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Technical Report

No. 13557

FINITE ELEMENT ANALYSIS

OF THE ARMORED VEHICLE LAUNCHED BRIDGE (AVLB)

MARCH 1992

By
Roberto P. Garcia
Stephen G. Lambrecht
U.S. Army Tank-Automotive Command
ATTN: AMSTA-RYC
Warren, MI 48397-5000

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U.S. ARMY TANK-AUTOMOTIVE COMMAND
RESEARCH, DEVELOPMENT & ENGINEERING CENTER
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Roberto P. Garcia
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13. ABSTRACT *(Maximum 200 words)*

The Armored Vehicle Launched Bridge (AVLB) is a folding bridge that was fielded in the early 1960's as the Army's standard heavy assault bridge. The bridge is rated for normal crossings of military load classifiecation of 60 tons (MLC 60) over a maximum gap of 60 feet and a vehicle speed of 25 mph. The System Simulation and Technology Division, AMSTA-RY, was tasked by the Systems Engineering Directorate, AMSTA-U, to perform an anlaysis of the AVLB over a 60-foot gap while an M1A1 crosses it. The objective of this project was to perform a finite element analysis (FEA) of the whole AVLB to determine high-stress areas of concern.

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1.0. INTRODUCTION

The Armored Vehicle Launched Bridge (AVLB) is a folding bridge that was fielded in the early 1960s as the Army's standard heavy assault bridge. Fielded versions include both the M60 and M48 tank chassis. The bridge is constructed primarily of aluminum alloy and weighs approximately 29,500 lbs. FIGURE 1-1 depicts the deployed AVLB during strain gage testing.

The bridge is rated for normal crossings of military load classifications of 60 tons (MLC 60) over a maximum gap of 60 feet and a vehicle speed of 25 mph. MLC 61-64 loads at 8 mph are classified as caution crossings, and MLC 65-75 at 3 mph are classified as risk crossings for the same gap distance. The fielding of the M1A1 Abrams main battle tank with the T-158 track has resulted in a load classification of MLC 68, which is a risk category for crossing the AVLB.

The System Simulation and Technology Division, AMSTA-RY, was tasked by the Systems Engineering Directorate, AMSTA-U, to perform an analysis of the AVLB over a 60-foot gap while an M1A1 crosses it. The Analytical and Physical Simulation Branch, AMSTA-RYA, performed the flexible body dynamic analysis portion of this project, and the Computer-Aided Engineering Branch, AMSTA-RYC, performed the quasi-static finite element analysis. This report covers the finite element analysis aspect.

2.0. OBJECTIVE

The objective of this project was to perform a finite element analysis of the whole AVLB to determine high-stress areas of concern. A low-resolution beam Finite Element Model (FEM) of the AVLB was created first, in order to obtain certain modal characteristics of the bridge. The information from the beam model was used by Dr. Roger A. Wehage and Mr. Micheal J. Belczynski of AMSTA-RYA to create a Symbolically Optimized Vehicle Analysis System (SOVAS) model of the AVLB to interact with a current M1A1 model. These mathematical models were used to determine distributed vehicle dynamic reaction loads on the whole AVLB. Time histories of all forces and moments from the dynamic analysis were used as inputs to a higher resolution plate finite element model of AVLB. Several different finite element analyses were performed for the purpose of locating potential high-stress areas.

3.0. CONCLUSIONS

The results of this report are based on a bridge in "like new condition" with no rust or other damage. Also, no fatigue analysis or prototype tests were performed for this project. No mud loads or steering corrections were applied to the bridge and the ends were level and simply supported.

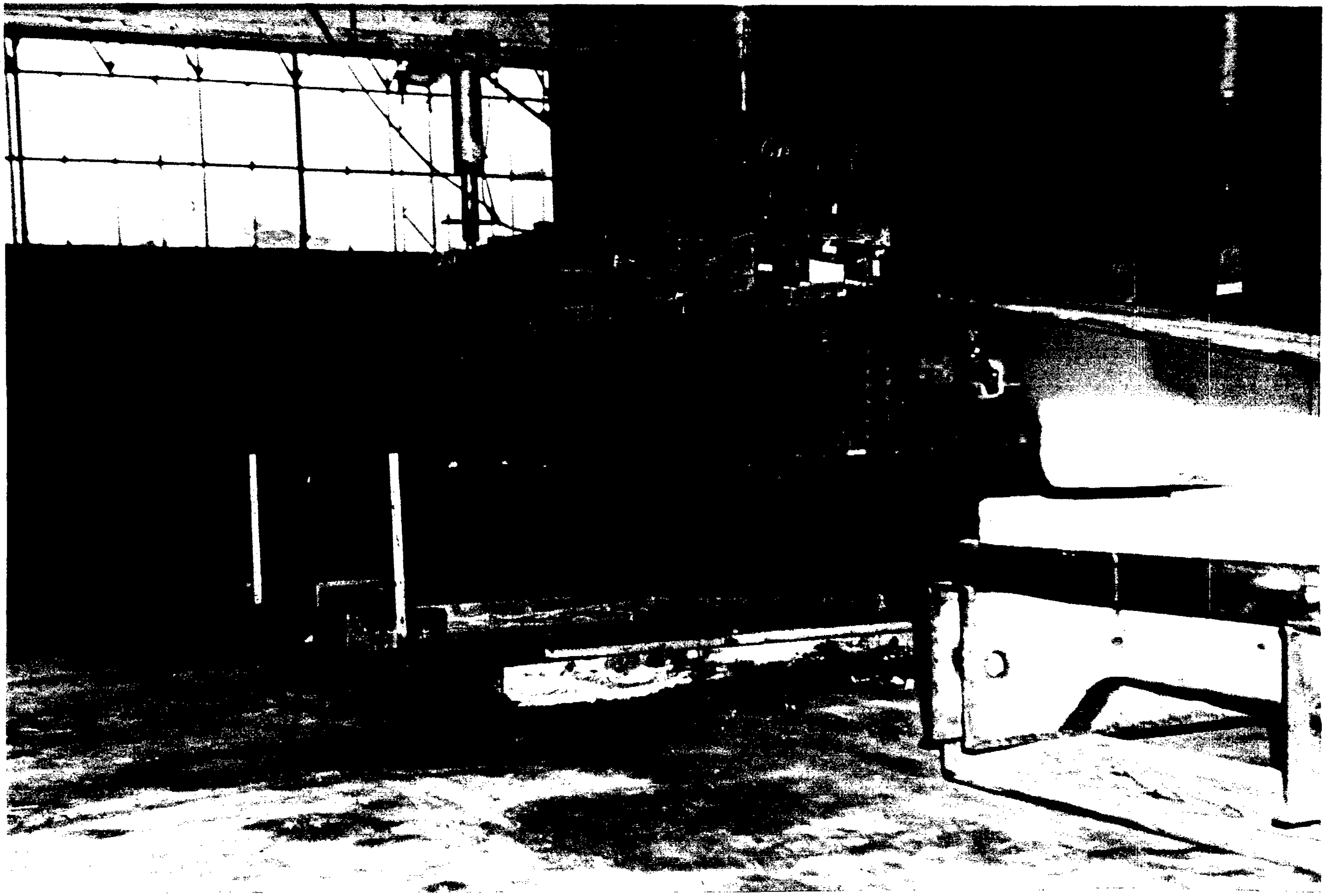

FIGURE 1-1. Armored Vehicle Launched Bridge.

The area just above the center hinges consistently had the highest stresses. On the analyses that simulated the M1A1 directly over the center of the bridge, the von Mises stresses were considerably greater than the ultimate strength of the material, indicating a structural failure near this location. The speed of the vehicle did not seem to have an effect on the magnitude of the stress; however, with increased speeds, the bridge seemed to sway more from side to side. TABLE 3-1 below summarizes the results from this project. These values were compared to the yield strength of 2014-T6 aluminum which is 60.2 ksi.

Analysis	Von Mises Stress	Max. Displacement
Gravity	12,469 psi	1.245 in.
Static (68.2 ton)	119,119 psi	10.80 in.
3mph (Quarter span)	58,480 psi	5.936 in.
3mph (Center)	119,234 psi	10.82 in.
8mph (Quarter Span)	66,663 psi	6.820 in.
8mph (Center)	118,169 psi	10.70 in.
25mph (Quarter Span)	61,566 psi	6.101 in.
25mph (Center)	118,993 psi	10.64 in.

TABLE 3-1. Summary of Plate Finite Element Analysis Results.

4.0. RECOMMENDATIONS

It is recommended that a more detailed model, perhaps a 3-D solid model, of the center hinge and surrounding area be created and a finite element analysis be performed. This analysis would further pinpoint the critical location and would better quantify the stress results. It was found that this hinge location is the only real area of concern on the bridge. This location may have to be redesigned or modified on the actual AVLB, in order to support the increased vehicle loads.

5.0. DISCUSSION

5.1. Approach

The technical approach used for this project was based on the utilization of computer-aided simulation and finite element analysis methods. This project used a three-step process. First, a low-resolution beam finite element model of the bridge was created in order to obtain certain modal characteristics of the bridge quickly. This information was then used by AMSTA-RYA to create a model of the bridge in their SOVAS package. They, in turn, performed a number of dynamic runs simulating a 68.2-ton M1A1 driving down the center line of the AVLB with no steering corrections at three different vehicle speeds; 3 mph, 8 mph, and 25 mph. These runs resulted in a set of force loadings for each.

During the time taken to perform the dynamic simulations, a more detailed plate model of the bridge was created. The force loadings for the different speeds were then applied to this plate model to determine the critical stresses, strains, and deflections, while pinpointing areas of concern.

5.2. Finite Element Method

The finite element method is an analysis technique for solving the differential equations of complex problems. This method has become a valuable tool for modeling structural, mechanical, thermal, and fluid systems. In finite element analysis, a structure is broken down into simple discrete regions, or finite elements. These simple structural elements, which can be beams, shells, or solids, have elastic behavior that can be formulated mathematically. These elements are then assembled to form the overall structure of the item being analyzed. It is mandatory that the behavior of the model closely exhibits the behavior of the actual physical structure, in order to obtain realistic results and verify the model.

5.3. Computer Software and Hardware

5.3.1. PATRAN. PATRAN is a pre/postprocessing software package developed by PDA Engineering. PATRAN is used to visually create the FEM. PATRAN's postprocessor allows the analyst to view the results of the analysis in graphical form. PATRAN resides on a VAX 8800 and viewed using Tektronix terminals. PATRAN is also on a Silicon Graphics Personal Iris workstation.

5.3.2. ABAQUS. ABAQUS is a large-scale, general-purpose finite element analysis program capable of analyzing complex structures. The analyst first needs an input file, which in this case was created using PATRAN. The input file defines the shape and material properties of the model, as well as boundary conditions and loads. The program then assembles and solves a system of equations on TACOM's Cray-2 Supercomputer and outputs the results. ABAQUS was developed by Hibbitt, Karlsson, & Sorensen, Inc.

5.4. Finite Element Models

The finite element model contains all the information needed to run the analysis. The model defines the actual shape and dimensions of the bridge, the materials used and their properties, and any boundary conditions and force loadings.

The models were constructed using PATRAN. Using grids, lines, and patches, the geometry of the bridge was created first. The finite elements and corresponding nodal points were then made using the geometry. The materials were defined along with the element thicknesses and boundary conditions. This PATRAN model was then translated into an ABAQUS input model using a translator called PATABA. The force loadings and masses were added to the ABAQUS input file using the vi editor on the Cray-2 super computer. Two finite element models were created for this project-- a low-resolution beam model and a more detailed plate model.

5.4.1. Beam model. This low-resolution, three-dimensional (3-D) model is composed of 2-D B3 ABAQUS beam elements. The model has 228 nodes, 252 beam type elements, and 1912 degrees of freedom (DOF). See FIGURE 5-1. With beam elements, the cross section of each element was defined in ABAQUS. This beam model was used to obtain certain modal characteristics of the bridge quickly. Such characteristics include: eigenvalues and eigenvectors, the stiffness matrix, and nodal generalized masses, which were obtained after performing an analysis for the first six mode shapes. This information was used by AMSTA-RYA to develop the dynamic modal representation of the bridge suitable for interacting with the M1A1 vehicle model. A complete listing of the ABAQUS input file for this beam model is located in Appendix C.

5.4.2. Plate model. Although the beam model is a good representation of the bridge giving good results, it is not detailed enough to pinpoint areas of concern. It is for this reason a more detailed plate model of the AVLB was created. This model is composed of 37,250 shell elements, the majority of which are quad type, and 18,780 nodes. None of the rivets were modeled for this project. The entire bridge was modeled; no symmetry was used, since the loadings were not symmetrical. FIGURE 5-2 depicts the AVLB plate model, and FIGURE 5-3 shows the plate model viewed from the underside.

The plate model is constructed of SR4 quad/4 elements and STRI3 tri/3 elements. The quad/4 elements have four nodes, one at each of the corners, and the tri/3 elements have 3 nodes. These shell elements have six degrees of freedom, giving the entire model 112,680 degrees of freedom. The STRI3 elements are flat faceted elements, which were used since the AVLB model has no curved or rounded surfaces. With shell elements, the thickness of each element needed to be given. This model has twenty-four (24) different properties, or thicknesses defined.

5.4.3. Materials. There are a number of different types of materials on the AVLB, but only two classes: steel and aluminum. On the two finite element models, the density, Modulus of Elasticity, and Poison's Ratio are the same for all the materials in their class. Therefore, only two classes of materials are defined, steel and aluminum. See TABLE 5-1. It is not until the results are being interpreted that the actual specific material with its yield, ultimate, and shear strengths is compared. See Appendix A for a complete list of material types on the AVLB, along with their properties.

