NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

August 21, 2008

MATERIALS LABORATORY STUDY Report No. 08-086

A. Accident

Place	:	Minneapolis, Minnesota
Date	:	August 1, 2007
Vehicle	:	I-35W Highway Bridge
NTSB No.	:	HWY07MH024
Investigator	:	Mark Bagnard

B. Report Subjects

1) Truss Analysis of Member Loads during Construction
2) Angle Between Adjacent Members at Node U10

C. Truss Analysis of Member Loads during Construction

The forces in the main truss members of Bridge 9340 varied as the structure was being erected. The magnitude and direction of the member loads depended on which main truss members had been erected, and whether the structure was in a cantilevered or continuous phase. Construction loads, for the cantilevered[1] and continuous[2] structures, were obtained from documents produced by both the Minnesota Highway Department and the bridge design consultant Sverdrup & Parcel and Associates (Sverdrup & Parcel). Design service loads were taken from the Construction Plans for Bridge 9340 approved June 18th, 1965.

While the Minnesota Highway Department and Sverdrup & Parcel independently reported the construction loads, no record of any supporting calculations for the erection procedure were found among the archived documents. To evaluate the reported loads, a 2-D model was created using a general purpose frame analysis software program, VisualAnalysis 5.5. The model was used to calculate the loads in the truss during construction.

The 2-D truss was created with the node geometry provided in the design drawings. The main truss members were defined according to cross sectional area and moment of

[1] The cantilevered structure is the stage during construction just before the trusses are joined at nodes U14 and L13.
[2] The continuous structure is the stage during construction just after the trusses are joined at nodes U14 and L13.

inertia, as defined by the design drawings and verified in the field. The self weight of the main truss members was calculated by the software as a function of material and cross sectional area. The lateral and sway bracing self weight transferred into the main truss at the lower nodes and at the floor truss connection 10.25 feet below the upper nodes. The self weight of the lateral bracing was estimated based on the length of the box members to be 7,000 pounds (7 kips) at each panel point. The sway frames from nodes L1 to L5 and from L11 to L14 had a single chevron brace and were estimated to weigh 3 kips at those panel points. The sway frames from nodes L6 to L10 had two chevron braces and were estimated to weigh 6 kips at those panel points. The floor truss was estimated to weigh 12 kips. The deck stringers were assumed to not be installed, and the self weight of the stringers was not applied to the truss model.

The truss was modeled with ideal pins at the nodes that did not transfer moment at the ends of the members, except those members that were unsupported at one end during erection. To stabilize the unsupported member, rotational restraints were placed on the connected end of the unsupported member and the other members framing into the supporting node. The truss was modeled with vertical restraints at L1 and L8, and horizontal restraint at L8. Additional out-of-plane rotational restraints were applied to the model to allow the analysis program to run. For consistency tension loads are designated as positive values, compressive loads are negative.

Starting with the structure on the Erection Sequence Drawing ES-4.1, found in figure 3 of the Erection Sequence Report (Materials Laboratory Factual Report No 08-073), a series of models were created by adding members in the same order as appeared in figure 3. The models were analyzed with respect to dead load only. It was determined that the model with the highest loads in the members around node U10 was when all of the steel, from nodes 0 to 14, was erected just prior to closure of the center span. Table 1 presents the results of the VisualAnalysis model and the Minnesota Highway Department estimates. Also included in table 1 and subsequent tables is the load for the lower chord below node U10.

Table 1: Cantilever Truss Loads

Member	Visual Analysis Member Force (kip)	MN Hwy Dept[3] Member Force (kip)
U8/U10	723	769
U10/U12	351	379
U10/L10	48	Not Available
L9/U10	-342	-342
U10/L11	305	270
L9/L11	-533	-572

[3] G. McNerney, Minnesota Highway Department, (Truss Construction Stress Calculation) June 1967. [9340_F032_017.pdf]

When the truss was closed at mid-span the loads in the members changed in magnitude and some members experienced a load reversal. Table 2 presents the forces in the main truss members around U10 from the steel self weight after closure at mid-span, as calculated from the VisualAnalysis model, by the Minnesota Highway Department, and by Sverdrup & Parcel.

Table 2: Continuous Truss Loads Steel Only

Member	Visual Analysis Member Force (kip)	MN Hwy Dept[4] Member Force (kip)	Sverdrup & Parcel[5] Member Force (kip)
U8/U10	340	391	370
U10/U12	-114	-108	-111
U10/L10	48	Not Available	86.3
L9/U10	-403	-422	-437
U10/L11	327	359	367
L9/L11	-109	-141	-142

The model data from Tables 1 and 2 was then compared to the design dead load and service loads of the completed structure. Table 3 contains data results from the VisualAnalysis model when the truss was cantilevered and continuous with steel weight only, and the design dead and service loads presented in the 9340 Bridge Design Drawings.

Table 3: Comparison of Truss Loads During Stages of Construction

Member	Model Cantilever (kip)	Model Continuous Steel Only (kip)	Completed Structure Dead Load[6] (kip)	Completed Structure Service Design Load[7] (kip)
U8/U10	723	340	1551	2179
U10/U12	351	-114	-486	-972
U10/L10	48	48	271	540
L9/U10	-342	-403	-1680	-2238
U10/L11	305	327	1432	1975
L9/L11	-533	-109	-559	-919

[4] G. McNerney, Minnesota Highway Department, (Truss Construction Stress Calculation) June 1967. [9340_F032_017.pdf]
[5] Sverdrup & Parcel and Associates, (IBM Calculations), June 23, 1964. See the Appendix.
[6] Construction Plan for Bridge No. 9340, Sverdrup & Parcel and Associates, Approved June 16, 1965.
[7] Construction Plan for Bridge No. 9340, Sverdrup & Parcel and Associates, Approved June 16, 1965.

D. Angle Between Adjacent Members at Node U10

In order to compensate for the deflection of the bridge under its own self weight, the main truss members were fabricated to lengths longer or shorter than the final design node-to-node dimensions, referred to as cambered lengths. Without gravity, this process would cause the bridge to have a slightly arched shape (camber). The deflection of the individual components due to the structure's dead weight then resulted in a completed bridge with an upper chord that was approximately straight. The lengths of the deflected members subjected to the structure dead weight are referred to as geometric length.

The change in member lengths would also change the angles between adjacent members. The change in angle at node U10 between the stage of erection and after application of dead load is of interest as a possible contributor to the bowing of the U10 gusset plates between upper chord U8/U10 and diagonal L9/U10. Table 4 summarizes the node-to-node dimensions according to the Allied Structural Steel Company's fabrication drawings, both for geometric and cambered member lengths. Dimensions in the drawings are listed in feet and inches to the nearest 1/32 of an inch. The dimensions from the drawings are listed in Table 4 along with conversions to decimal notation.

