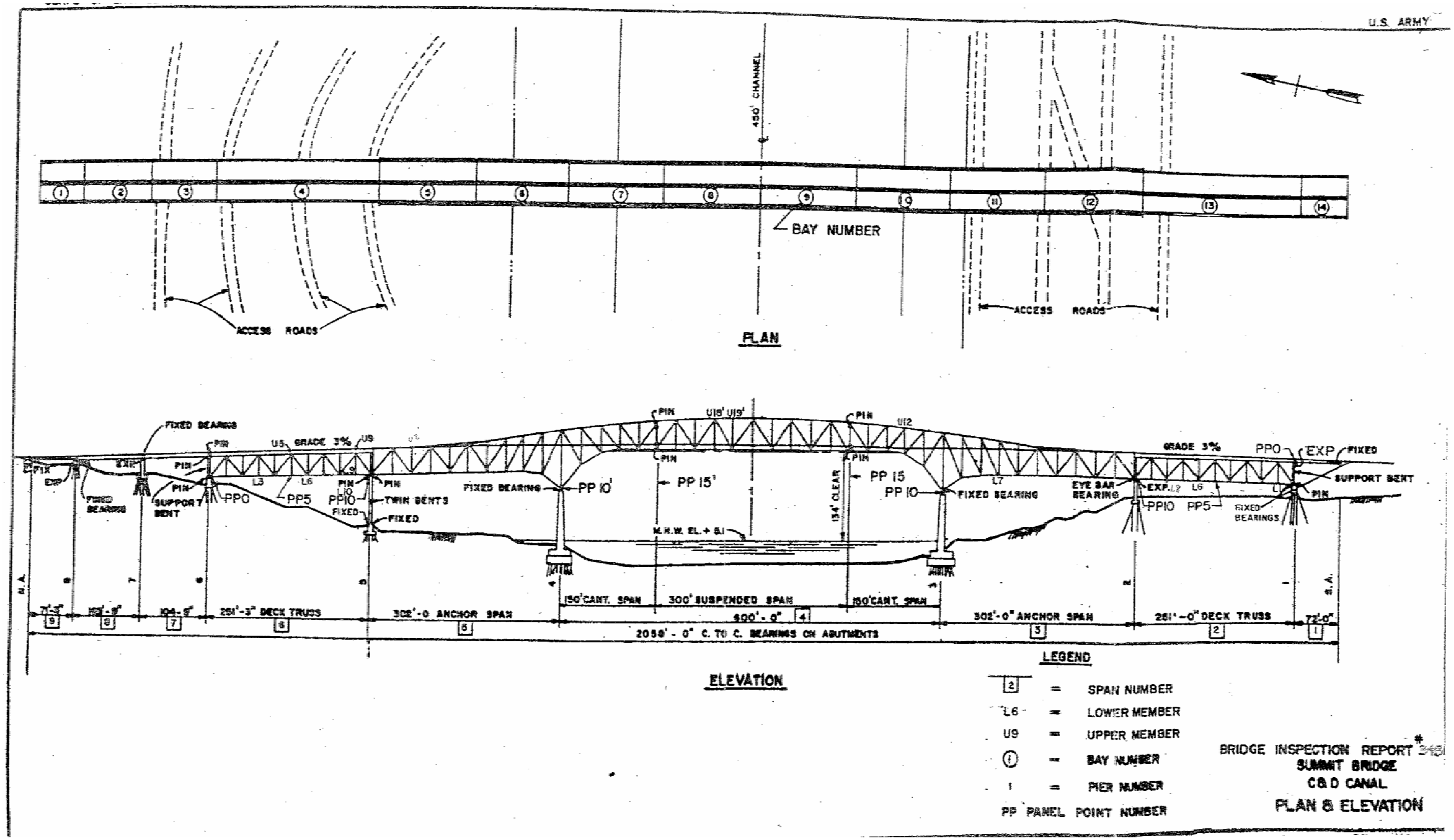
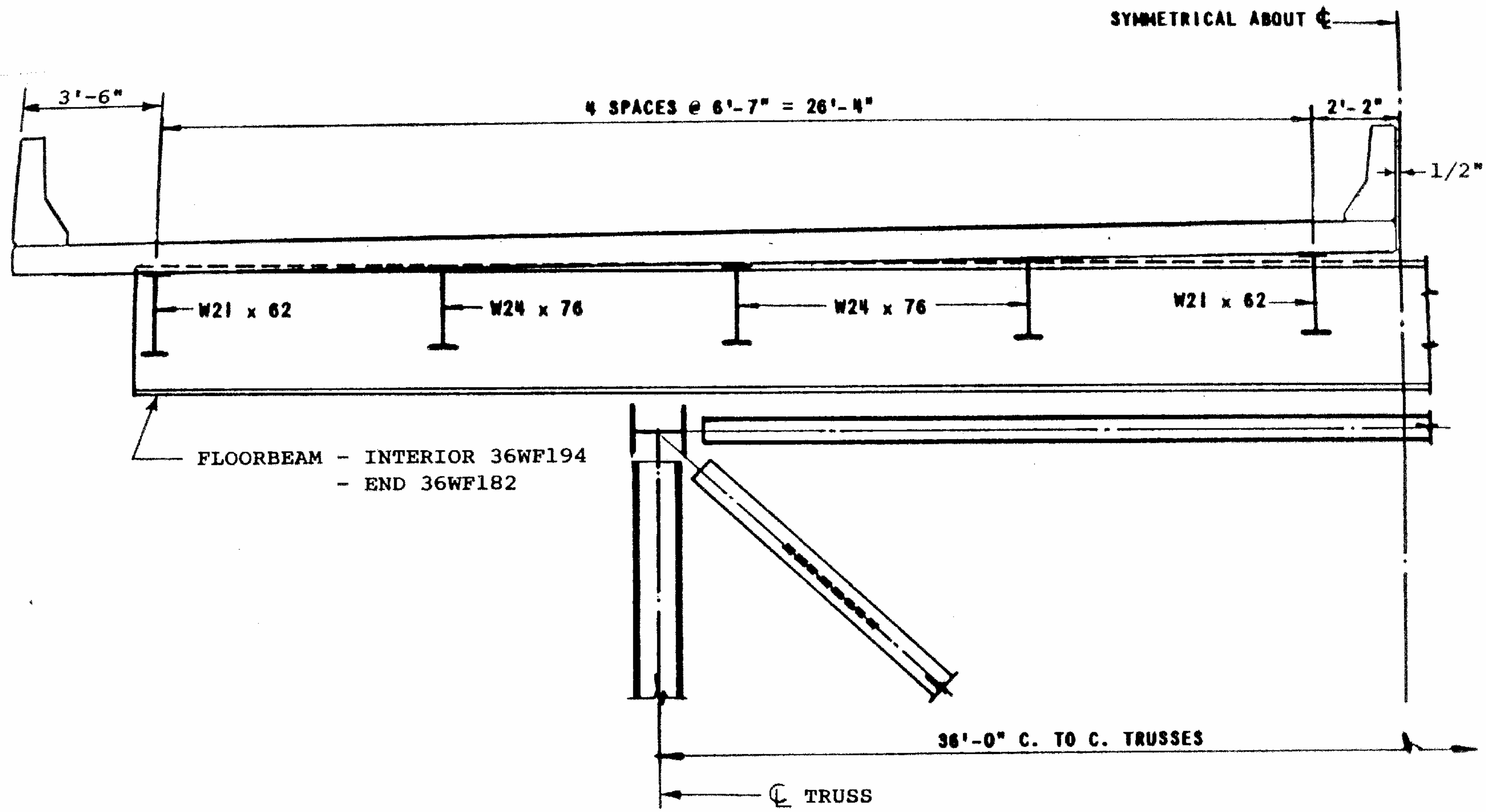
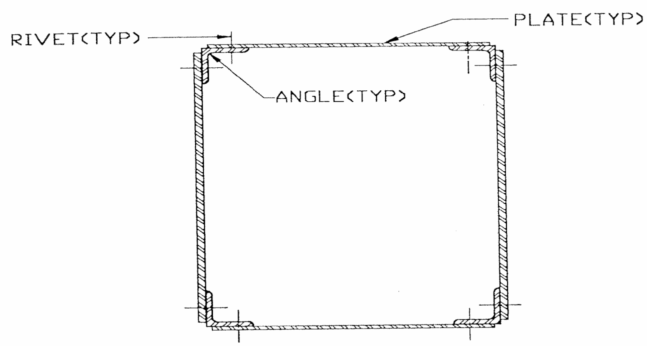