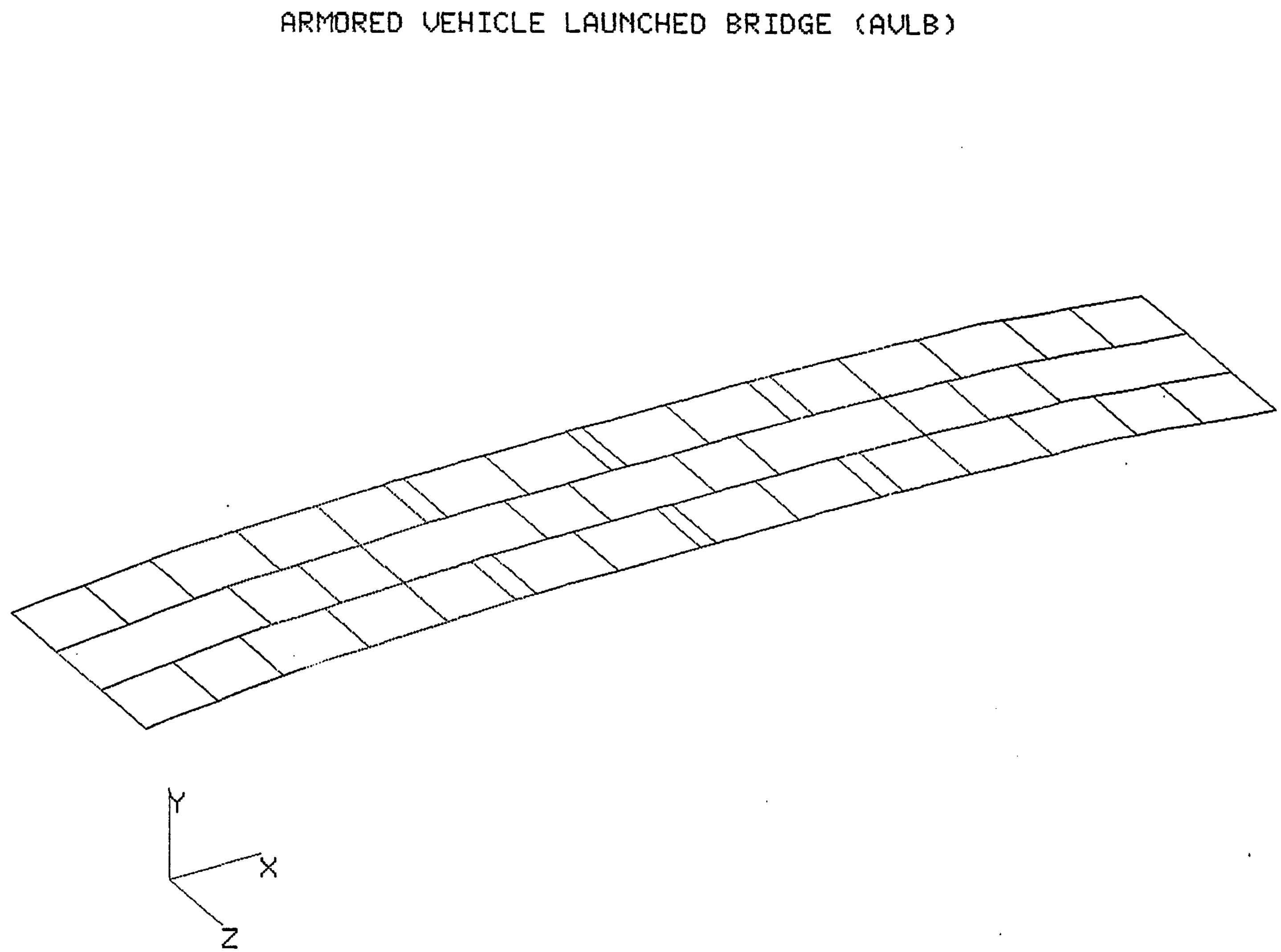

FIGURE 5-1. Beam Finite Element Model of AVLB.

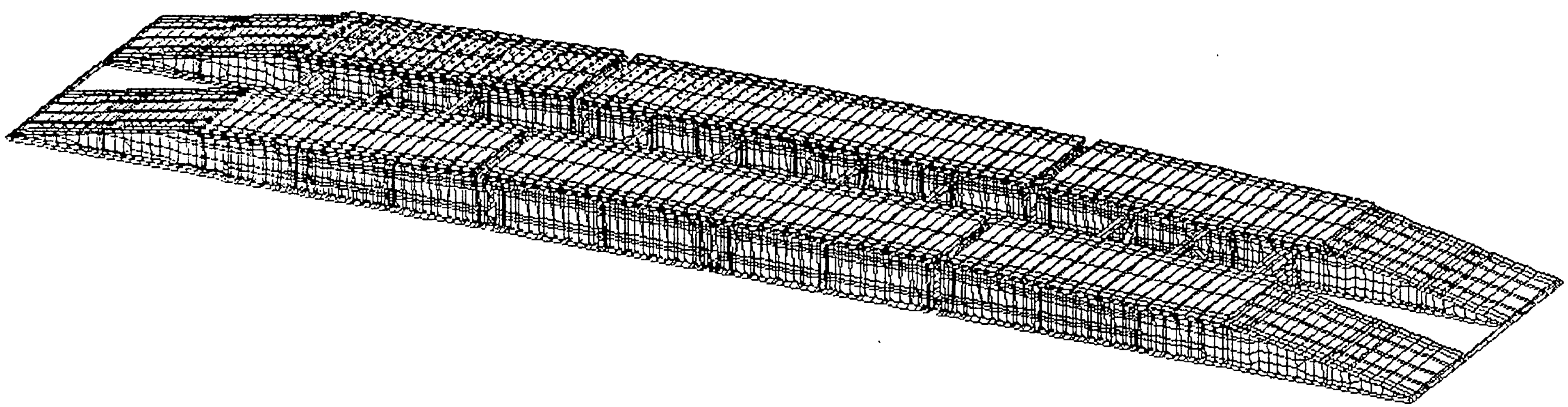

FIGURE 5-2. Plate Finite Element Model of AVLB.

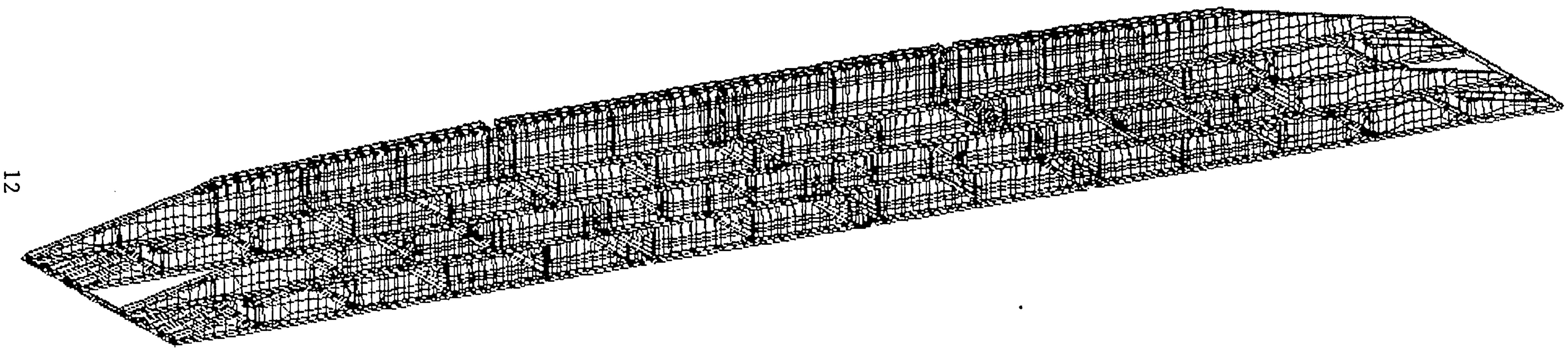

FIGURE 5-3. Under Side View of Plate Finite Element Model.

Property	2014-T6 Alum.	ASTM A36 Steel
Modulus of Elasticity	10.6×10^6 psi	29.0×10^6 psi
Ultimate Tensile Strength	70.1 ksi	58.0 ksi
Yield Strength	60.2 ksi	36.0 ksi
Shear Strength	42.1 ksi	21.0 ksi
Density	0.101 lb/in^3	0.284 lb/in^3
Poison's Ratio	0.34	0.31

TABLE 5-1. Properties of Two Materials on Bridge[1].

5.4.4. Added masses. On both the beam model and plate model certain items were not physically modeled, because they did not add to the structural integrity of the AVLB. TABLE 5-2 lists these items along with their actual weights. However, the weight of the finite element model must be the same as that of the actual AVLB, in order to determine the correct modal information and to include the gravity effects. The cylinder and quadrant were added at their respective locations on the bridge models as mass loads. An analysis simulating gravity acting on the bridge was performed, and the weight of the model was found to be 25,824.3 lb. The actual weight of the AVLB is 29,500 lb. The difference was then distributed as a mass load over the entire bridge model.

Item	Weight
Cylinder	1500 lbs
Quadrant	500 lbs
Cables	100 lbs ea.
Cable Ends	60 lbs ea.
Side Curbs	1800 lbs
Cylinder Braces	60 lbs
Launch Tongue	240 lbs
Quadrant Bracket	100 lbs
Beams for Cable Ends	250 lbs

TABLE 5-2. Nonstructural Items Added to Models as Mass Loads.

5.4.5. Boundary conditions. Both of the bridge models were constrained to simulate a 60-ft span or crossing distance. On the plate model, it actually was 59.81 ft. because of node locations. On both FEA models, the leading edge of the bridge is constrained from moving vertically, laterally, and longitudinally, while the trailing edge is constrained from moving vertically only. This boundary condition closely simulates the true condition, while also satisfying the type of constraints needed for the analysis code.

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[1]Beer, F. P. and E. R. Johnston, Jr., Mechanics of Materials, McGraw-Hill Book Company, 1981, p. 584

For the plate model, special constraints were needed to simulate the hinges and pinned locations of the AVLB. ABAQUS' Multi-Point Constraint (MPC) number 9 provides a pinned joint between two nodes. This makes the displacements equal but leaves the rotations, if they exist, independent of each other. This MPC number 9 was used at 24 locations on the bridge model.

5.5. Discussion of Results

The Finite Element Analysis (FEA) was run using ABAQUS on a Cray-2 Supercomputer. A quasi-static analysis type was used for this project, since it includes the effects of gravity. The analysis for the AVLB plate model had an average run wall clock time of about three hours. The results file from the analysis was then translated into a format that PATRAN can read using a product known as ABAPAT. The results are displayed and interpreted in PATRAN. PATRAN allows the analyst to visually display analysis results.

The Maximum Distortion Energy criterion was used to quantify the results for this project. According to this criterion, also known as the von Mises criterion, a given structural component is safe, as long as the maximum value of the distortion energy per unit volume in that material remains smaller than the distortion energy per unit volume required to cause yield in a tensile test specimen of the same material. For this project, the von Mises stress, which also takes into account the shear effects, was compared to the yield strength of the material.

The results from each analysis are discussed in the following sections. A summary of the results for the plate model are in TABLE 5-4.

5.5.1. Eigenvalues. The first analysis was an eigenvector analysis performed on the beam model, which gave the first six modal equations of motion. This analysis was performed to obtain certain properties of the bridge, in order for AMSTA-RYA to create the SOVAS model. The results and information from this analysis are listed in TABLE 5-3 below. It was later determined that the first five mode shapes were sufficient to represent the most significant bridge deflections under vehicle loading.

Mode Shape	Eigenvalue	Frequency
1	63.302	1.2663 Hz
2	805.56	4.5172 Hz
3	987.88	5.0023 Hz
4	2721.7	8.3032 Hz
5	3242.5	9.0627 Hz
6	4006.5	10.074 Hz

TABLE 5-3. AVLB Beam Model Eigenvalue Results.

5.5.2. Gravity load. The first analysis performed on the plate model simulated the AVLB at a 60-ft span with only gravity acting on it. Not only did this give some results such as maximum deflection and stress, but it also checked for any errors in the finite element model and ABAQUS input file. As expected, the results were symmetric about the longitudinal center line. The von Mises stress for this loading was 12,469 psi, and the maximum deflection was 1.245 inches. As would be expected, the maximum stress is well below the yield strength of the material. FIGURE 5-4 is the von Mises stress plot for this loading. The bridge is viewed from the under-side in this plot, so that all the hinges are visible. The highest stress occurred just above the center hinges. In fact, in all of the stress plots for this project, the highest stress occurred at this location.

5.5.3. Static vehicle. The next type of analysis simulated a 68.2-ton M1A1 parked directly over the center of the AVLB. The force loadings were taken from the SOVAS dynamic analysis of the M1A1 at 3 mph when located directly over the center of the bridge. The longitudinal and lateral force components, x and z respectfully, were removed leaving only the vertical forces. The von Mises stress from this condition was 119,119 psi, and the maximum deflection was 10.80 inches. This high stress indicates a failed condition. As can be seen in FIGURE 5-5, the stresses are higher toward the right side of the bridge. This can be accredited to the fact that the forces used were from the 3 mph dynamic analysis, and the bridge seemed to sway side to side when the vehicle is moving over the AVLB. The time period used here indicates the bridge was swaying toward the right. FIGURE 5-6 is a close-up of the right hinge, better showing the stress concentration.

As a model verification, the total elastic strains in the longitudinal direction were compared to strain gage data from an actual test at Ft. Belvoir. The strain values were of the same magnitude and within the same range. FIGURE 5-7 is a plot of the total elastic strains from this analysis. There was no specific test data for a 68.2-ton load, so an interpolation was made between bordering loads. Ft. Belvoir's Bridge Division testing results range from 1289 μstrain to 1875 μstrain. The analysis strain in the same location are in the range of 1240 μstrain to 1830 μstrain.