Table 4: Cambered and Geometric Lengths

Member	Geometric Length[8] (ft-in)	Geometric Length (ft)	Cambered Length[9] (ft-in)	Cambered Length (ft)
U8/U9	38'-0"	38.0000	37'-11 3/4"	37.9792
U9/U10	38'-0"	38.0000	37'-11 23/32"	37.9766
U8/L9	63'-10 7/16"	63.8698	63'-10"	63.8333
L9/U10	63'-10 7/16"	63.8698	63'-10 3/4"	63.8958
U8/L8	60'-0"	60.0000	60'-5/16"	60.0263
L8/L9	38'-11 23/32"	38.9766	38-11 15/16"	38.9948
U9/L9	51'-4"	51.3333	51'-4 1/8"	51.3438

Refer to figure 1 for a graphical representation of the geometric lengths and angles. The main truss members and gussets were laid out and reamed to the final geometry. In the layout, the angle between L9/U10 and U9/U10 was as specified in the steel detail drawings to be:

θ_R = 53° 29' 21" = 53.4892°[10]

[8] Bridge 9340 Steel Details, Industrial Construction Division Allied Structural Steel Company, Approved January 1965, Sheet L1.
[9] Bridge 9340 Steel Details, Industrial Construction Division Allied Structural Steel Company, Approved January 1965, Sheet L2.
[10] Bridge 9340 Steel Details, Industrial Construction Division Allied Structural Steel Company, Approved January 1965, Sheet L1.

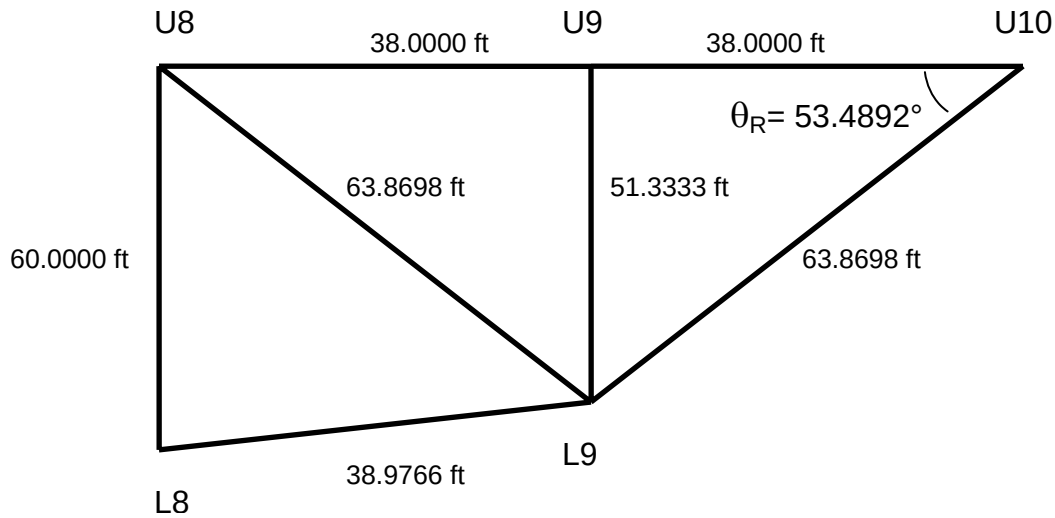


Figure 1: Geometric Lengths

The erection of main truss members at cambered lengths resulted in angles between adjacent members that were different than the design geometric angles. Two scenarios were examined to assess the possible range of angles that might have occurred. Figures 2 and 3 illustrate the two scenarios at erection.

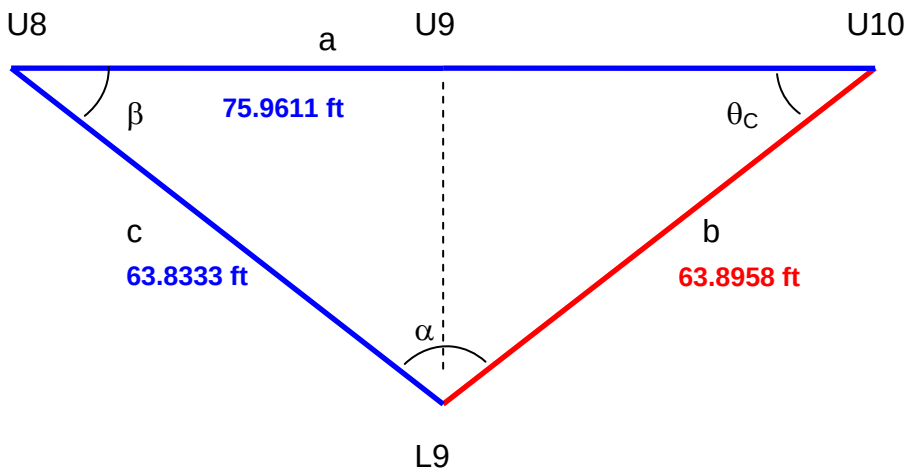


Figure 2: U8-U10-L9 Triangle Cambered Lengths

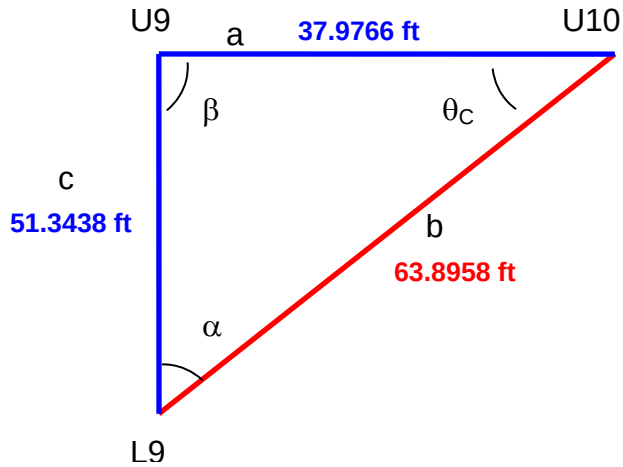


Figure 3: U9-U10-L9 Triangle Cambered Lengths

The law of cosines was used to determine the angle between top chord U8/U9 and diagonal L9/U10, as found in equation 1. The change in angle between cambered and final geometry positions was calculated using equation 2.

Equation 1: Law of Cosines

$$c^2 = a^2 + b^2 - 2ab\cos(\theta)$$

$$\theta = \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2ab}\right)$$

Equation 2: Change in Angle

$$\Delta\theta = \theta_C - \theta_R$$

Table 5 presents the angles calculate from the scenarios illustrated in figures 1, 2 and 3 from equations 1 and 2.

Table 5: Angle Calculations

	Geometric Shape	Cambered Angle U8-U10-L9	Cambered Angle U9-U10-L9
a (ft)	76.0000	75.9611	37.9766
b (ft)	63.8700	63.8958	63.8958
c (ft)	63.8700	63.8333	51.3438
a^2 (ft^2)	5776.00	5770.08	1442.2221
b^2 (ft^2)	4079.38	4082.68	4082.6771
c^2 (ft^2)	4079.38	4074.69	2636.1807
θ_C (deg)	53.4903	53.4706	53.4708
$\Delta\theta$ (deg)	0.0012	-0.0186	-0.0184

The change in angle, $\Delta\theta$, is small, so horizontal displacements were assumed to be negligible and that the width of the gusset plate, from centerline of node U10 to the edge, did not change. Vertical displacements at the free edge of the U10 gusset plate between the upper chord and diagonal L9/U10 could cause distortion of the U10 gusset. The length of the gusset plate, from centerline of node U10 to the south edge, was verified as 48.25 inches. The vertical distance, *d*, from centerline of the upper chord to the centerline of diagonal L9/U10 was calculated using equation 3.