U.S. ARMY
450' CHANNEL
BAY NUMBER
ACCESS ROADS
ACCESS ROADS
PLAN
FIXED BEARINGS
GRADE 3%
PIN
U18' U19'
U12
FIXED BEARING
PP 10'
PP 15'
PP 15
PP 10
FIXED BEARING
134' CLEAR
M.H.W. EL. + 8.1
TWIN BENTS
FIXED
SUPPORT BENT
PP0
PP5
PP10
EYE BAR BEARING
EXP.
FIXED BEARINGS
SUPPORT BENT
EXP
FIXED
150' CANT. SPAN
300' SUSPENDED SPAN
150' CANT. SPAN
600' - 0"
251'-3" DECK TRUSS
302'-0 ANCHOR SPAN
302'-0" ANCHOR SPAN
251'-0" DECK TRUSS
72'-0"
2059' - 0" C. TO C. BEARINGS ON ABUTMENTS
ELEVATION
LEGEND
= SPAN NUMBER
= LOWER MEMBER
= UPPER MEMBER
= BAY NUMBER
= PIER NUMBER
PP PANEL POINT NUMBER
BRIDGE INSPECTION REPORT
SUMMIT BRIDGE
C&D CANAL
PLAN & ELEVATION

Fig. 2

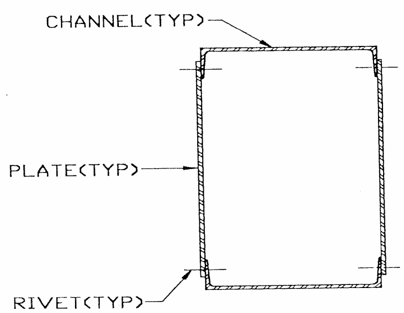


250 FT. DECK TRUSS
TYPICAL HALF CROSS SECTION

Fig. 3



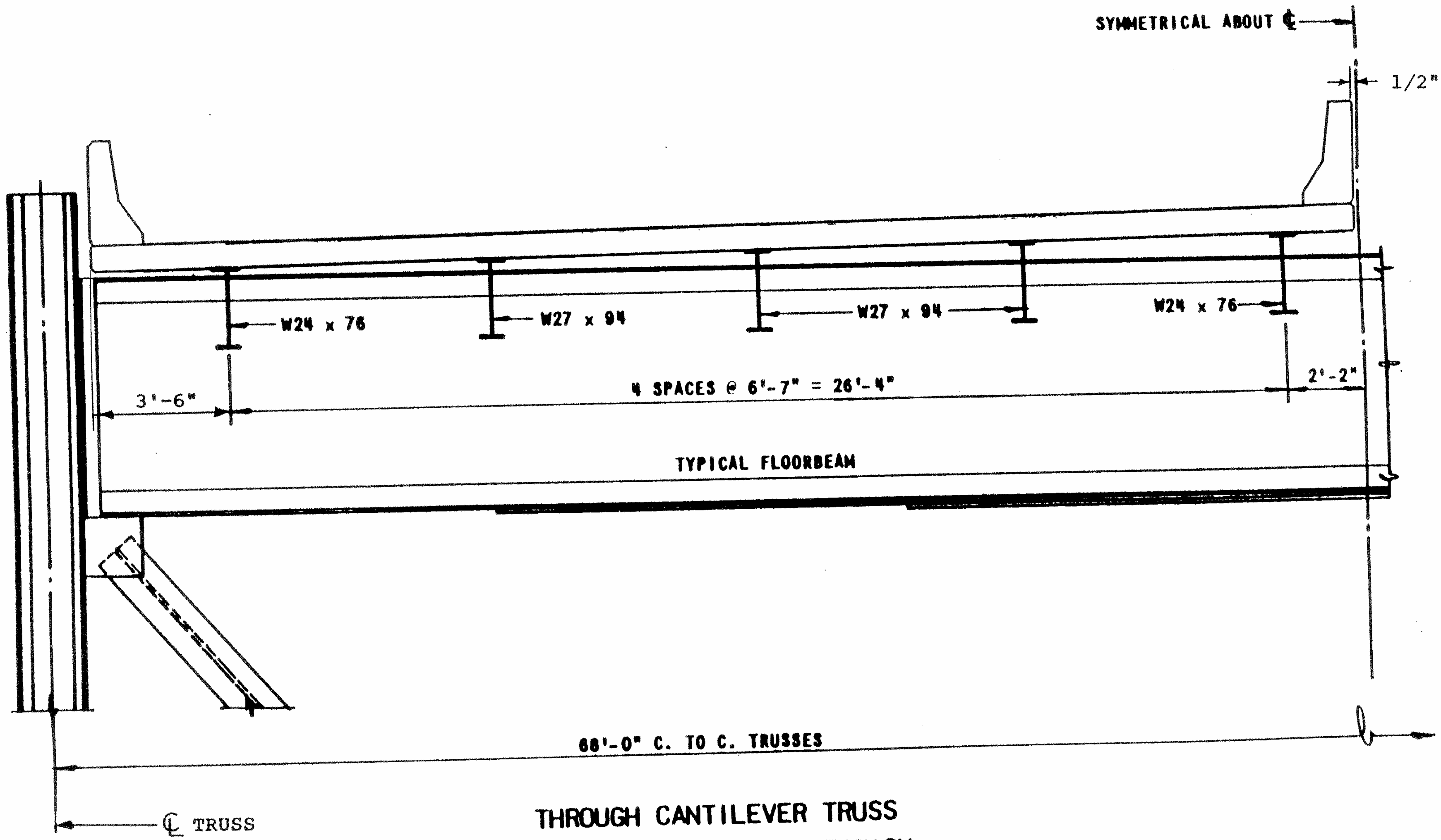
a. BOX SECTION: PLATES AND ANGLES



b. BOX SECTION: CHANNELS AND PLATES

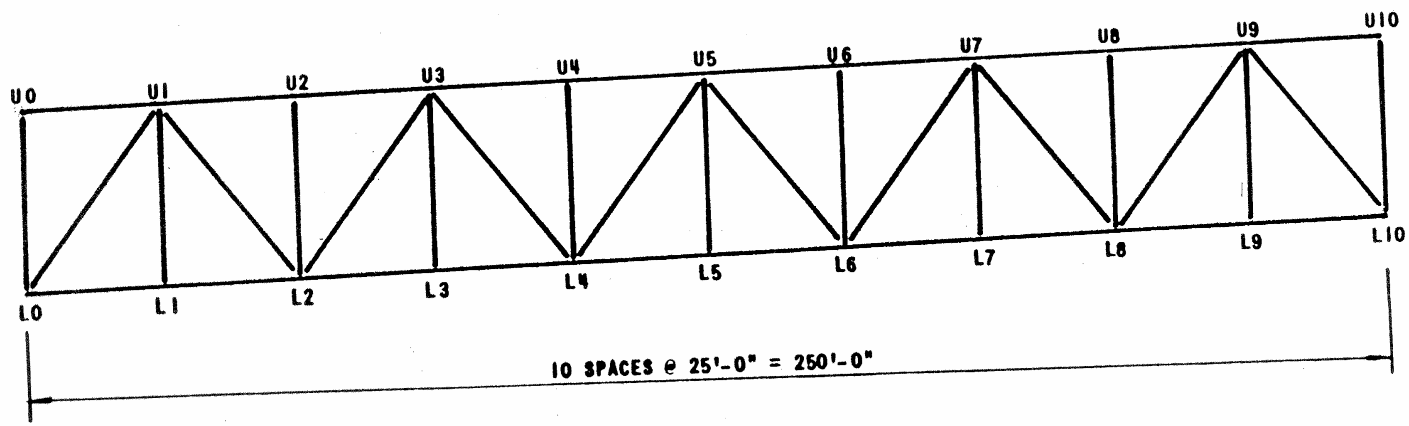
FIGURE 3. TYPICAL MEMBER CROSS SECTIONS

Fig. 4