5.5.4. Moving vehicle. For the analyses of the different vehicle speeds; 3 mph, 8 mph, and 25 mph, a quasi-static finite element analysis was performed using ABAQUS. The loads used are from the dynamic simulation of that speed at a particular time interval. Two different time periods were chosen for each speed-- when the M1A1 was directly over the center of the bridge and half way between the beginning and the center (quarter span). The stresses were consistently higher for all speeds when the vehicle was at the center. The speed of the vehicle did not seem to have an effect on the magnitude of the stress or

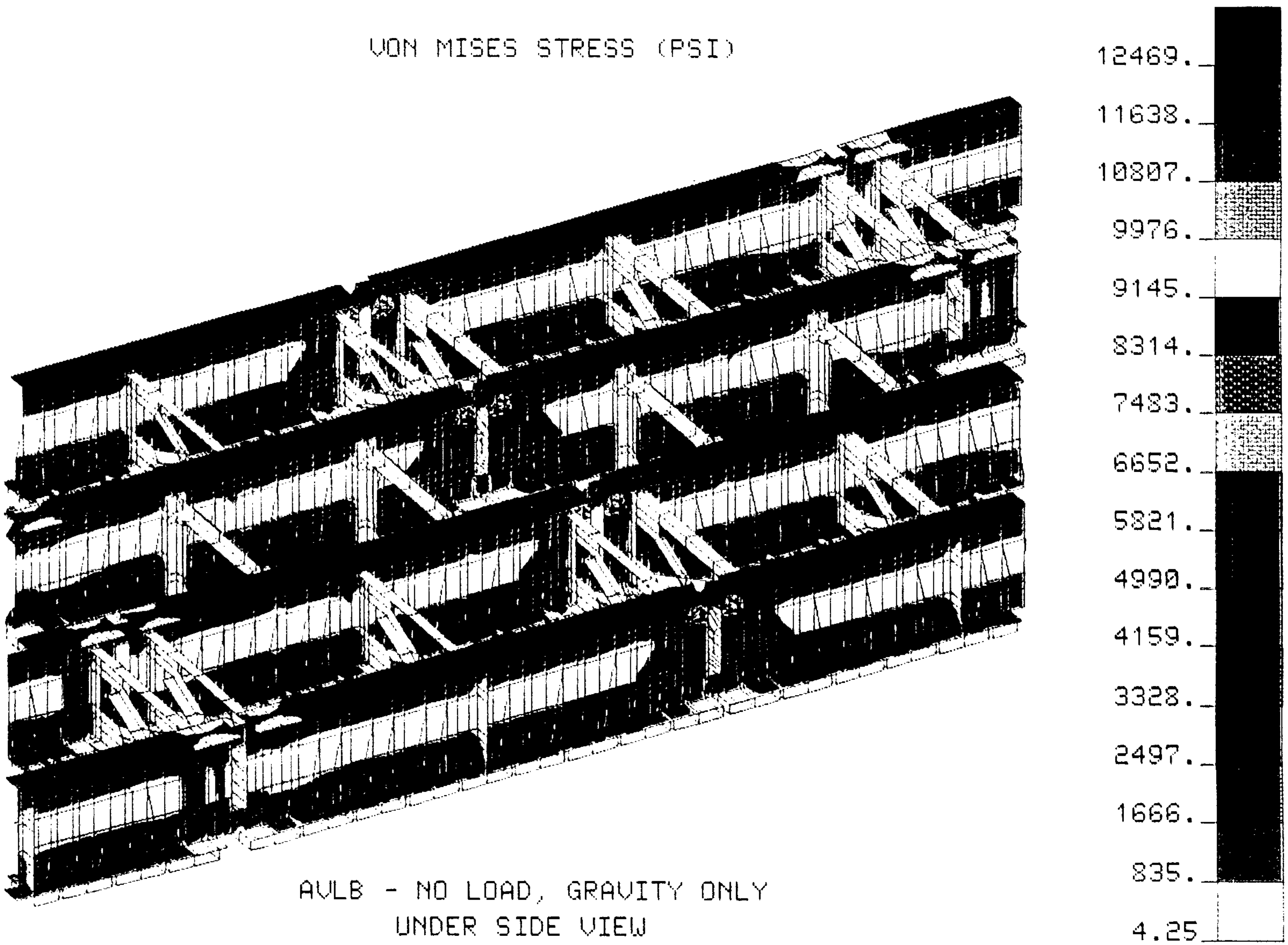

FIGURE 5-4. Von Mises Stress with Gravity Only.

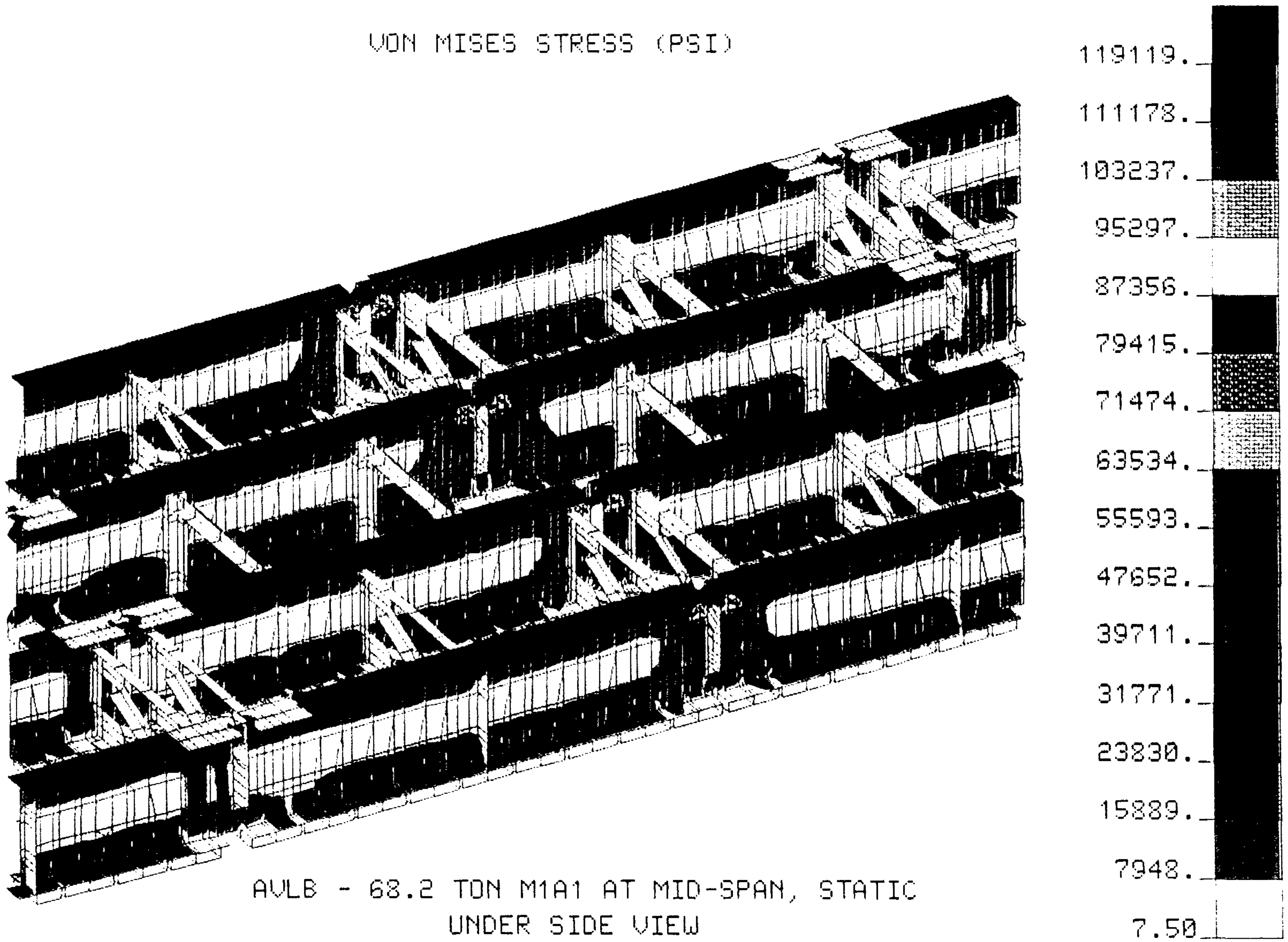

FIGURE 5-5. Von Mises Stress with M1A1 Parked Over Center.

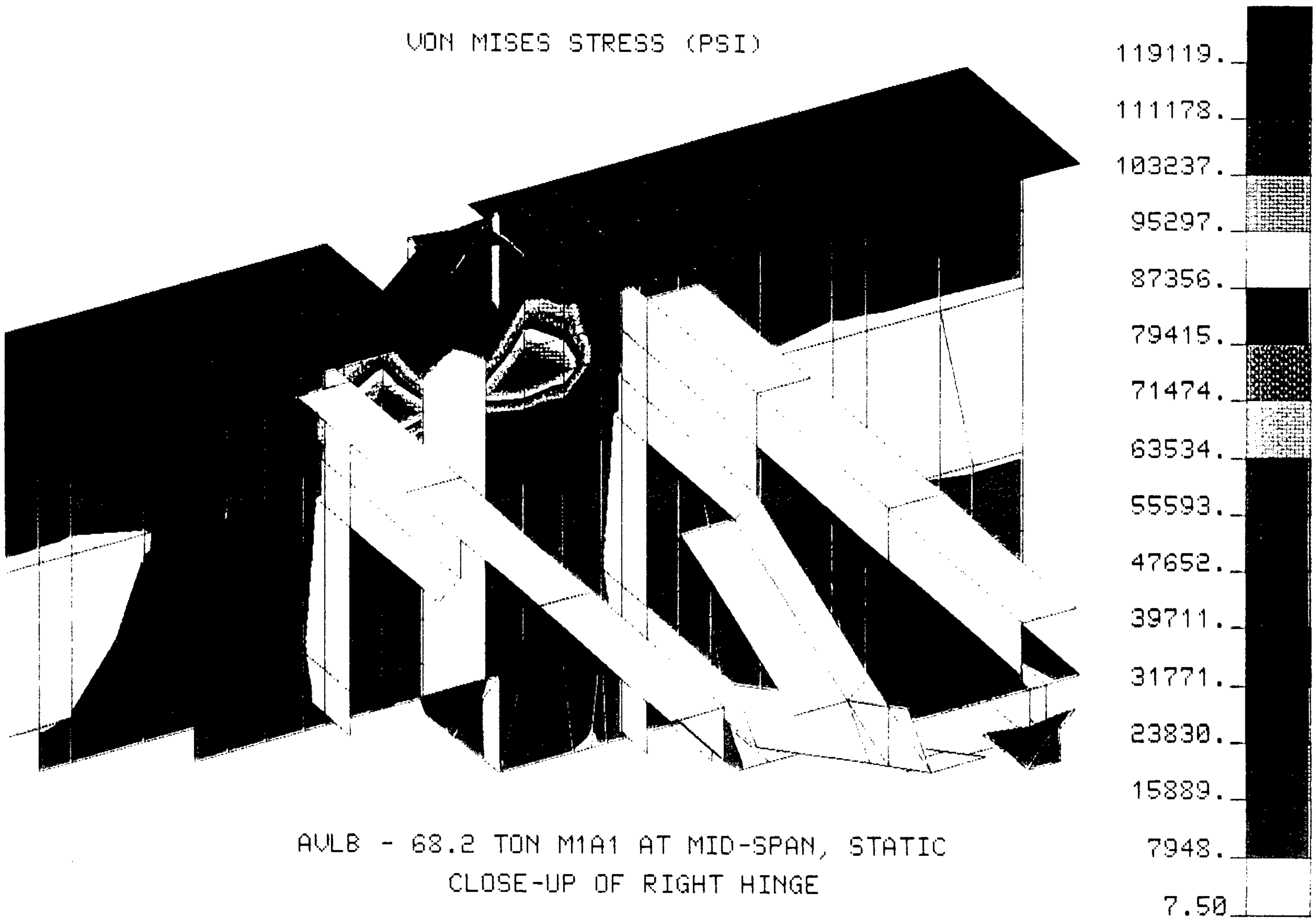

FIGURE 5-6. Close-up of Right Hinge Showing Von Mises Stress.