Equation 3: Vertical Distance

$$d = 48.25 \tan(\theta)$$

The angles and the vertical distances are compared in table 6 for the reamed, geometric and cambered geometries.

Table 6: Vertical Distance Calculations and Displacements

	Reamed Angle	Geometric Shape	Cambered Angle U8-U10-L9	Cambered Angle U9-U10-L9
θ (deg)	53.4892	53.4903	53.4706	53.4708
d (in)	65.1804	65.1831	65.1361	65.1367

Table 6 shows that the angle and the vertical distance along the edge of the U10 gusset plate would increase from the initial cambered position to the final geometric (or reamed) shape under the bridge dead weight, as illustrated in figure 5.

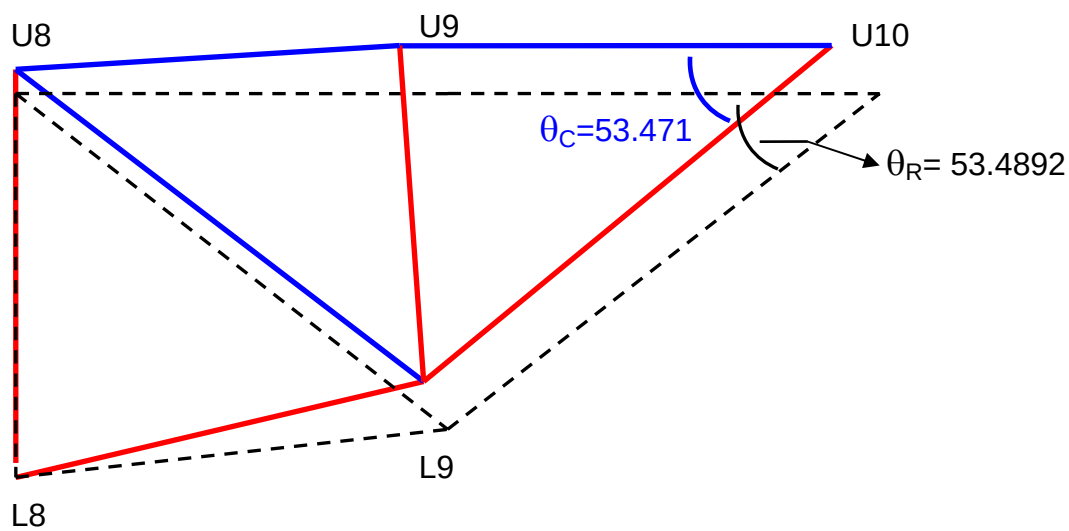


Figure 5: Comparison of Cambered and Geometric Deflections

Samuel Pond
Civil Engineer

Appendix

Sverdrup & Parcel and Associates, IBM Calculations for Bridge 9340, June 23, 1964.

Documents provided to the Safety Board by Jacobs Engineering.

SVERDRUP AND PARCEL AND ASSOCIATES, INC., ST. LOUIS, MISSOURI. COMPUTATIONS ON IBM 7072 JUNE 23, 1964 PAGE 1

PROGRAM NO. S1 FOR SPACE TRUSS ANALYSIS PROBLEM NO. 13

JOB NO. 2083 MINNESOTA BRIDGE NO. 9340

PROBLEM NO. 13 STEEL DEAD LOAD STRESSES

POINT NO.	X-FT.	Y-FT.	Z-FT.	PX-KIPS	PY-KIPS	PZ-KIPS	X-DEFL-IN	Y-DEFL-IN	Z-DEFL-IN
1	0.000	0.000	0.000	0.000	-87.500	0.000	-0.608	-0.198	0.000
2	38.000	-30.000	0.000	0.000	-58.500	0.000	-0.513	0.000	0.000
3	76.000	0.000	0.000	0.000	-57.500	0.000	-0.544	-0.008	0.000
4	114.000	-32.449	0.000	0.000	-57.400	0.000	-0.529	-0.006	0.000
5	152.000	0.000	0.000	0.000	-62.000	0.000	-0.537	0.066	0.000
6	190.000	-39.796	0.000	0.000	-66.400	0.000	-0.547	0.130	0.000
7	228.000	0.000	0.000	0.000	-81.500	0.000	-0.441	0.124	0.000
8	266.000	-52.041	0.000	0.000	-101.100	0.000	-0.664	0.046	0.000
9	304.000	0.000	0.000	0.000	-97.200	0.000	-0.315	-0.085	0.000
10	304.000	-60.000	0.000	0.000	-50.600	0.000	-0.731	0.000	0.000
11	342.000	-51.360	0.000	0.000	-104.100	0.000	-0.677	-0.495	0.000
12	380.000	0.000	0.000	0.000	-86.300	0.000	-0.201	-0.951	0.000
13	418.000	-39.840	0.000	0.000	-78.100	0.000	-0.584	-1.445	0.000
14	456.000	0.000	0.000	0.000	-78.200	0.000	-0.260	-1.849	0.000
15	494.000	-36.000	0.000	0.000	-81.800	0.000	-0.436	-2.146	0.000
16	532.000	0.000	0.000	0.000	-84.000	0.000	-0.371	-2.256	0.000
17	570.000	-36.000	0.000	0.000	-81.800	0.000	-0.311	-2.156	0.000
18	608.000	0.000	0.000	0.000	-78.200	0.000	-0.482	-1.867	0.000
19	646.000	-39.840	0.000	0.000	-78.100	0.000	-0.160	-1.467	0.000
20	684.000	0.000	0.000	0.000	-86.300	0.000	-0.547	-0.971	0.000
21	722.000	-51.360	0.000	0.000	-104.100	0.000	-0.059	-0.506	0.000
22	760.000	-60.000	0.000	0.000	-50.600	0.000	0.000	0.000	0.000
23	760.000	0.000	0.000	0.000	-97.200	0.000	-0.437	-0.083	0.000
24	798.000	-52.041	0.000	0.000	-101.100	0.000	-0.070	0.068	0.000
25	836.000	0.000	0.000	0.000	-81.500	0.000	-0.315	0.168	0.000
26	874.000	-39.796	0.000	0.000	-66.400	0.000	-0.195	0.198	0.000
27	912.000	0.000	0.000	0.000	-62.000	0.000	-0.209	0.150	0.000
28	950.000	-32.449	0.000	0.000	-58.400	0.000	-0.231	0.088	0.000
29	988.000	0.000	0.000	0.000	-61.700	0.000	-0.178	0.070	0.000
30	1026.000	-30.000	0.000	0.000	-65.500	0.000	-0.280	0.000	0.000
31	1064.000	0.000	0.000	0.000	-173.300	0.000	-0.083	-0.352	0.000