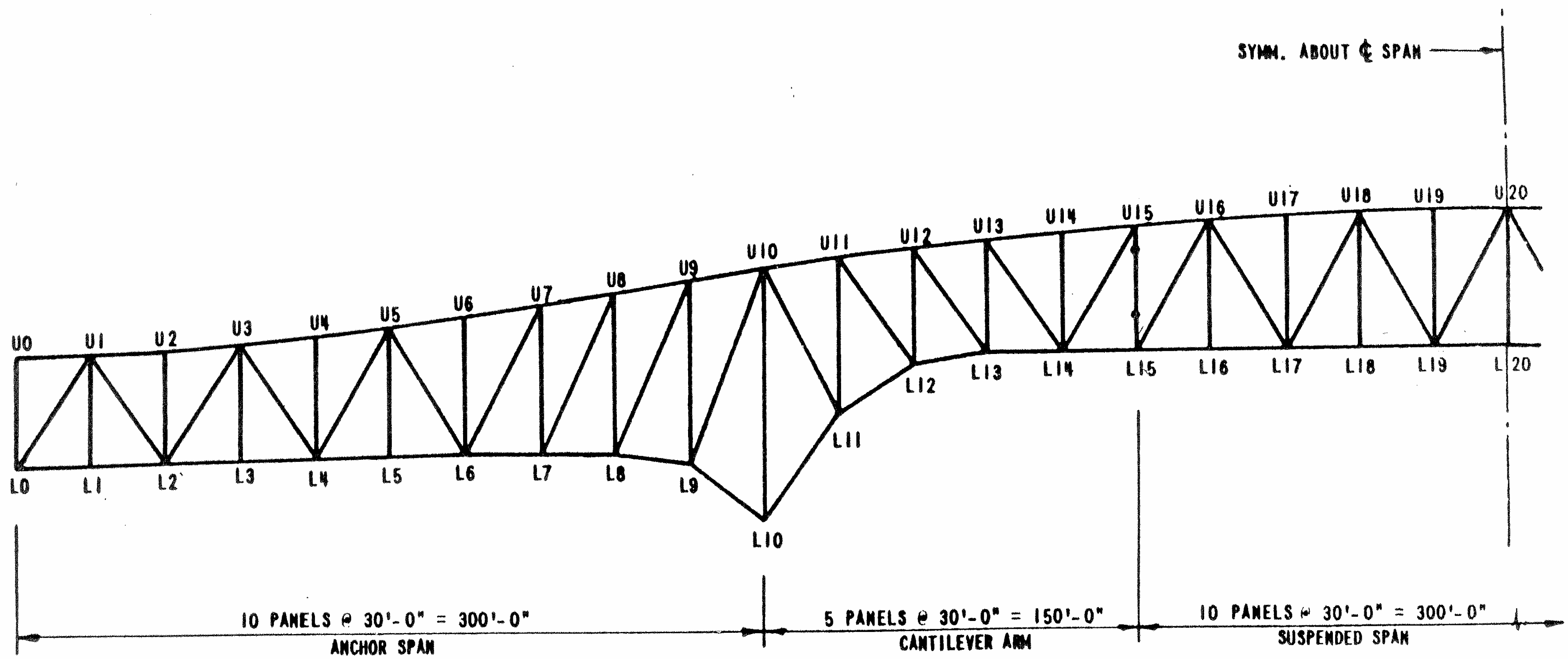
THROUGH CANTILEVER TRUSS
TYPICAL HALF CROSS SECTION

Fig. 5



250 FT. DECK TRUSS
FRAMING PLAN AND ELEVATION

Fig. 6



THROUGH CANTILEVER TRUSS

HALF ELEVATION AND FRAMING PLAN

Fig. 7

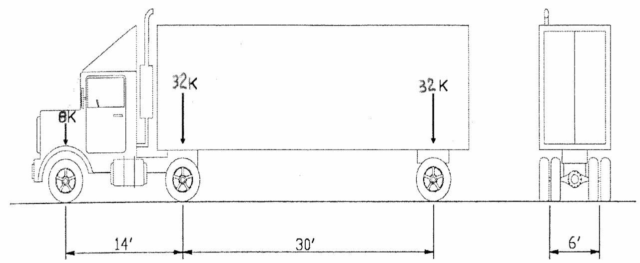
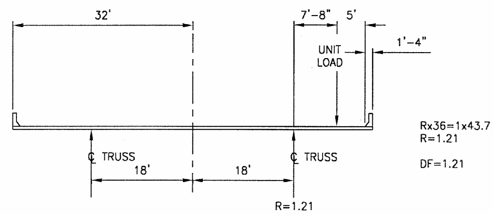
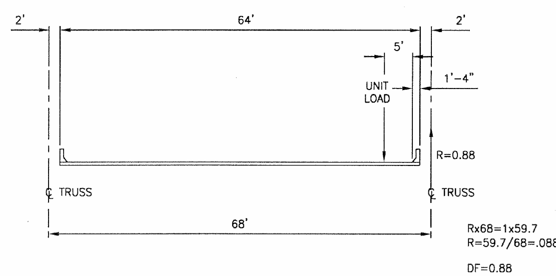


FIGURE 7. AASHTO(2004) FATIGUE TRUCK

Fig. 8



A. 250' DECK TRUSS



B. THRU CANTILEVER TRUSS

FIG. 8 CALCULATION OF DISTRIBUTION FACTOR