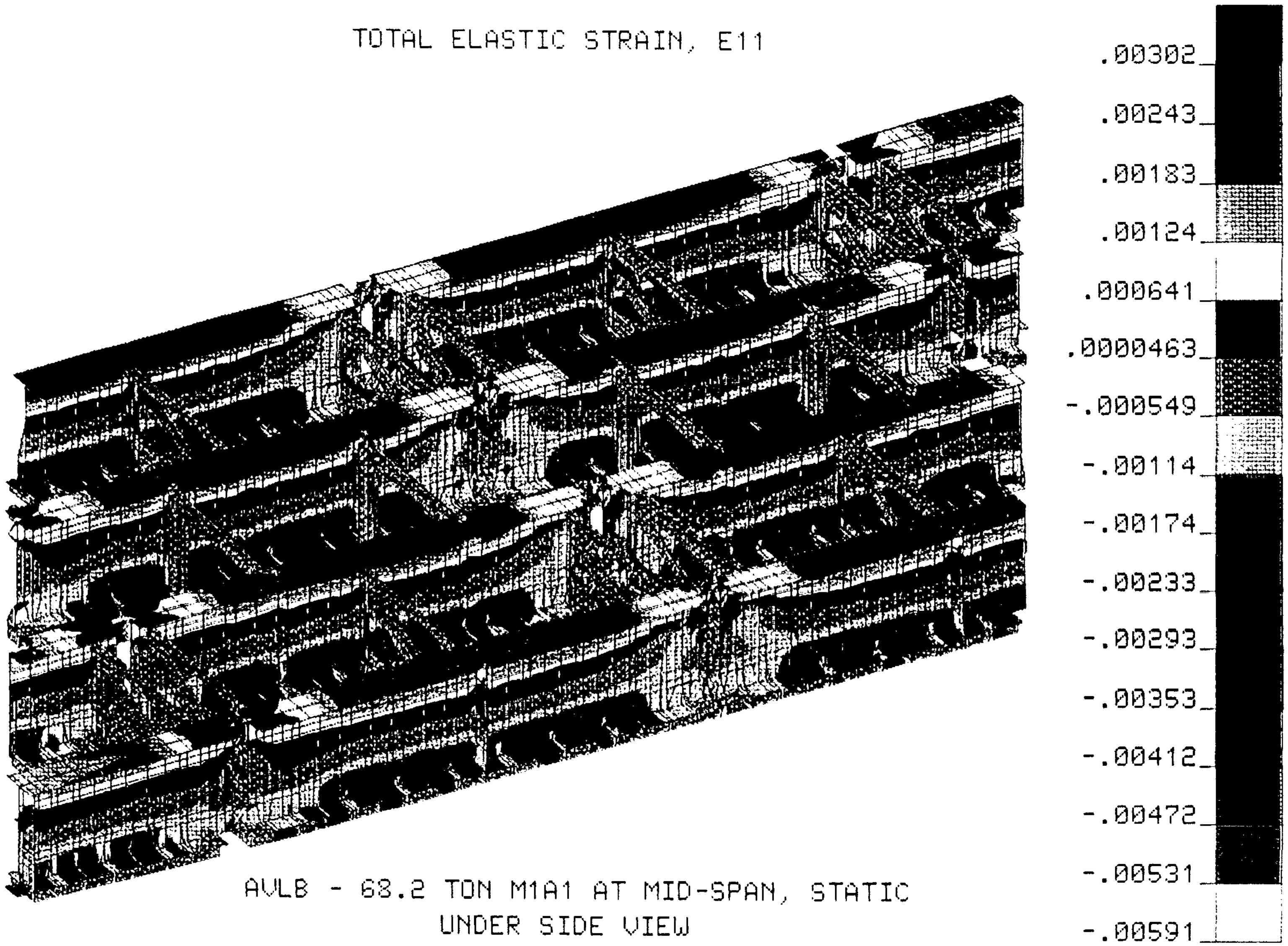

FIGURE 5-7. Total Elastic Strains with M1A1 parked over center.

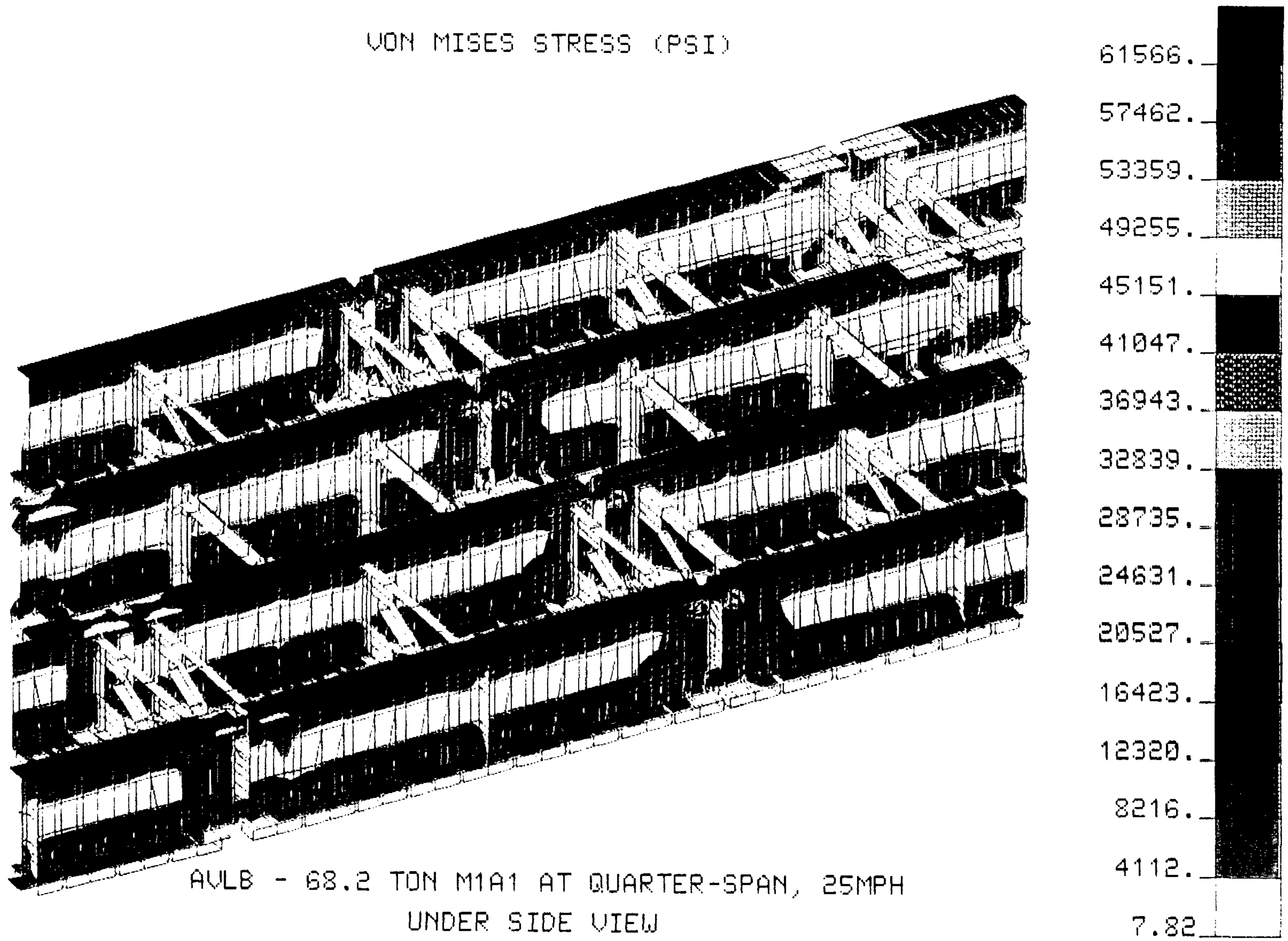

FIGURE 5-8. Von Mises Stress with M1A1 at Quarter Span.

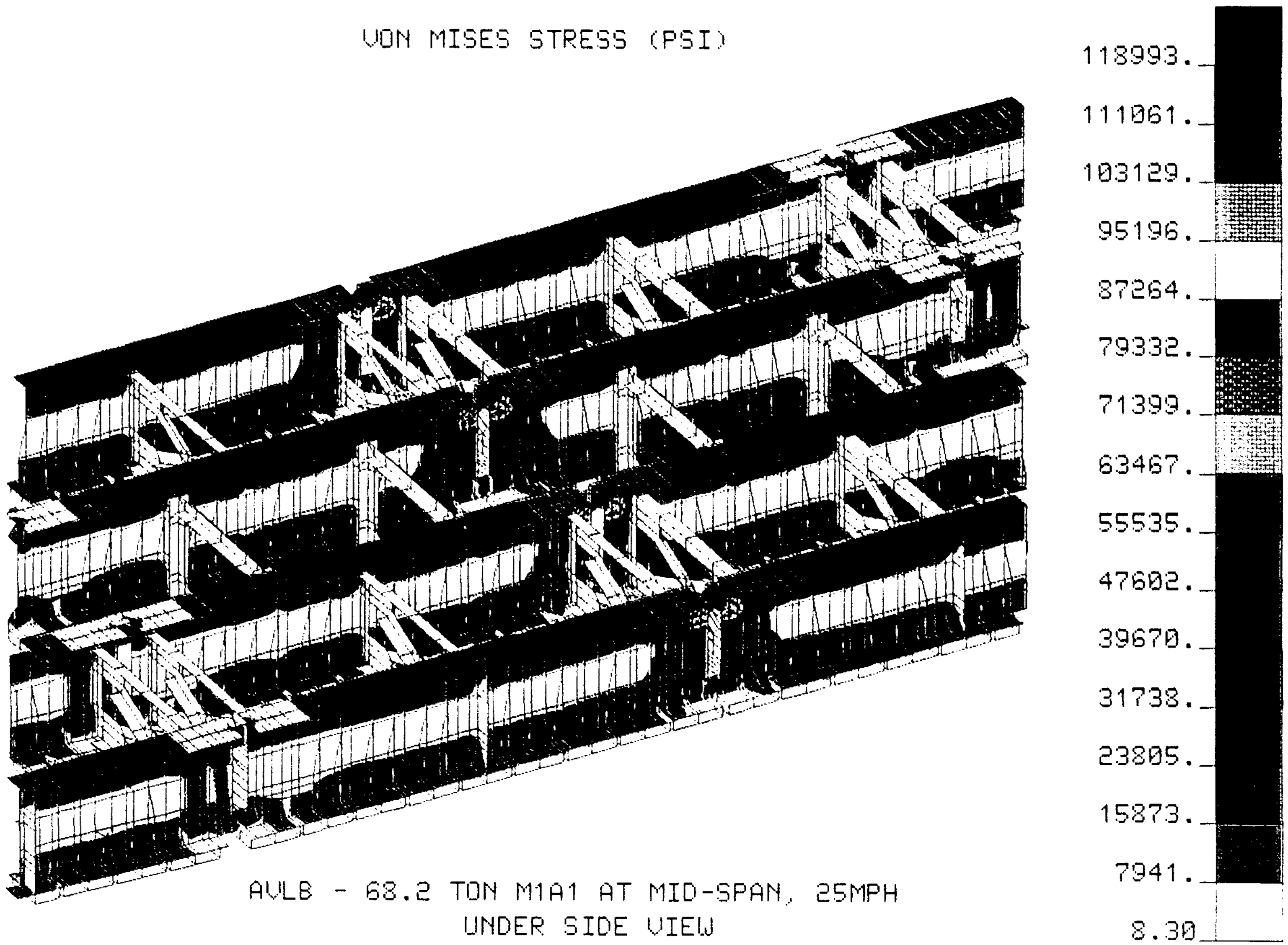

FIGURE 5-9. Von Mises Stress with M1A1 at Center.

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the deflection. The speed did seem to effect the swaying of the bridge, which may have some fatigue effects on the life of the AVLB. This sway is especially noticeable on the 25 mph analysis. On the stress plot at quarter span, FIGURE 5-8, the stresses are higher toward the left side of the bridge. Then on the 25 mph plot with the vehicle at the center, FIGURE 5-9, the stresses are higher towards the right side.

Analysis	Von Mises Stress	Max. Displacement
Gravity	12,469 psi	1.245 in.
Static (68.2 ton)	119,119 psi	10.80 in.
3mph (Quarter span)	58,480 psi	5.936 in.
3mph (Center)	119,234 psi	10.82 in.
8mph (Quarter Span)	66,663 psi	6.820 in.
8mph (Center)	118,169 psi	10.70 in.
25mph (Quarter Span)	61,566 psi	6.101 in.
25mph (Center)	118,993 psi	10.64 in.

TABLE 5-4. Summary of Plate Finite Element Analysis Results.

The location just above the hinges always had the highest stress value at all speeds and all vehicle locations. Most of this stress is shear in the x-y plane, as can be seen in FIGURE 5-10. In actuality, the stress might not be in this exact location. On the actual AVLB, the hinge is riveted on. When the AVLB failed in actual tests, a crack appeared at the last rivet location on the hinge on the lower flange. See FIGURE 5-11. This analysis shows there exists a problem in this general hinge location. A more detailed finite element model of this area would further pinpoint the critical location.

5.5.5. Additional analyses. In order to determine if the thickness around the hinge area has any effect on the stress or its location, a final analysis was performed on the AVLB, with the vehicle at the center and a speed of 8 mph. The thickness of one of the hinges at the location of the high stress was increased from 0.375 inches to 1.125 inches. As can be seen in the von Mises stress plot in FIGURE 5-12., the stress concentration is still in the same location; however the magnitude decreased, by about 50 ksi, to the value of 62 ksi. This is just above the yield strength of the 2014-T6 aluminum material.

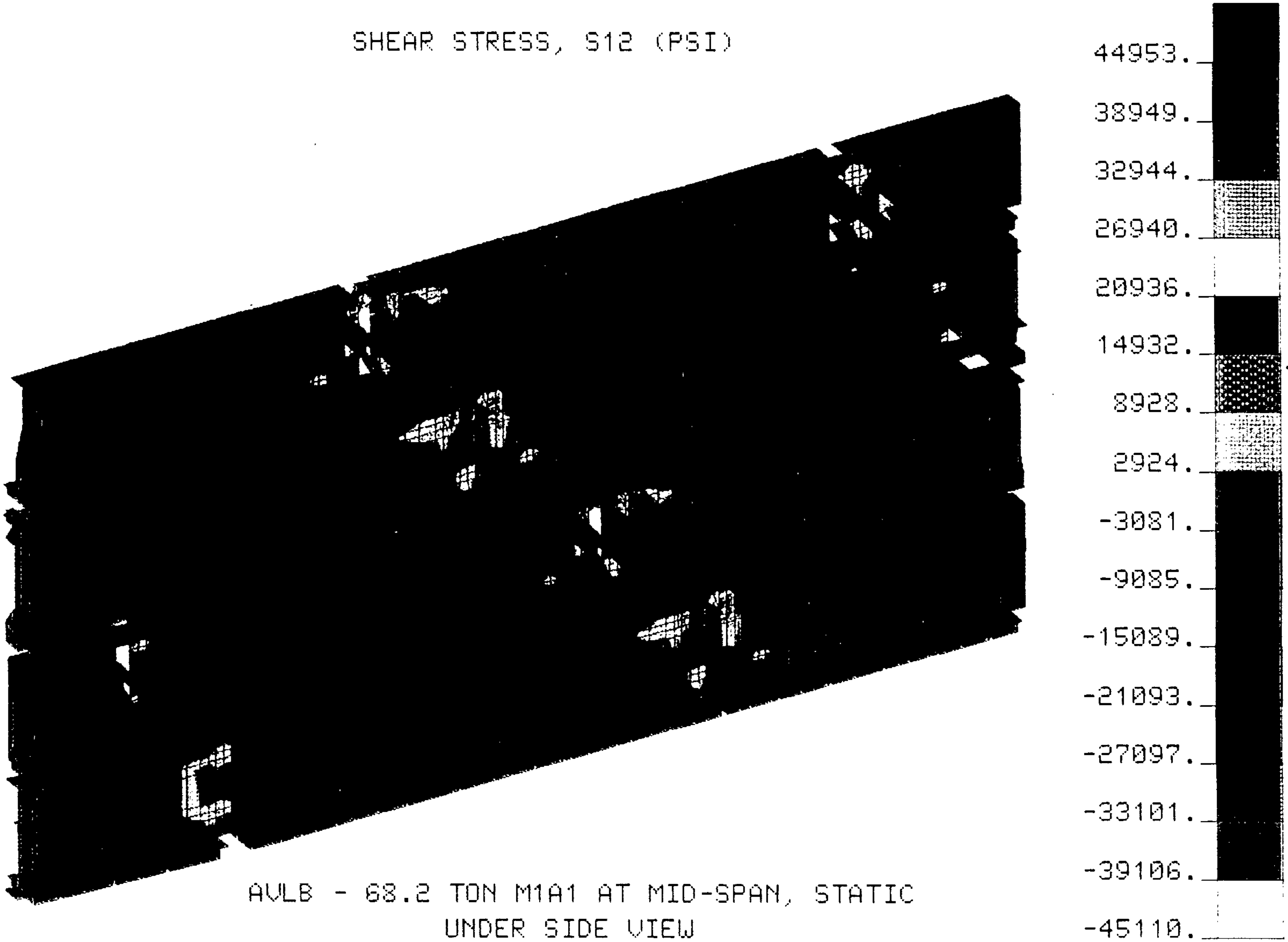


FIGURE 5-10. Shear Stress with M1A1 Parked Over Center.