Sheet 2

SVERDRUP AND PARCEL. CONTINUATION OF RESULTS FOR PROGRAM S1 JUNE 23, 1964 PROBLEM 13 PAGE 2

MEMBER NO.	END PT. A	END PT. B	LENGTH-FT.	AREA-IN2	E-KSI	FORCE-KIPS	STRESS-KSI
1	1	2	48.415	57.00	30000.	-141.182	-2.477
2	1	3	76.000	52.90	30000.	110.833	2.095
3	2	3	48.415	69.70	30000.	-106.662	-1.530
4	2	4	76.039	50.30	30000.	-27.095	-0.539
5	3	4	49.969	27.70	30000.	13.246	0.478
6	3	5	76.000	73.90	30000.	17.040	0.231
7	4	5	49.969	32.30	30000.	66.447	2.057
8	4	6	76.354	68.30	30000.	-67.849	-0.993
9	5	6	55.025	60.70	30000.	-145.361	-2.395
10	5	7	76.000	52.90	30000.	167.958	3.175
11	6	7	55.025	57.70	30000.	180.961	3.136
12	6	8	76.980	89.30	30000.	-296.664	-3.322
13	7	8	64.438	98.20	30000.	-262.941	-2.678
14	7	9	76.000	108.90	30000.	448.001	4.114
15	8	9	64.438	74.00	30000.	286.556	3.872
16	8	10	38.825	173.70	30000.	-630.266	-3.628
17	9	10	60.000	187.80	30000.	-661.217	-3.521
18	10	11	38.970	173.70	30000.	-632.615	-3.642
19	9	11	63.889	91.70	30000.	413.748	4.512
20	9	12	76.000	98.40	30000.	370.896	3.769
21	11	12	63.889	133.70	30000.	-437.859	-3.275
22	11	13	76.868	68.30	30000.	-111.666	-1.635
23	12	13	55.057	86.90	30000.	367.194	4.225
24	12	14	76.000	73.90	30000.	-142.993	-1.935
25	13	14	55.057	98.20	30000.	-307.142	-3.128
26	13	15	76.097	96.30	30000.	355.494	3.692
27	14	15	52.345	57.70	30000.	209.482	3.631
28	14	16	76.000	139.10	30000.	-507.079	-3.645
29	15	16	52.345	46.80	30000.	-64.447	-1.377
30	15	17	76.000	134.80	30000.	553.917	4.109
31	16	17	52.345	46.80	30000.	-57.680	-1.232
32	16	18	76.000	139.10	30000.	-512.007	-3.681
33	17	18	52.345	57.70	30000.	203.406	3.525
34	17	19	76.097	96.30	30000.	364.853	3.789
35	18	19	55.057	98.20	30000.	-301.376	-3.069
36	18	20	76.000	73.90	30000.	-156.358	-2.116
37	19	20	55.057	86.90	30000.	364.006	4.189
38	19	21	76.868	68.30	30000.	-95.925	-1.404
39	20	21	63.889	133.70	30000.	-434.998	-3.254
40	20	23	76.000	98.40	30000.	353.592	3.593
41	21	23	63.889	91.70	30000.	412.915	4.503
42	21	22	38.970	173.70	30000.	-614.442	-3.537
43	22	23	60.000	187.80	30000.	-648.918	-3.455
44	22	24	38.825	173.70	30000.	-612.180	-3.524
45	23	24	64.438	74.00	30000.	272.147	3.678
46	23	25	76.000	108.90	30000.	438.695	4.028
47	24	25	64.438	98.20	30000.	-243.478	-2.479
48	24	26	76.980	89.30	30000.	-298.911	-3.347
49	25	26	55.025	57.70	30000.	159.200	2.759
50	25	27	76.000	52.90	30000.	185.173	3.500
51	26	27	55.025	60.70	30000.	-119.397	-1.967
52	26	28	76.354	68.30	30000.	-103.189	-1.511
53	27	28	49.969	32.30	30000.	37.501	1.161
54	27	29	76.000	73.90	30000.	74.208	1.004
55	28	29	49.969	29.90	30000.	42.430	1.419
56	28	30	76.039	62.80	30000.	-106.514	-1.696

Sheet 3

SVERDRUP AND PARCEL. CONTINUATION OF RESULTS FOR PROGRAM S1 JUNE 23, 1964 PROBLEM 13 PAGE 3

MEMBER NO.	END PT. A	END PT. B	LENGTH-FT.	AREA-IN2	E-KSI	FORCE-KIPS	STRESS-KSI
57	29	30	48.415	75.70	30000.	-144.029	-1.903
58	29	31	76.000	70.40	30000.	219.523	3.118
59	30	31	48.415	84.70	30000.	-279.671	-3.302

Sheet 4

FORM 6613 GV

SVERDRUP AND PARCEL. CONTINUATION OF RESULTS FOR PROGRAM S1 JUNE 23, 1964 PROBLEM 13 PAGE 4

POINT NO.	RX-KIPS	RY-KIPS	RZ-KIPS
2	-0.013	211.203	0.000
10	-0.009	981.278	0.000
22	0.029	961.243	0.000
30	0.004	324.613	0.000

NUMBER OF ITERATIONS = 159 CV = 0.90 MIN. ACC. = 0.000050 AVG. ACC. = 0.000012

EOJ 712

Sheet 5

SVERDRUP AND PARCEL AND ASSOCIATES, INC., ST. LOUIS, MISSOURI. COMPUTATIONS ON IBM 7072 MARCH 18 1964 PAGE 1

PROGRAM NO. S1 FOR SPACE TRUSS ANALYSIS PROBLEM NO. 12

JOB NO. 2083 MINNESOTA BRIDGE NO. 9340

PROBLEM NO. 12 DEAD LOAD STRESSES AND DEFLECTIONS

Horiz. Jt. Movement under Full D.L.