FIGURE 5-11. Fracture During Actual AVLB Testing.

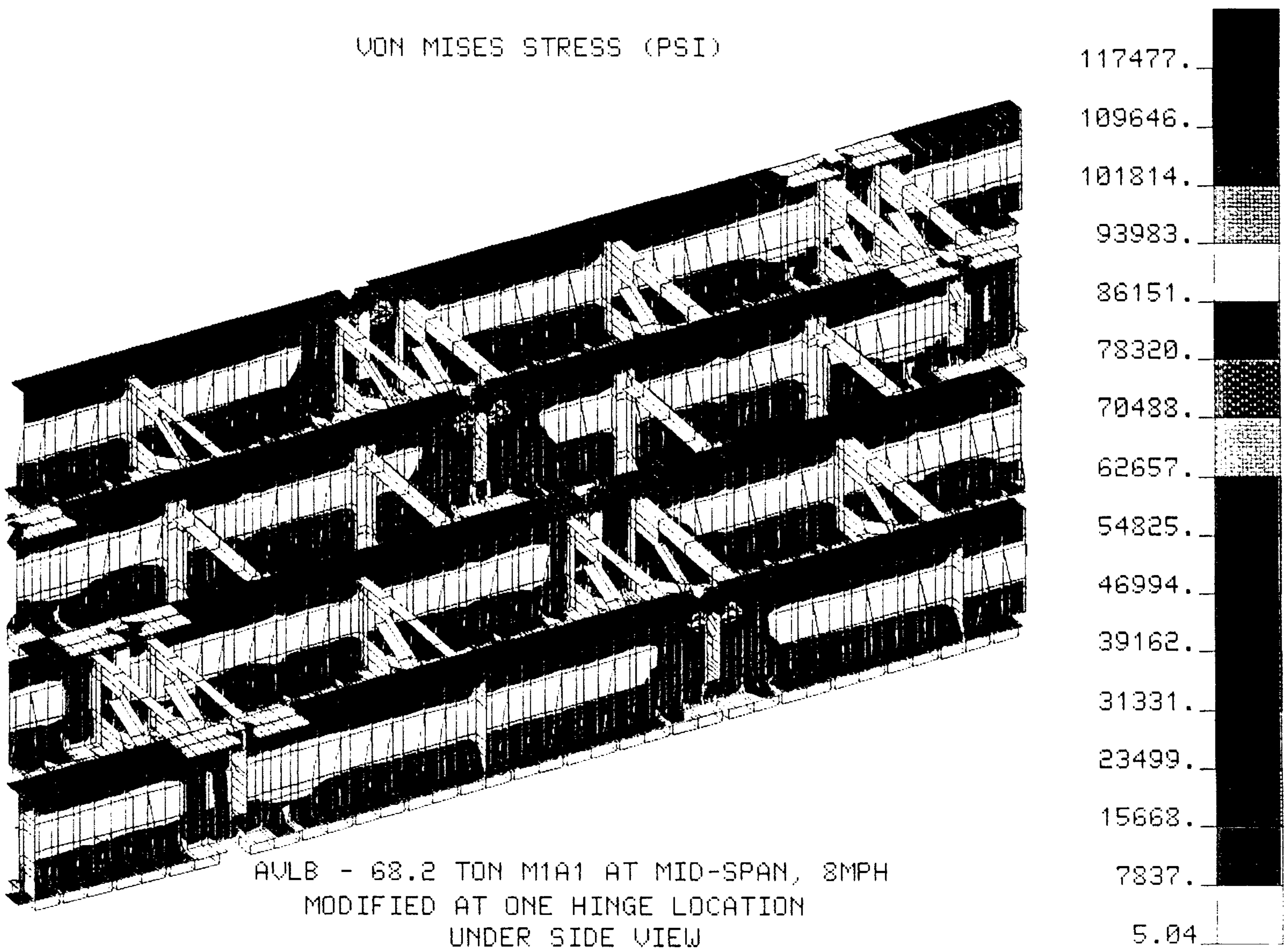


FIGURE 5-12. Von Mises Stress with Modified Hinge Area.

APPENDIX A

AVLB Materials and Properties

ALUMINUM ALLOYS

Designation	Density	Strengths		
		Ultimate	Yield	Shear
6061-T6	0.098 lb/in^3	45.0 ksi	39.9 ksi	29.7 ksi
2014-T6	0.101 lb/in^3	70.1 ksi	60.2 ksi	42.1 ksi

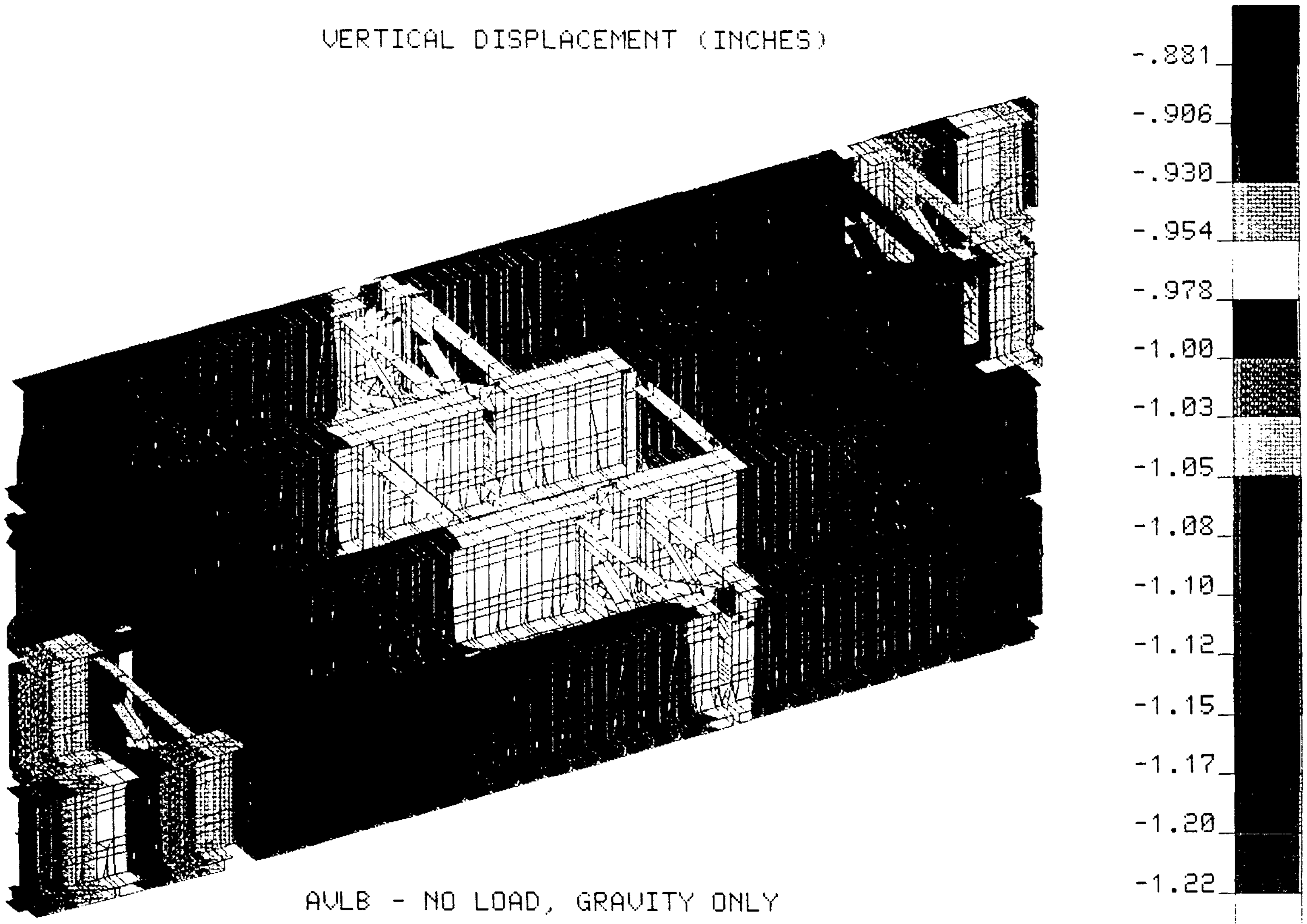
FERROUS METALS

Designation	Density	Strengths		
		Ultimate	Yield	Shear
ASTM A108	0.284 lb/in^3	55.0 ksi	30.0 ksi	-------
ASTM A120	0.284 lb/in^3	---------	---------	-------
ASTM A36	0.284 lb/in^3	58.0 ksi	36.0 ksi	21.0 ksi
ASTM A441	0.284 lb/in^3	60-70 ksi	40-50 ksi	-------
ASTM A575	0.284 lb/in^3	---------	---------	-------
ASTM A514	0.284 lb/in^3	120 ksi	100 ksi	55 ksi

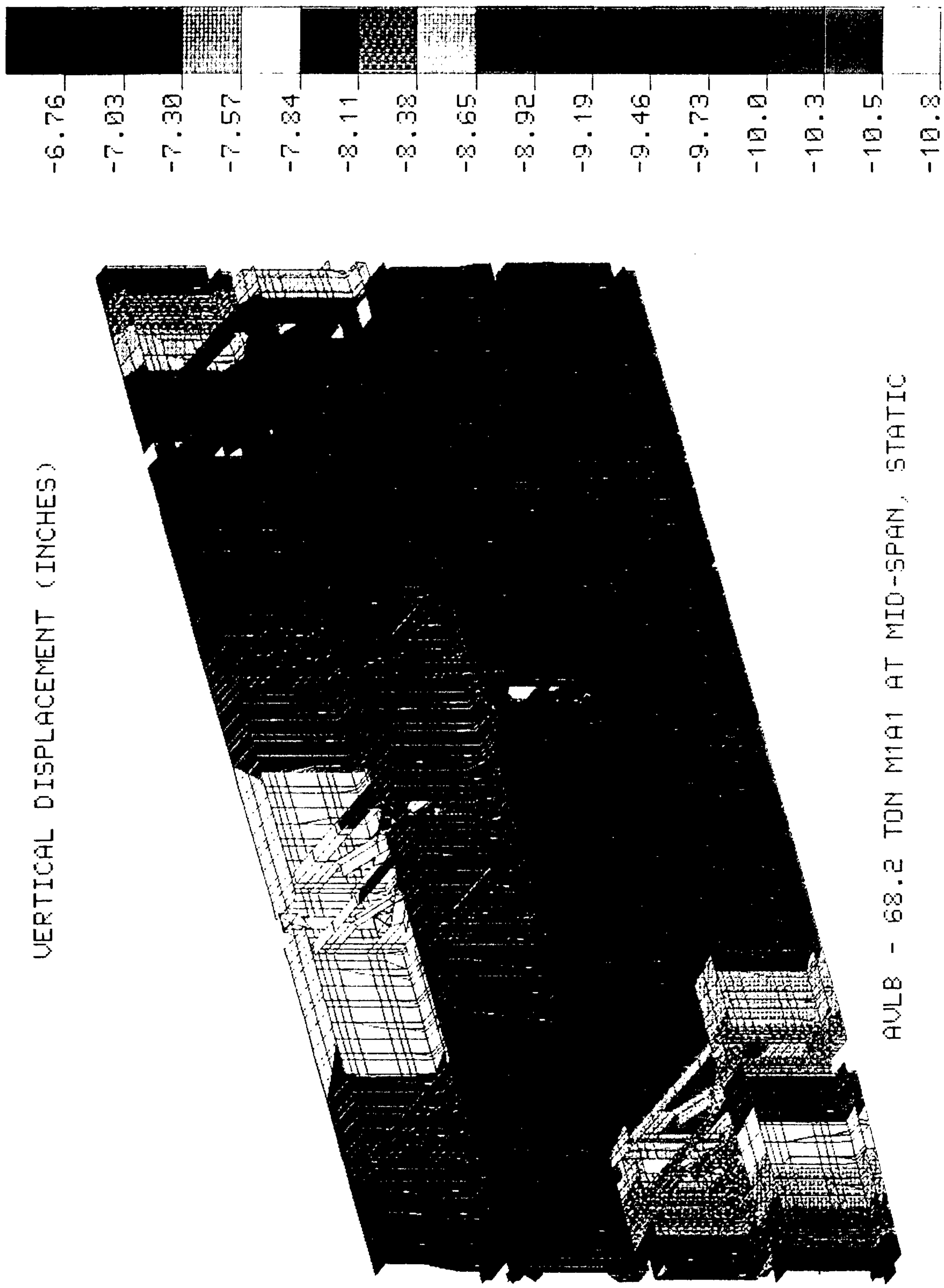
APPENDIX B

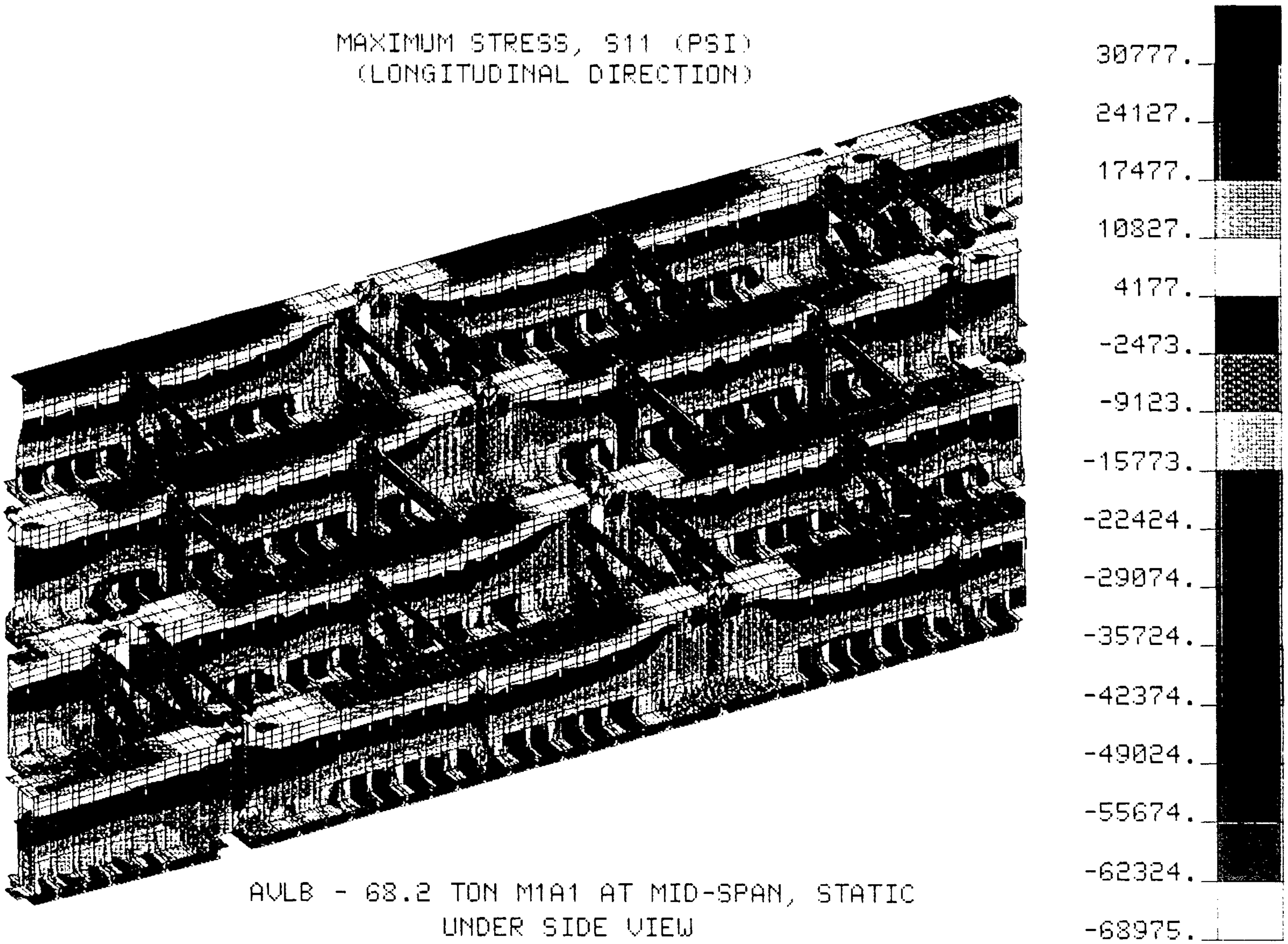
Result Plots of AVLB Plate Model Analysis

VERTICAL DISPLACEMENT (INCHES)



AVLB - NO LOAD, GRAVITY ONLY
UNDER SIDE VIEW


VERTICAL DISPLACEMENT (INCHES)
AVLB - 68.2 TON M1A1 AT MID-SPAN, STATIC
-6.76
-7.03
-7.30
-7.57
-7.84
-8.11
-8.38
-8.65
-8.92
-9.19
-9.46
-9.73
-10.0
-10.3
-10.5
-10.8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-42374.
-49024.
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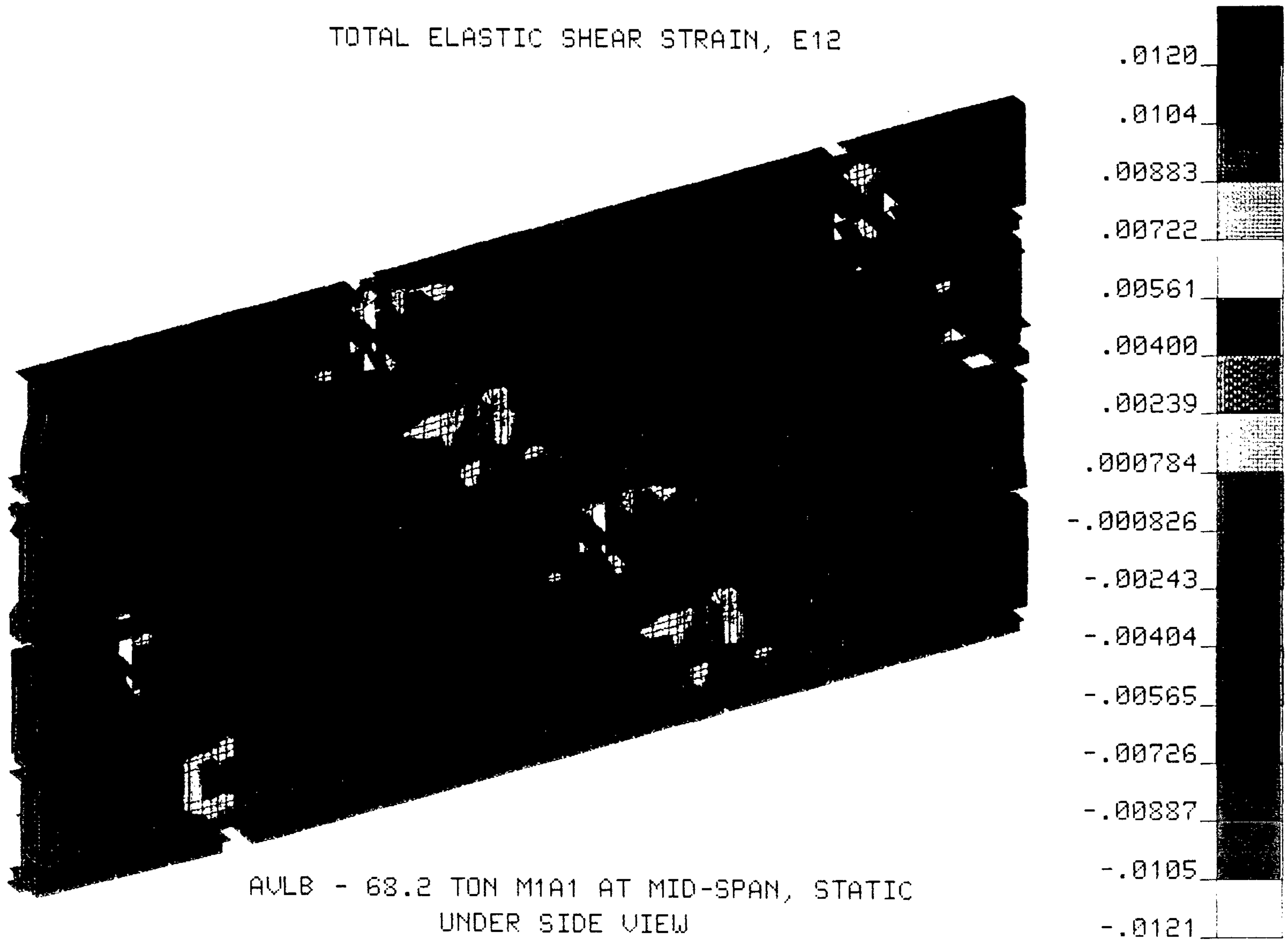
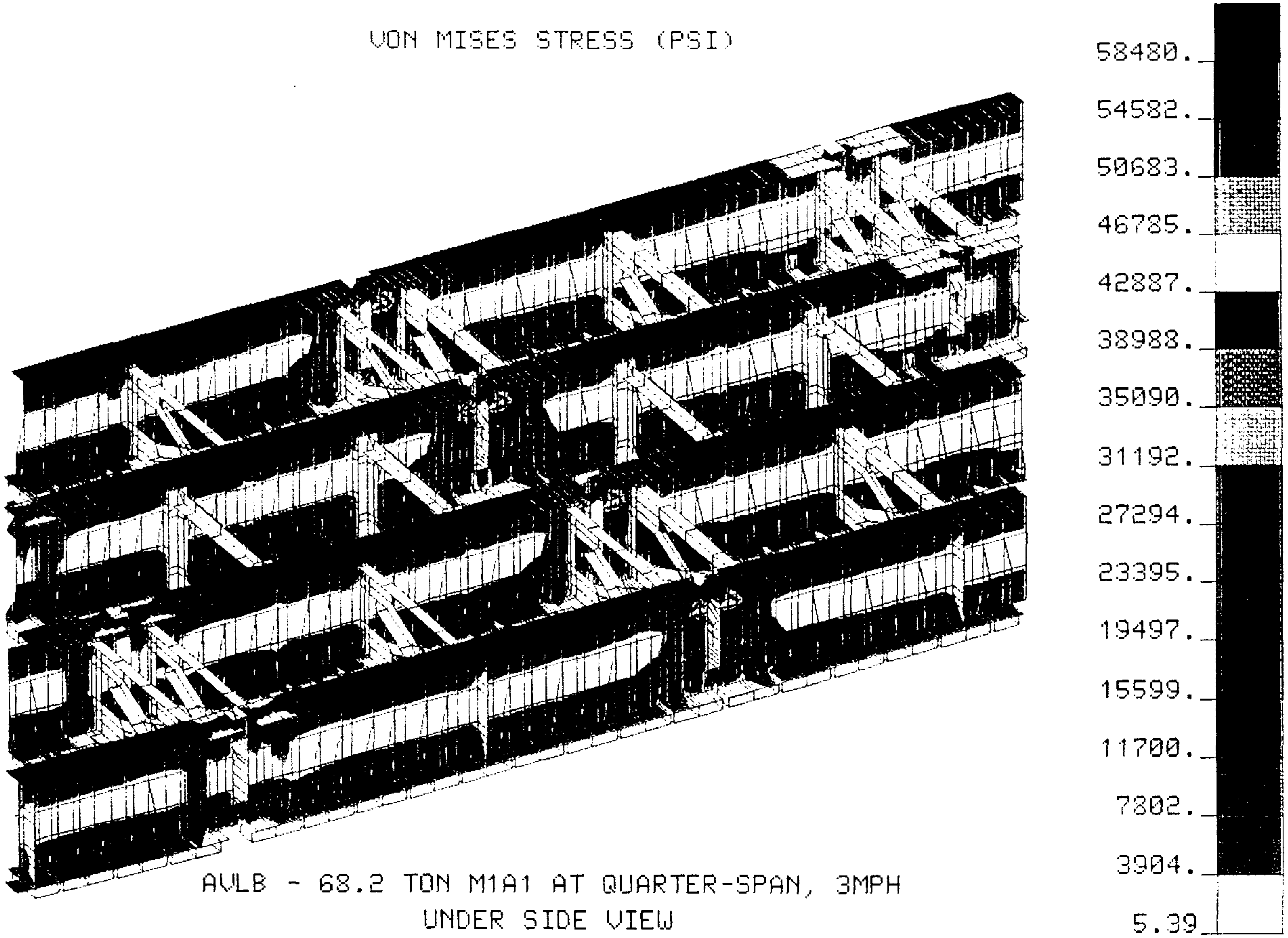
AVLB - 68.2 TON M1A1 AT MID-SPAN, STATIC
UNDER SIDE VIEW