2

POINT NO.	X-FT.	Y-FT.	Z-FT.	PX-KIPS	PY-KIPS	PZ-KIPS	X-DEFL-IN	Y-DEFL-IN	Z-DEFL-IN	
1	0.000	0.000	0.000	0.000	-347.000	0.000	-2.037	-0.443	0.000	
2	38.000	-30.000	0.000	0.000	-338.500	0.000	-1.930=1 5/16"	0.000	0.000	PIER 5
3	76.000	0.000	0.000	0.000	-285.000	0.000	-1.785	-0.481	0.000	
4	114.000	-32.449	0.000	0.000	-337.400	0.000	-1.909	-0.841	0.000	
5	152.000	0.000	0.000	0.000	-255.000	0.000	-1.878	-0.572	0.000	
6	190.000	-39.796	0.000	0.000	-346.400	0.000	-1.858	-0.233	0.000	
7	228.000	0.000	0.000	0.000	-309.000	0.000	-1.613	-0.001	0.000	
8	266.000	-52.041	0.000	0.000	-381.100	0.000	-2.208	-0.054	0.000	
9	304.000	0.000	0.000	0.000	-290.200	0.000	-1.121	-0.323	0.000	
10	304.000	-60.000	0.000	0.000	-50.600	0.000	-2.428=2 7/16"	0.000	0.000	PIER 6
11	342.000	-51.360	0.000	0.000	-384.100	0.000	-2.272	-1.715	0.000	
12	380.000	0.000	0.000	0.000	-313.800	0.000	-0.642	-3.321	0.000	
13	418.000	-39.840	0.000	0.000	-305.600	0.000	-2.009	-5.127	0.000	
14	456.000	0.000	0.000	0.000	-305.700	0.000	-0.822	-6.637	0.000	
15	494.000	-36.000	0.000	0.000	-361.800	0.000	-1.472	-7.763	0.000	
16	532.000	0.000	0.000	0.000	-277.000	0.000	-1.233	-8.155	0.000	
17	570.000	-36.000	0.000	0.000	-361.800	0.000	-1.013	-7.801	0.000	
18	608.000	0.000	0.000	0.000	-305.700	0.000	-1.647	-6.704	0.000	
19	646.000	-39.840	0.000	0.000	-305.600	0.000	-0.467	-5.208	0.000	
20	684.000	0.000	0.000	0.000	-313.800	0.000	-1.847	-3.394	0.000	
21	722.000	-51.360	0.000	0.000	-384.100	0.000	-0.172	-1.757	0.000	
22	760.000	-60.000	0.000	0.000	-50.600	0.000	0.000=0	0.000	0.000	PIER 7
23	760.000	0.000	0.000	0.000	-290.200	0.000	-1.388	-0.317	0.000	
24	798.000	-52.041	0.000	0.000	-381.100	0.000	0.230	0.025	0.000	
25	836.000	0.000	0.000	0.000	-309.000	0.000	-0.906	0.159	0.000	
26	874.000	-39.796	0.000	0.000	-346.400	0.000	0.609	0.017	0.000	
27	912.000	0.000	0.000	0.000	-255.000	0.000	-0.610	-0.258	0.000	
28	950.000	-32.449	0.000	0.000	-338.400	0.000	-0.622	-0.482	0.000	
29	988.000	0.000	0.000	0.000	-289.200	0.000	-0.622	-0.182	0.000	
30	1026.000	-30.000	0.000	0.000	-345.500	0.000	-0.730=3/4"	0.000	0.000	PIER 8
31	1064.000	0.000	0.000	0.000	-628.200	0.000	-0.279	-0.946	0.000	

Sheet 6

SVERDRUP AND PARCEL CONTINUATION OF RESULTS FOR PROGRAM S1 MARCH 18 1964 PROBLEM 12 PAGE 2

MEMBER NO.	END PT. A	END PT. B	LENGTH-FT.	AREA-IN2	E-KSI	FORCE-KIPS	STRESS-KSI
1	1	2	48.415	57.00	30000.	-559.996	-9.824
2	1	3	76.000	52.90	30000.	439.533	8.309
3	2	3	48.415	69.70	30000.	-661.542	-9.491
4	2	4	76.039	50.30	30000.	79.744	1.585
5	3	4	49.969	27.70	30000.	192.374	6.945
6	3	5	76.000	73.90	30000.	-225.996	-3.058
7	4	5	49.969	32.30	30000.	320.596	9.926
8	4	6	76.354	68.30	30000.	-17.891	-0.262
9	5	6	55.025	60.70	30000.	-640.435	-10.551
10	5	7	76.000	52.90	30000.	460.089	8.697
11	6	7	55.025	57.70	30000.	883.371	15.310
12	6	8	76.980	89.30	30000.	-1083.946	-12.138
13	7	8	64.438	98.20	30000.	-1173.686	-11.952
14	7	9	76.000	108.90	30000.	1762.280	16.183
15	8	9	64.438	74.00	30000.	1216.052	16.433
16	8	10	38.825	173.70	30000.	-2533.201	-14.584
17	9	10	60.000	187.80	30000.	-2526.721	-13.454
18	10	11	38.970	173.70	30000.	-2542.686	-14.638
19	9	11	63.889	91.70	30000.	1560.442	17.017
20	9	12	76.000	98.40	30000.	1551.282	15.765
21	11	12	63.889	133.70	30000.	-1679.787	-12.564
22	11	13	76.868	68.30	30000.	-558.505	-8.177
23	12	13	55.057	86.90	30000.	1432.474	16.484
24	12	14	76.000	73.90	30000.	-436.509	-5.907
25	13	14	55.057	98.20	30000.	-1214.845	-12.371
26	13	15	76.097	96.30	30000.	1276.601	13.257
27	14	15	52.345	57.70	30000.	833.724	14.449
28	14	16	76.000	139.10	30000.	-1880.245	-13.517
29	15	16	52.345	46.80	30000.	-213.986	-4.572
30	15	17	76.000	134.80	30000.	2035.566	15.101
31	16	17	52.345	46.80	30000.	-188.776	-4.034
32	16	18	76.000	139.10	30000.	-1898.546	-13.649
33	17	18	52.345	57.70	30000.	811.063	14.057
34	17	19	76.097	96.30	30000.	1311.399	13.618
35	18	19	55.057	98.20	30000.	-1193.310	-12.152
36	18	20	76.000	73.90	30000.	-486.138	-6.578
37	19	20	55.057	86.90	30000.	1420.612	16.348
38	19	21	76.868	68.30	30000.	-500.045	-7.321
39	20	21	63.889	133.70	30000.	-1669.109	-12.484
40	20	23	76.000	98.40	30000.	1487.113	15.113
41	21	23	63.889	91.70	30000.	1557.504	16.985
42	21	22	38.970	173.70	30000.	-2475.112	-14.249
43	22	23	60.000	187.80	30000.	-2484.016	-13.227
44	22	24	38.825	173.70	30000.	-2465.848	-14.196
45	23	24	64.438	74.00	30000.	1166.098	15.758
46	23	25	76.000	108.90	30000.	1725.819	15.848
47	24	25	64.438	98.20	30000.	-1105.939	-11.262
48	24	26	76.980	89.30	30000.	-1087.474	-12.178
49	25	26	55.025	57.70	30000.	807.715	13.999
50	25	27	76.000	52.90	30000.	515.824	9.751
51	26	27	55.025	60.70	30000.	-549.730	-9.057
52	26	28	76.354	68.30	30000.	-136.815	-2.003
53	27	28	49.969	32.30	30000.	219.573	6.798
54	27	29	76.000	73.90	30000.	-30.797	-0.417
55	28	29	49.969	29.90	30000.	290.710	9.723
56	28	30	76.039	62.80	30000.	190.376	-3.031