TOTAL ELASTIC SHEAR STRAIN, E12



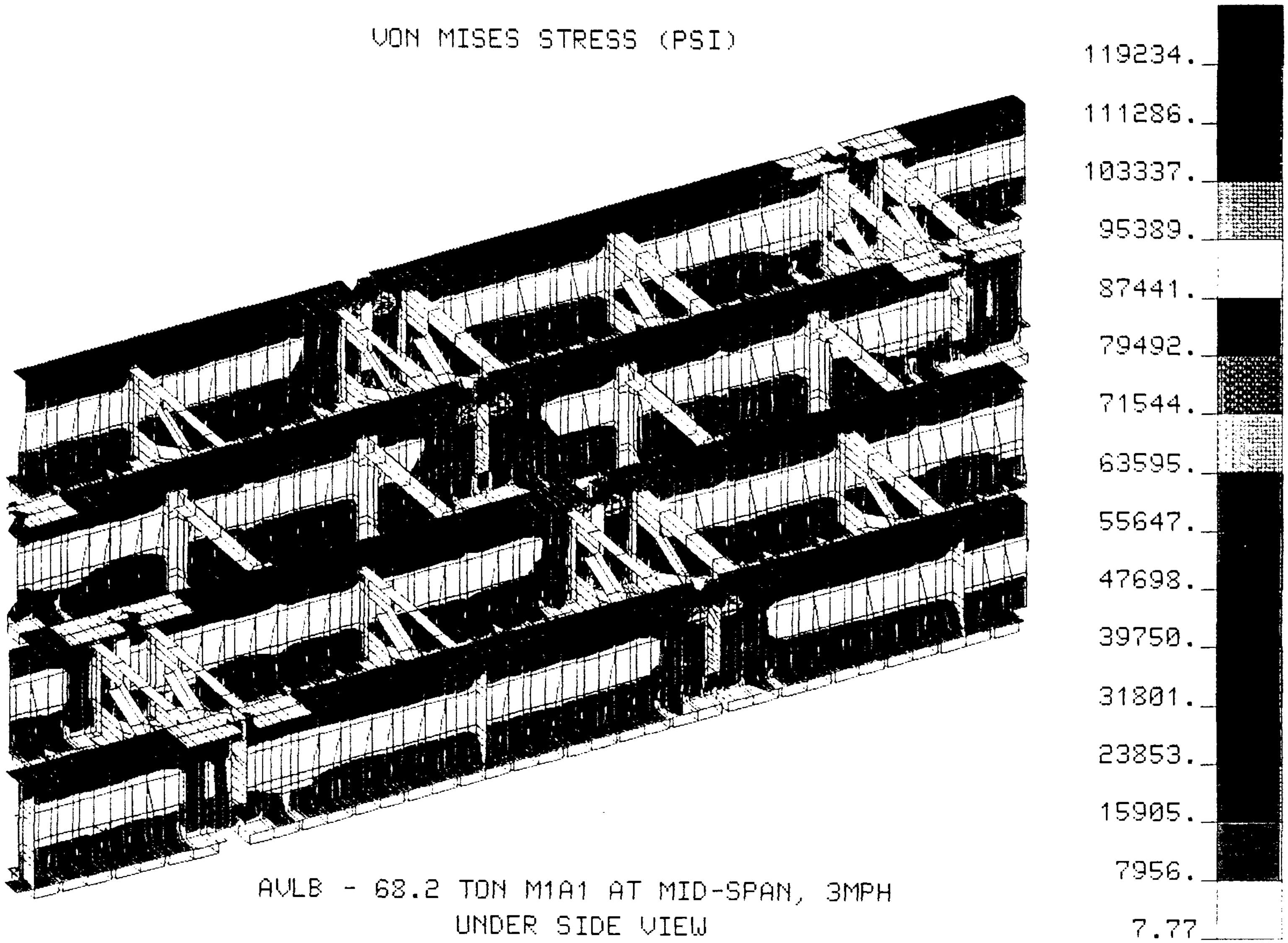
AVLB - 68.2 TON M1A1 AT MID-SPAN, STATIC
UNDER SIDE VIEW

VON MISES STRESS (PSI)

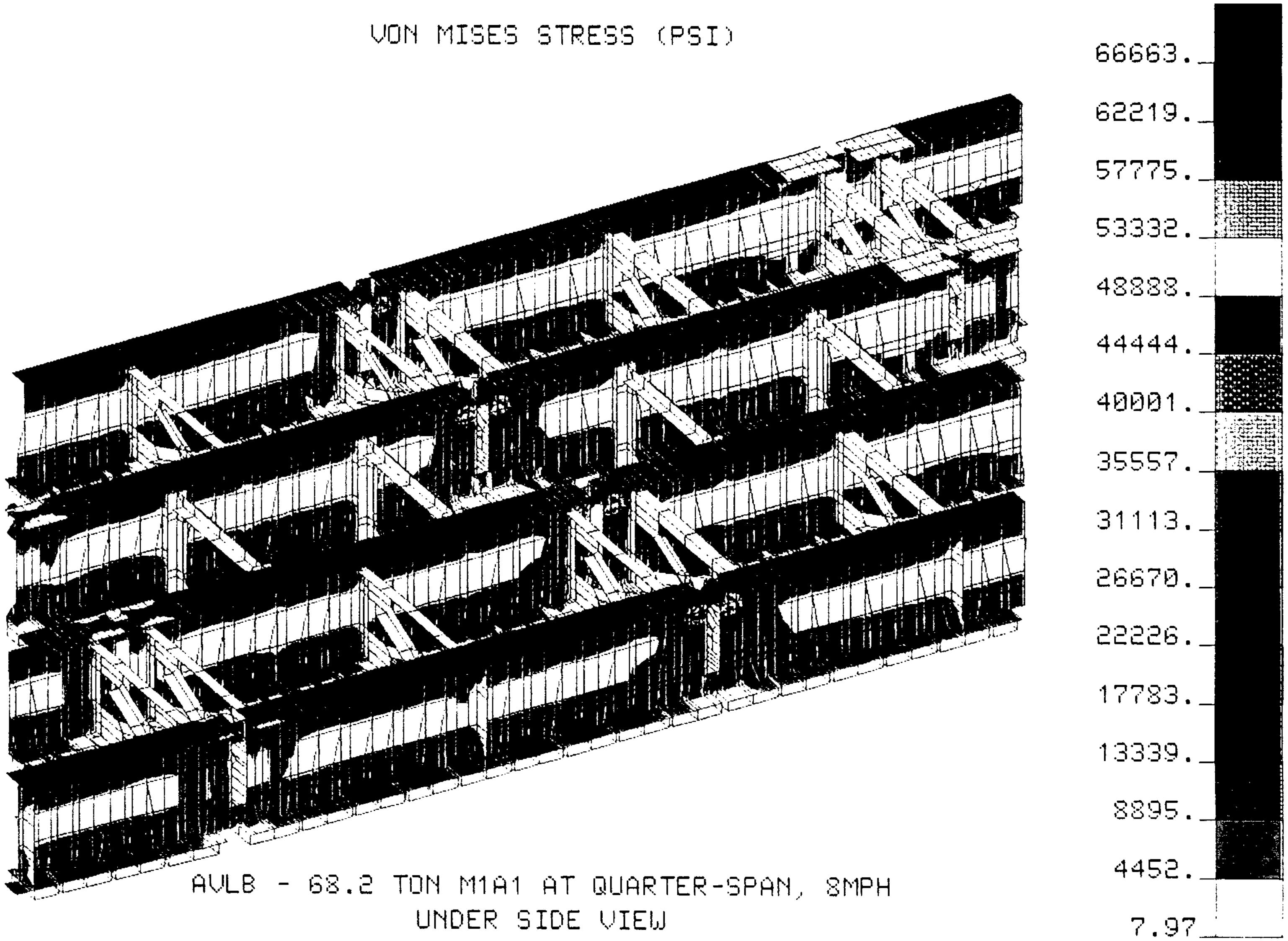


AVLB - 68.2 TON M1A1 AT QUARTER-SPAN, 3MPH
UNDER SIDE VIEW

VON MISES STRESS (PSI)

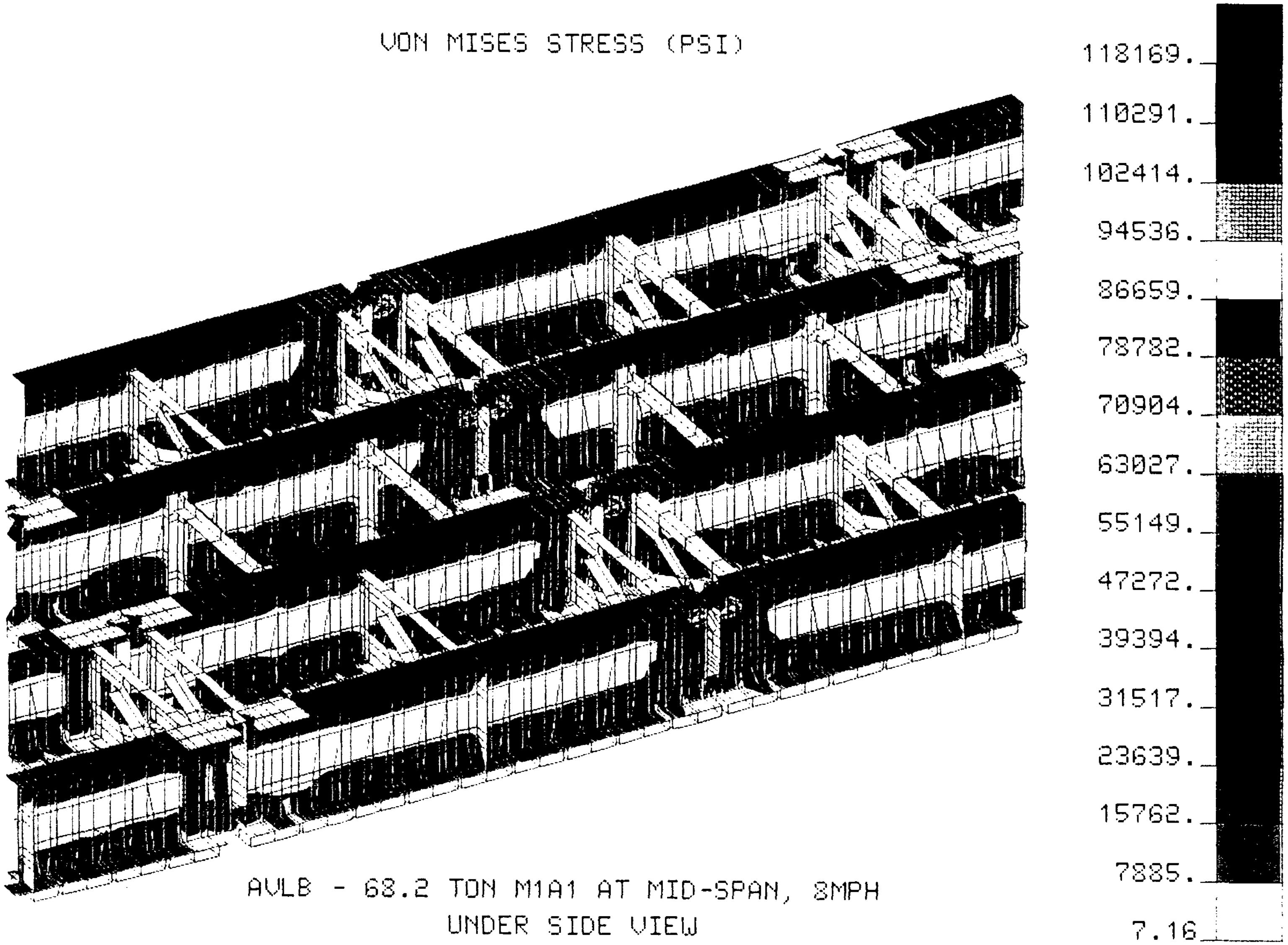


AVLB - 68.2 TON M1A1 AT MID-SPAN, 3MPH
UNDER SIDE VIEW



AVLB - 68.2 TON M1A1 AT QUARTER-SPAN, 8MPH
UNDER SIDE VIEW

VON MISES STRESS (PSI)



AVLB - 68.2 TON M1A1 AT MID-SPAN, 8MPH
UNDER SIDE VIEW

APPENDIX C

ABAQUS Input File of AVLB Beam Model

```
*HEADING
AVLB BEAM MODEL WITH 60 ft SPAN AND ADDED MASS FOR MODE SHAPES  SGL
** NEUTRAL FILE GENERATED ON: 30-APR-91 08:47:25  PATABA VERSION: 3.1
**
**  NODE DEFINITIONS
**
*NODE
      9,  0.297475006E+03,  0.150000000E+02, -0.513750000E+02
     10,  0.297475006E+03,  0.150000000E+02, -0.766875000E+02
     11,  0.297475006E+03,  0.150000000E+02, -0.102000000E+03
     12,  0.339475006E+03,  0.150000000E+02, -0.513750000E+02
     13,  0.339475006E+03,  0.150000000E+02, -0.766875000E+02
     14,  0.339475006E+03,  0.150000000E+02, -0.102000000E+03
     15,  0.408225006E+03,  0.150000000E+02, -0.513750000E+02
     16,  0.408225006E+03,  0.150000000E+02, -0.766875000E+02
     17,  0.408225006E+03,  0.150000000E+02, -0.102000000E+03
     18,  0.450225006E+03,  0.150000000E+02, -0.513750000E+02
     19,  0.450225006E+03,  0.150000000E+02, -0.766875000E+02
     20,  0.450225006E+03,  0.150000000E+02, -0.102000000E+03
     21,  0.260100006E+03,  0.150000000E+02,  0.000000000E+00
     22,  0.260100006E+03,  0.150000000E+02, -0.256875000E+02
     23,  0.260100006E+03,  0.150000000E+02, -0.513750000E+02
     24,  0.313850006E+03,  0.150000000E+02,  0.000000000E+00
     25,  0.313850006E+03,  0.150000000E+02, -0.256875000E+02
     26,  0.313850006E+03,  0.150000000E+02, -0.513750000E+02
     27,  0.368850006E+03,  0.150000000E+02,  0.000000000E+00
     28,  0.368850006E+03,  0.150000000E+02, -0.256875000E+02
     29,  0.368850006E+03,  0.150000000E+02, -0.513750000E+02
     30,  0.378850006E+03,  0.150000000E+02,  0.000000000E+00
     31,  0.378850006E+03,  0.150000000E+02, -0.256875000E+02
     32,  0.378850006E+03,  0.150000000E+02, -0.513750000E+02
     33,  0.433850006E+03,  0.150000000E+02,  0.000000000E+00
     34,  0.433850006E+03,  0.150000000E+02, -0.256875000E+02
     35,  0.433850006E+03,  0.150000000E+02, -0.513750000E+02
     36,  0.487600006E+03,  0.150000000E+02, -0.102000000E+03
     37,  0.487600006E+03,  0.150000000E+02, -0.127687500E+03
     38,  0.487600006E+03,  0.150000000E+02, -0.153375000E+03
     39,  0.433850006E+03,  0.150000000E+02, -0.102000000E+03
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     41,  0.433850006E+03,  0.150000000E+02, -0.153375000E+03
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     49,  0.313850006E+03,  0.150000000E+02, -0.127687500E+03
     50,  0.313850006E+03,  0.150000000E+02, -0.153375000E+03
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```

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285,  0.634450012E+03,  0.106915216E+02, -0.766875000E+02
```

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     410,  0.223787506E+03,  0.140787802E+02, -0.102000000E+03
     413,  0.223787506E+03,  0.140787802E+02, -0.153375000E+03
     416,  0.523912537E+03,  0.140787802E+02,  0.000000000E+00
     419,  0.523912537E+03,  0.140787802E+02, -0.513750000E+02
     422,  0.523912537E+03,  0.140787802E+02, -0.102000000E+03
     425,  0.523912537E+03,  0.140787802E+02, -0.153375000E+03
     427,  0.000000000E+00,  0.000000000E+00, -0.766875000E+02
     430,  0.747700012E+03,  0.000000000E+00, -0.766875000E+02
**
**  ELEMENT DEFINITIONS
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*ELEMENT, TYPE=B33      , ELSET=R4N
  129,  175,  218
  131,  177,  221
  133,  178,  224
  135,  180,  227
*ELEMENT, TYPE=B33      , ELSET=R5N
  130,  218,  187
  132,  221,  189
  134,  224,  190
  136,  227,  192
*ELEMENT, TYPE=B33      , ELSET=R6N
  145,  187,  242
  147,  189,  245
  149,  190,  248
  151,  192,  251
*ELEMENT, TYPE=B33      , ELSET=R7N
  146,  242,  199
  148,  245,  201
  150,  248,  202
  152,  251,  204
*ELEMENT, TYPE=B33      , ELSET=R8N
  157,  199,  262
  158,  201,  264
  159,  202,  266
  160,  204,  268
*ELEMENT, TYPE=B33      , ELSET=E7N
  209,  262,  344
  210,  264,  284
  211,  266,  286
  212,  268,  350
*ELEMENT, TYPE=B33      , ELSET=E8N
  213,  344,  352
  215,  284,  355
  217,  286,  358
  219,  350,  296
*ELEMENT, TYPE=B33      , ELSET=E9N
  214,  352,  293
  216,  355,  295
  218,  358,  296
  220,  361,  298
*ELEMENT, TYPE=B33      , ELSET=E10N
  225,  293,  372
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  226,  295,  281
  227,  296,  283
  228,  298,  378
*ELEMENT, TYPE=B33      , ELSET=E11N
  237,  372,  392
  239,  281,  395
  241,  283,  398
  243,  378,  401
*ELEMENT, TYPE=B33      , ELSET=E12N
  238,  392,  305
  240,  395,  278
  242,  398,  280
  244,  401,  310
*ELEMENT, TYPE=B33      , ELSET=E13N
  253,  305,  416
  255,  278,  419
  257,  280,  422
  259,  310,  425
*ELEMENT, TYPE=B33      , ELSET=E14N
  254,  416,  317
  256,  419,  319
  258,  422,  320
  260,  425,  322
*ELEMENT, TYPE=B33      , ELSET=E15N
  265,  317,  129
  266,  319,  131
  267,  320,  133
  268,  322,  135
*ELEMENT, TYPE=B33      , ELSET=CCM
    1,    9,   10
    2,   10,   11
    3,   12,   13
    4,   13,   14
    5,   15,   16
    6,   16,   17
    7,   18,   19
    8,   19,   20
*ELEMENT, TYPE=B33      , ELSET=CIS
    9,   21,   22
   10,   22,   23
   11,   24,   25
   12,   25,   26
   13,   27,   28
   14,   28,   29
   15,   30,   31
   16,   31,   32
   17,   33,   34
   18,   34,   35
   19,   36,   37
   20,   37,   38
   21,   39,   40
   22,   40,   41
   23,   42,   43
   24,   43,   44
   25,   45,   46
   26,   46,   47
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    32,   55,   56
*ELEMENT, TYPE=B33       , ELSET=CR
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    34,   58,   59
    35,   23,   61
    36,   61,    9
    37,   54,   64
    38,   64,   11
    39,   56,   67
    40,   67,   68
    49,   81,   82
    50,   82,   27
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    52,   85,   29
    53,   14,   88
    54,   88,   45
    55,   90,   91
    56,   91,   47
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    66,  107,   23
    67,  109,   54
    68,  111,   56
    69,   59,   24
    70,    9,   26
    71,   11,   48
    72,   68,   50
    73,   24,   81
    74,   26,   12
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    89,   27,  154
    90,   29,  156
    91,   45,  158
    92,   47,  160
*ELEMENT, TYPE=B33       , ELSET=CRN
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    43,   53,   73
    44,   73,   18
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    46,   76,   20
    47,   38,   79
    48,   79,   80
    57,   93,   94
    58,   94,   30
    59,   15,   97
    60,   97,   32
    61,   17,  100
    62,  100,   42
    63,  102,  103
    64,  103,   44
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    78,  131,   53
    79,  133,   36
    80,  135,   38
    81,   71,   33
    82,   18,   35
    83,   20,   39
    84,   80,   41
    85,   33,   93
    86,   35,   15
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    88,   41,  102
    93,   30,  154
    94,   32,  156
    95,   42,  158
    96,   44,  160
*ELEMENT, TYPE=B33      , ELSET=R1
    97,  169,  170
    98,  170,  171
    99,  172,  173
   100,  173,  174
   101,  175,  176
   102,  176,  177
   103,  178,  179
   104,  179,  180
   269,  171,  427
   270,  427,  172
   271,  177,  430
   272,  430,  178
*ELEMENT, TYPE=B33      , ELSET=R2
   105,  181,  182
   106,  182,  183
   107,  184,  185
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   111,  190,  191
   112,  191,  192
*ELEMENT, TYPE=B33      , ELSET=R3
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*ELEMENT, TYPE=B33      , ELSET=E1
   161,  269,  270
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*ELEMENT, TYPE=B33      , ELSET=E2
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   164,  273,  274
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*ELEMENT, TYPE=B33      , ELSET=E3
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*ELEMENT, TYPE=B33      , ELSET=E4
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*ELEMENT, TYPE=B33      , ELSET=E5
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  182,  300,  275
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  186,  306,  278
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  200,  260,  330
*ELEMENT, TYPE=B33      , ELSET=E8
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  207,  330,  341
*ELEMENT, TYPE=B33      , ELSET=E9
  202,  332,  287
  204,  335,  289
  206,  338,  290
  208,  341,  292
*ELEMENT, TYPE=B33      , ELSET=E10
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  224,  292,  370
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*ELEMENT, TYPE=B33     , ELSET=E13
  245,  299,  404
  247,  275,  407
  249,  277,  410
  251,  304,  413
*ELEMENT, TYPE=B33     , ELSET=E14
  246,  404,  311
  248,  407,  313
  250,  410,  314
  252,  413,  316
*ELEMENT, TYPE=B33     , ELSET=E15
  261,  311,  105
  262,  313,  107
  263,  314,  109
  264,  316,  111
*ELEMENT, TYPE=B33     , ELSET=R4
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  123,  171,  209
  125,  172,  212
  127,  174,  215
*ELEMENT, TYPE=B33     , ELSET=R5
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  124,  209,  183
  126,  212,  184
  128,  215,  186
*ELEMENT, TYPE=B33     , ELSET=R6
  137,  181,  230
  139,  183,  233
  141,  184,  236
  143,  186,  239
*ELEMENT, TYPE=B33     , ELSET=R7
  138,  230,  193
  140,  233,  195
  142,  236,  196
  144,  239,  198
*ELEMENT, TYPE=B33     , ELSET=R8
  153,  193,  254
  154,  195,  256
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*ELEMENT, TYPE=MASS, ELSET=CYL
  300, 23
  301, 54
  302, 276
*ELEMENT, TYPE=MASS, ELSET=QUAD
  303, 156
  304, 158
*ELEMENT, TYPE=MASS, ELSET=ALL
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  525, 410
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  529, 422
  530, 425
  531, 427
*ELGEN, ELSET=ALL
  305, 48,1,1,1
  356, 36,1,1,1
  431, 33,1,1,1
  485, 14,1,1,1
*ELEMENT, TYPE=MASS, ELSET=ALL
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*ELSET, ELSET=BRIDG, GENERATE
 1, 531, 1
** E15N,E15,E14,E14N,E13N,E13,R4,R3,R2,E12N,E12,E11N,E11,R4N,R5,E10N,E10,E9N
** E9,E8N,E8,R5N,E7N,E7,E6,E5,R7,R6N,R6,E3,E4,E2,E1,R8N,R8,R7N,R1,CRN,CR,CIS,CCM
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**  ADDED ELEMENT PROPERTIES
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*BEAM SECTION, SECTION=RECT, ELSET=CCM, MATERIAL=ALUM
 0.5, 28.9
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=RECT, ELSET=CIS, MATERIAL=ALUM
 0.5, 28.9
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=CR, MATERIAL=ALUM
 15.0, 32.4, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=CRN, MATERIAL=ALUM
 15.0, 32.4, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=PIPE, ELSET=R1, MATERIAL=STEEL
 1.5, 0.125
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=RECT, ELSET=R2, MATERIAL=ALUM
 0.5, 6.68
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=RECT, ELSET=R3, MATERIAL=ALUM
 0.5, 15.96
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=R4, MATERIAL=STEEL
 1.5, 3.0, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=R4N, MATERIAL=STEEL
 1.5, 3.0, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=R5, MATERIAL=STEEL
 2.355, 5.09, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=R5N, MATERIAL=STEEL
 2.355, 5.09, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=R6, MATERIAL=STEEL
 4.71, 10.18, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=R6N, MATERIAL=STEEL
 4.71, 10.18, 10.0, 12.0, 0.5, 2.0, 0.5
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*BEAM SECTION, SECTION=I-BEAM, ELSET=R7, MATERIAL=STEEL
 6.857, 14.824, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=R7N, MATERIAL=STEEL
 6.857, 14.824, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=R8, MATERIAL=STEEL
 9.004, 19.46, 10.0, 12.0, 0.5, 2.0, 0.5
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*BEAM SECTION, SECTION=I-BEAM, ELSET=R8N, MATERIAL=STEEL
 9.004, 19.46, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=RECT, ELSET=E1, MATERIAL=ALUM
 0.5, 19.613
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=RECT, ELSET=E2, MATERIAL=ALUM
 0.5, 22.66
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=RECT, ELSET=E3, MATERIAL=ALUM
 0.5, 25.498
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=RECT, ELSET=E4, MATERIAL=ALUM
 0.5, 21.96
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=RECT, ELSET=E5, MATERIAL=ALUM
 0.5, 25.498
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=RECT, ELSET=E6, MATERIAL=ALUM
 0.5, 28.396
 1.0,0.0,0.0
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E7, MATERIAL=ALUM
 10.5, 22.7, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E7N, MATERIAL=ALUM
 10.5, 22.7, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E8, MATERIAL=ALUM
 10.7, 23.113, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E8N, MATERIAL=ALUM
 10.7, 23.113, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E9, MATERIAL=ALUM
 11.24, 24.28, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E9N, MATERIAL=ALUM
 11.24, 24.28, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E10, MATERIAL=ALUM
 11.79, 25.46, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E10N, MATERIAL=ALUM
 11.79, 25.46, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E11, MATERIAL=ALUM
 12.11, 26.16, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E11N, MATERIAL=ALUM
 12.11, 26.16, 10.0, 12.0, 0.5, 2.0, 0.5
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**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E12, MATERIAL=ALUM
 12.75, 27.55, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E12N, MATERIAL=ALUM
 12.75, 27.55, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E13, MATERIAL=ALUM
 13.425, 28.998, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E13N, MATERIAL=ALUM
 13.425, 28.998, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E14, MATERIAL=ALUM
 14.08, 30.414, 10.0, 12.0, 0.5, 2.0, 0.5
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*BEAM SECTION, SECTION=I-BEAM, ELSET=E14N, MATERIAL=ALUM
 14.08, 30.414, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E15, MATERIAL=ALUM
 14.77, 31.896, 10.0, 12.0, 0.5, 2.0, 0.5
**
*BEAM SECTION, SECTION=I-BEAM, ELSET=E15N, MATERIAL=ALUM
 14.77, 31.896, 10.0, 12.0, 0.5, 2.0, 0.5
**
**
*MASS, ELSET=CYL

 1.294
**
*MASS, ELSET=QUAD

 0.647
**
*MASS, ELSET=ALL

 0.085
**
**   MATERIAL DEFINITIONS
**
*MATERIAL, NAME=ALUM
*ELASTIC, TYPE=ISO
 10.0E06, .34
*DENSITY
 0.00026161
**
*MATERIAL, NAME=STEEL
*ELASTIC, TYPE=ISO
 29.0E06, .3
*DENSITY
 0.00073574
**
**  LOAD CASE     1
*STEP
 6 LOWEST MODES
*FREQUENCY
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    6
**
**
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     169,  2,,    0.0
     169,  3,,    0.0
     171,  1,,    0.0
     171,  2,,    0.0
     172,  1,,    0.0
     172,  2,,    0.0
     174,  1,,    0.0
     174,  2,,    0.0
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     177,  2,,    0.0
     178,  2,,    0.0
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     212,  2,,    0.0
     215,  2,,    0.0
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**EL PRINT, POSITION=INTEGRATION POINTS
*NODE FILE, GLOBAL=YES
U
RF
*NODE PRINT, GLOBAL=YES
U
RF
*END STEP
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