2

Sheet 2

SVERDRUP AND PARCEL. CONTINUATION GE RESULTS FOR PROGRAM S1 MARCH 18 1964 PROBLEM 12 PAGE 3

MEMBER NO.	END PT. A	END PT. B	LENGTH-FT.	AREA-IN2	E-KSI	FORCE-KIPS	STRESS-KSI
57	29	30	48.415	75.70	30000.	-771.378	-10.190
58	29	31	76.000	70.40	30000.	795.721	11.303
59	30	31	48.415	84.70	30000.	-1013.807	-11.969

2

Sheet 8

SVERDRUP AND PARCEL. CONTINUATION OF RESULTS FOR PROGRAM S1 MARCH 18 1964 PROBLEM 12 PAGE 4

POINT NO.	RX-KIPS	RY-KIPS	RZ-KIPS
2	-C.CC1	1097.987	0.000
10	C.CC4	3660.363	0.000
22	-C.C34	3588.869	0.000
30	C.CC1	1445.548	0.000

NUMBER OF ITERATIONS = 224 CV = 0.90 MIN. ACC. = 0.000074 AVG. ACC. = 0.000002

2

Sheet 9

SVERDRUP AND PARCEL AND ASSOCIATES, INC., ST. LOUIS, MISSOURI. COMPUTATIONS ON IBM 7072 MARCH 18 1964 PAGE 1

PROGRAM NO. S1 FOR SPACE TRUSS ANALYSIS PROBLEM NO. 11

JOB NO. 2082 MINNESOTA BRIDGE NO. 9340

PROBLEM NO. 11 INFLUENCE LINE OF REACTION AT POINT 10

POINT NO.	X-FT.	Y-FT.	Z-FT.	PX-KIPS	PY-KIPS	PZ-KIPS	X-DEFL-IN	Y-DEFL-IN	Z-DEFL-IN
1	0.000	0.000	0.000	0.000	0.000	0.000	-0.526	-2.144	0.000
2	38.000	-38.000	0.000	0.000	0.000	0.000	1.167	0.000	0.000
3	76.000	0.000	0.000	0.000	0.000	0.000	-0.526	2.309	0.000
4	114.000	-32.449	0.000	0.000	0.000	0.000	1.143	4.653	0.000
5	152.000	0.000	0.000	0.000	0.000	0.000	-0.296	6.581	0.000
6	190.000	-39.796	0.000	0.000	0.000	0.000	1.134	8.061	0.000
7	228.000	0.000	0.000	0.000	0.000	0.000	0.226	8.986	0.000
8	266.000	-52.041	0.000	0.000	0.000	0.000	1.038	9.610	0.000
9	304.000	0.000	0.000	0.000	0.000	0.000	0.517	9.999	0.000
10	304.000	-60.000	0.000	0.000	0.000	0.000	1.022	10.000	0.000
11	342.000	-51.360	0.000	0.000	0.000	0.000	0.864	10.261	0.000
12	380.000	0.000	0.000	0.000	0.000	0.000	0.845	10.252	0.000
13	418.000	-39.840	0.000	0.000	0.000	0.000	0.467	9.855	0.000
14	456.000	0.000	0.000	0.000	0.000	0.000	1.231	9.046	0.000
15	494.000	-36.000	0.000	0.000	0.000	0.000	0.327	7.948	0.000
16	532.000	0.000	0.000	0.000	0.000	0.000	1.354	6.652	0.000
17	570.000	-36.000	0.000	0.000	0.000	0.000	0.256	5.282	0.000
18	608.000	0.000	0.000	0.000	0.000	0.000	1.374	3.937	0.000
19	646.000	-39.840	0.000	0.000	0.000	0.000	0.174	2.700	0.000
20	684.000	0.000	0.000	0.000	0.000	0.000	1.234	1.619	0.000
21	722.000	-51.360	0.000	0.000	0.000	0.000	0.106	0.741	0.000
22	760.000	-60.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	760.000	0.000	0.000	0.000	0.000	0.000	1.052	0.011	0.000
24	798.000	-52.041	0.000	0.000	0.000	0.000	0.188	-0.614	0.000
25	836.000	0.000	0.000	0.000	0.000	0.000	0.875	-1.096	0.000
26	874.000	-39.796	0.000	0.000	0.000	0.000	0.525	-1.396	0.000
27	912.000	0.000	0.000	0.000	0.000	0.000	0.559	-1.358	0.000
28	950.000	-32.449	0.000	0.000	0.000	0.000	0.697	-1.050	0.000
29	988.000	0.000	0.000	0.000	0.000	0.000	0.420	-0.507	0.000
30	1026.000	-30.000	0.000	0.000	0.000	0.000	0.747	0.000	0.000
31	1064.000	0.000	0.000	0.000	0.000	0.000	0.420	0.415	0.000

2

Sheet 10

SVERDRUP AND PARCEL. CONTINUATION OF RESULTS FOR PROGRAM S1 MARCH 18 1964 PROBLEM 11 PAGE 2

MEMBER NO.	END PT. A	END PT. B	LENGTH-FT.	AREA-IN2	E-KSI	FORCE-KIPS	STRESS-KSI
1	1	2	48.415	57.00	30000.	0.721	0.013
2	1	3	76.000	52.90	30000.	0.457	0.009
3	2	3	48.415	69.70	30000.	368.534	5.287
4	2	4	76.039	50.30	30000.	-287.963	-5.725
5	3	4	49.969	27.70	30000.	-351.242	-12.680
6	3	5	76.000	73.90	30000.	557.603	7.545
7	4	5	49.969	32.30	30000.	254.348	7.875
8	4	6	76.354	68.30	30000.	-751.230	-10.999
9	5	6	55.025	60.70	30000.	-227.476	-3.748
10	5	7	76.000	52.90	30000.	908.823	17.180
11	6	7	55.025	57.70	30000.	109.292	1.894
12	6	8	76.980	89.30	30000.	-992.302	-11.112
13	7	8	64.438	98.20	30000.	-96.946	-0.987
14	7	9	76.000	108.90	30000.	1042.524	9.573
15	8	9	64.438	74.00	30000.	20.602	0.278
16	8	10	38.825	173.70	30000.	-1068.625	-6.152
17	9	10	60.000	187.80	30000.	-5.471	-0.029
18	10	11	38.970	173.70	30000.	-1069.934	-6.160
19	9	11	63.889	91.70	30000.	-13.429	-0.146
20	9	12	76.000	98.40	30000.	1063.267	10.806
21	11	12	63.889	133.70	30000.	-92.281	-0.690
22	11	13	76.868	68.30	30000.	-1007.421	-14.750
23	12	13	55.057	86.90	30000.	102.717	1.182
24	12	14	76.000	73.90	30000.	937.498	12.686
25	13	14	55.057	98.20	30000.	-257.666	-2.624
26	13	15	76.097	96.30	30000.	-746.822	-7.755
27	14	15	52.345	57.70	30000.	271.106	4.699
28	14	16	76.000	139.10	30000.	562.880	4.047
29	15	16	52.345	46.80	30000.	-325.094	-6.946
30	15	17	76.000	134.80	30000.	-311.775	-2.313
31	16	17	52.345	46.80	30000.	324.952	6.943
32	16	18	76.000	139.10	30000.	91.278	0.656
33	17	18	52.345	57.70	30000.	-312.816	-5.421
34	17	19	76.097	96.30	30000.	152.309	1.582
35	18	19	55.057	98.20	30000.	296.947	3.024
36	18	20	76.000	73.90	30000.	-340.753	-4.611
37	19	20	55.057	86.90	30000.	-202.330	-2.328
38	19	21	76.868	68.30	30000.	503.422	7.371
39	20	21	63.889	133.70	30000.	181.996	1.361
40	20	23	76.000	98.40	30000.	-588.473	-5.980
41	21	23	63.889	91.70	30000.	-89.053	-0.971
42	21	22	38.970	173.70	30000.	676.398	3.894
43	22	23	60.000	187.80	30000.	82.737	0.441
44	22	24	38.825	173.70	30000.	652.882	3.759
45	23	24	64.438	74.00	30000.	-13.474	-0.182
46	23	25	76.000	108.90	30000.	-633.008	-5.813
47	24	25	64.438	98.20	30000.	60.208	0.613
48	24	26	76.980	89.30	30000.	603.516	6.758
49	25	26	55.025	57.70	30000.	-66.736	-1.157
50	25	27	76.000	52.90	30000.	-550.869	-10.413
51	26	27	55.025	60.70	30000.	138.674	2.285
52	26	28	76.354	68.30	30000.	456.201	6.679
53	27	28	49.969	32.30	30000.	-154.211	-4.774
54	27	29	76.000	73.90	30000.	-337.308	-4.564
55	28	29	49.969	29.90	30000.	213.211	7.131
56	28	30	76.039	62.80	30000.	174.970	2.786

2

Sheet 11

SVERDRUP AND PARCEL. CONTINUATION OF RESULTS FOR PROGRAM S1 MARCH 18 1964 PROBLEM 11 PAGE 3

MEMBER NO.	END PT. A	END PT. B	LENGTH-FT.	AREA-IN2	E-KSI	FORCE-KIPS	STRESS-KSI
57	29	30	48.415	75.70	30000.	-223.051	-2.947
58	29	31	76.000	70.40	30000.	0.214	0.003
59	30	31	48.415	84.70	30000.	0.037	0.000

2

Sheet 12

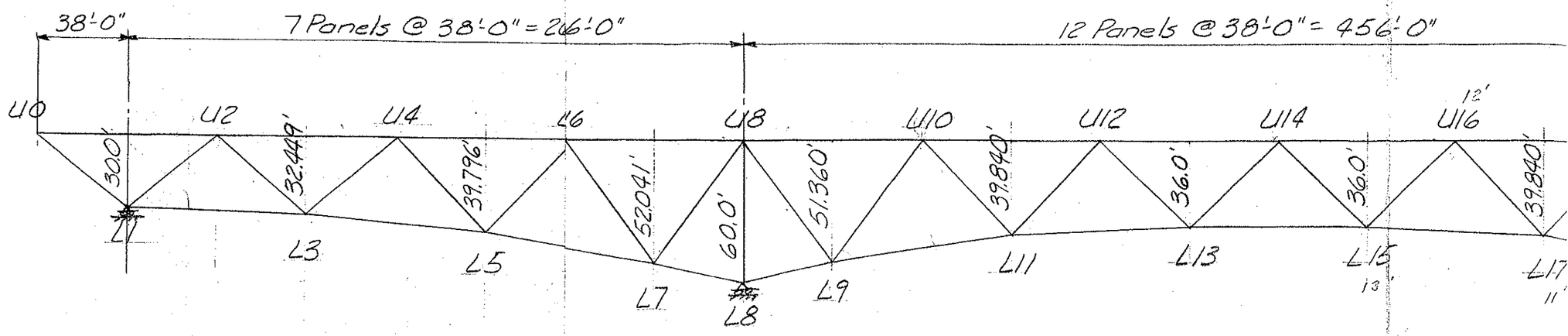
SVERDRUP AND PARCEL, CONTINUATION OF RESULTS FOR PROGRAM S1 MARCH 18 1964 PROBLEM 11 PAGE 4

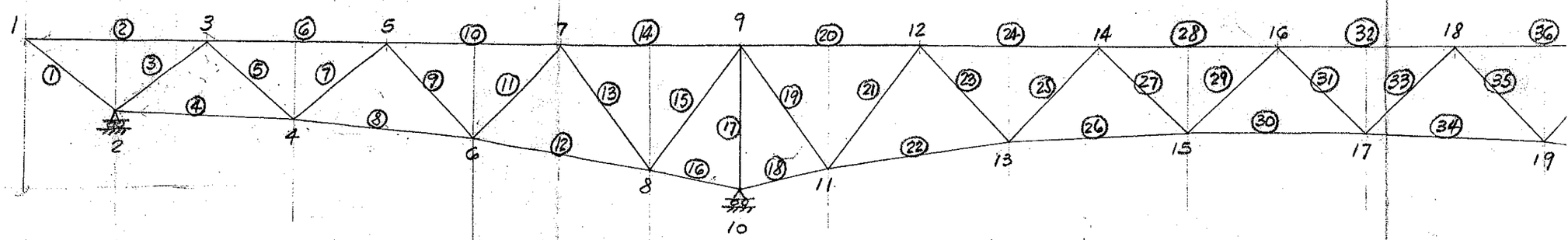
POINT NO.	RX-KIPS	RY-KIPS	RZ-KIPS
2	-0.877	-238.081	0.000
10	2.624	461.753	0.000
22	2.548	-366.541	0.000
30	-0.219	143.824	0.000

NUMBER OF ITERATIONS = 401 CV = 0.20 MIN. ACC. = 0.000998 AVG. ACC. = 0.000214

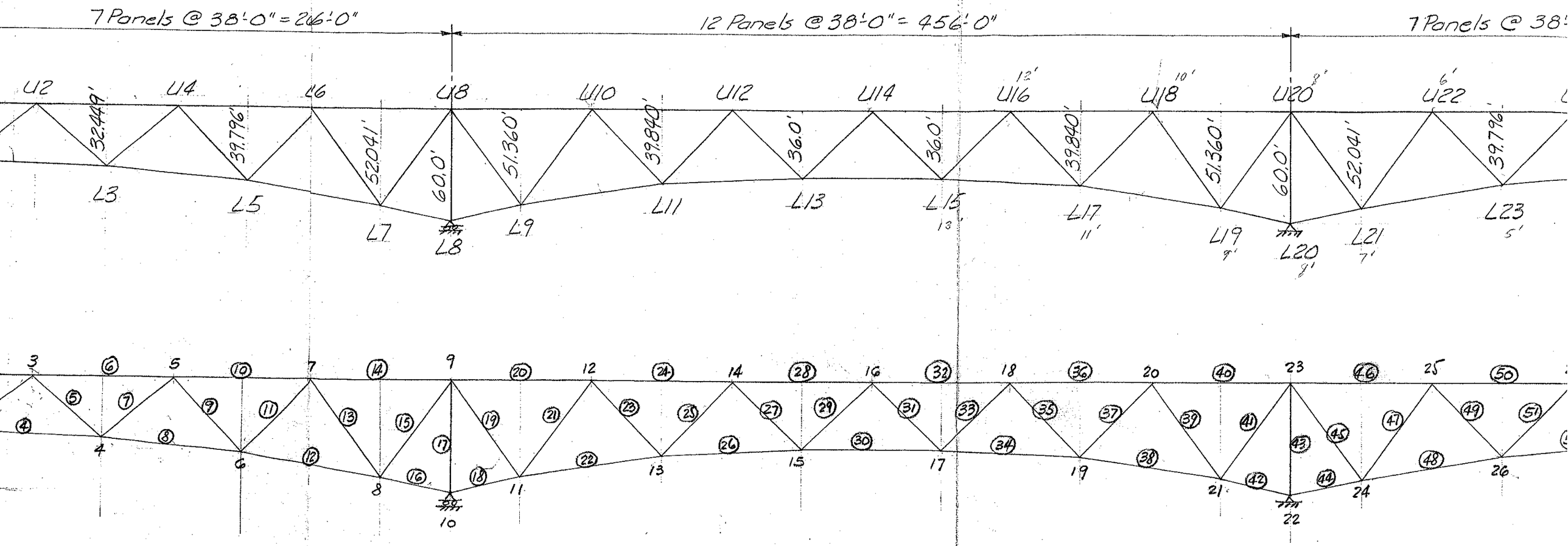
2

Sheet 13

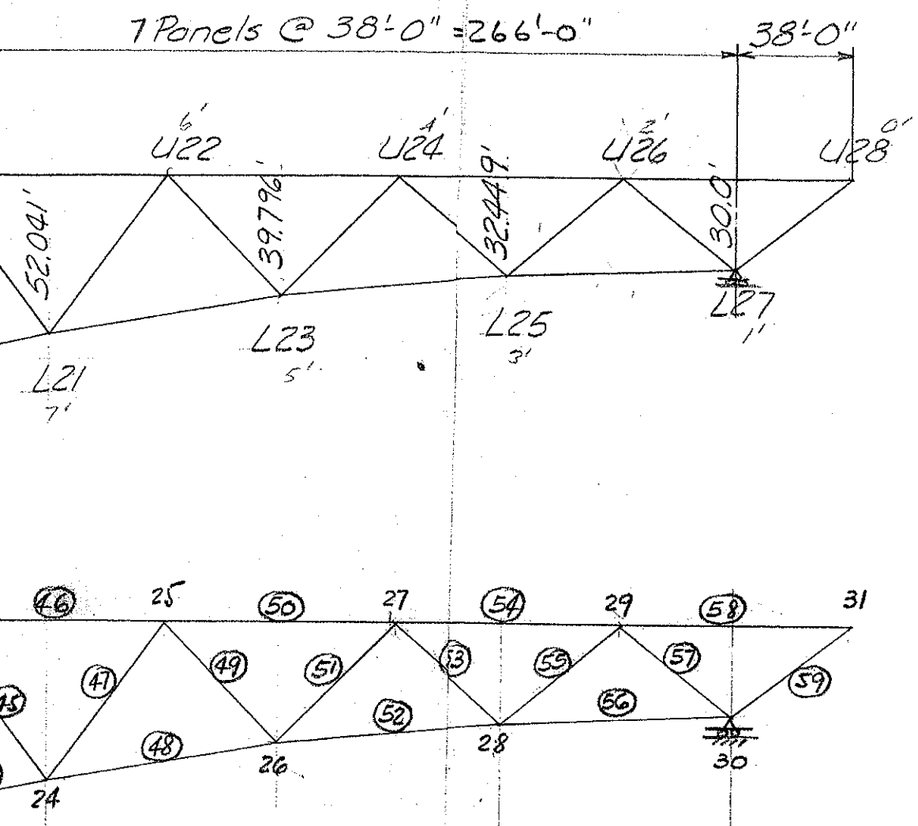




Joints & Member Designation for IBM Program



Joints & Member Designation for IBM Program



Member	Area
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U_2U_4	73.9
U_4U_6	52.9
U_6U_8	108.9
U_8U_{10}	98.4
$U_{10}U_{12}$	73.9
$U_{12}U_{14}$	139.1
$U_{14}U_{16}$	139.1
$U_{16}U_{18}$	73.9
$U_{18}U_{20}$	98.4
$U_{20}U_{22}$	108.9
$U_{22}U_{24}$	52.9
$U_{24}U_{26}$	73.9
$U_{26}U_{28}$	70.4
L_1L_3	50.3
L_3L_5	68.3
L_5L_7	89.3
L_7L_8	173.7
L_8L_9	173.7
L_9L_{11}	68.3
$L_{11}L_{13}$	96.3
$L_{13}L_{15}$	134.8
$L_{15}L_{17}$	96.3
$L_{17}L_{19}$	68.3
$L_{19}L_{20}$	173.7
$L_{20}L_{21}$	173.7
$L_{21}L_{23}$	89.3
$L_{23}L_{25}$	68.3
$L_{25}L_{27}$	62.8

Member	Area
U_0L_1	57.0
L_1U_2	69.7
U_2L_3	27.7
L_3U_4	32.3
U_4L_5	60.7
L_5U_6	57.7
U_6L_7	98.2
L_7U_8	74.0
U_8L_9	91.7
L_9U_{10}	133.7
$U_{10}L_{11}$	86.9
$L_{11}U_{12}$	98.2
$U_{12}L_{13}$	57.7
$L_{13}U_{14}$	46.8
$U_{14}L_{15}$	46.8
$L_{15}U_{16}$	57.7
$U_{16}L_{17}$	98.2
$L_{17}U_{18}$	86.9
$U_{18}L_{19}$	133.7
$L_{19}U_{20}$	91.7
$U_{20}L_{21}$	74.0
$L_{21}U_{22}$	98.2
$U_{22}L_{23}$	57.7
$L_{23}U_{24}$	60.7
$U_{24}L_{25}$	32.3
$L_{25}U_{26}$	29.9
$U_{26}L_{27}$	75.7
$L_{27}U_{28}$	84.7
U_8L_8	187.8
$U_{20}L_{20}$	187.8

Panel Pt.	Dead Load
0	347.0
1	338.5
2	285.0
3	337.4
4	255.0
5	346.4
6	309.0
7	381.1
8	340.8
9	384.1
10	313.8
11	305.6
12	305.7
13	361.8
14	277.0
15	361.8
16	305.7
17	305.6
18	313.8
19	384.1
20	340.8
21	381.1
22	309.0
23	346.4
24	255.0
25	338.4
26	289.2
27	345.5
28	628.2

MINNESOTA BRIDGE #9340 JOB No.: 2083

SCALE: 1" = 50'

Sheet 1