U.S. Department
of Transportation
Federal Railroad
Administration

RESIDUAL STRESS MEASUREMENTS OF RETROFITTED TANK CAR WELDMENTS

Office of Research and
Development
Washington D.C. 20590

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Final Report

METRIC CONVERSION FACTORS

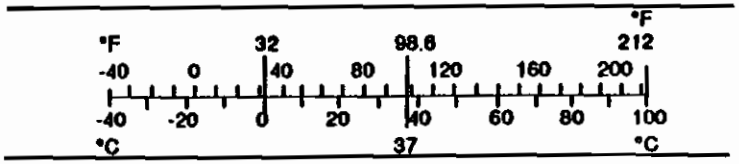
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hecteres (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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16. Abstract

A series of residual stress measurements were made on two tank cars that were retrofitted with stiffener beams. The measurements were made on the tank shell exterior in the vicinity of fillet skip welds, which were used to attach the stiffener beams to the tank structure. One of the cars had been newly retrofitted; the second car was operated for five years in revenue service after the retrofit application.

The measured stresses on the newly retrofitted car were substantially higher than on the car which had seen service indicating that some shakedown of the weld stresses may occur during the service life of the car. However, significant tensile stresses (on the order of 30 ksi) were measured in the vicinity of the fillet welds having a throat size greater than .25 inch.

It is recommended that the stress measurements be performed on several other tank cars in order to confirm that the stresses that were observed in the two test cars are representative for the fleet of cars that is under study.

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Table of Contents

1.0 INTRODUCTION 1

2.0 OBJECTIVE 1

3.0 INSTRUMENTATION 1

4.0 PROCEDURES 2

4.1 MEASUREMENT LOCATION SELECTION 3

4.2 STRAIN DATA COLLECTION 7

4.3 STRAIN DATA ANALYSIS 8

5.0 RESULTS 11

6.0 CONCLUSIONS 13

7.0 RECOMMENDATIONS 13

APPENDIX A: STRAIN GAGE POSITIONS, CALCULATED STRESSES, AND PHOTOGRAPHS 14

APPENDIX B: CALCULATED STRESSES FOR EACH .01 INCH DEPTH INCREMENT 35

APPENDIX C: PERCENT STRAIN RELEIVED VS. ASTM STANDARD 59

Figures

Figure 1 - Vishay Strain Indicator 2
Figure 2 - Stiffener Weld Layout 3
Figure 3 - Measurement Locations on GATX 92202 4
Figure 4 - Measurement Locations on GATX 10360 5
Figure 5 - Milling Fixture with Alignment Microscope Installed 8
Figure 6 - Typical Strain Gage Arrangement 9
Figure 7 - Data Reduction Coefficients $\overline{a}$ and $\overline{b}$ for UM Gages 10

Tables

Table 1 - Measurement Location and Selection Criteria - GATX 92202 6
Table 2 - Measurement Location and Selection Criteria - GATX 10360 6

1.0 INTRODUCTION

The Federal Railroad Administration (FRA) has determined that, in a number of instances, structural modifications not in conformance with tank car specifications were made to a number of DOT Class 111A100W Stub Sill Tank Cars. Specifically, in attaching an underbelly span stiffener to the tank shell of the car, fillet welds were applied which exceeded the Association of American Railroads (AAR) R17.01 specification covering welds applied without post-weld heat treatment. There is a concern that the oversized welds may have introduced large tensile residual stresses in the tank shell immediately adjacent to the weld fillets that join the base of the stiffener beam to the tank shell.

In order to clarify this issue, the FRA retained the AAR to perform residual stress measurements on a sampling of the modified cars at the Transportation Test Center (TTC), Pueblo, Colorado. This report documents the procedures used and the results obtained in the test program.

2.0 OBJECTIVE

The objective of the test program was to determine the magnitude of surface residual stresses produced by underbelly span stiffener beam welds on two tank cars, one with no service time after being modified, and the other with 5 years of service time after being modified. Data from the first car (no service time) were used as a baseline, and were assumed to be representative for this particular modification method. Data from the second car (5 years of service time) were to be used, in conjunction with the data from the first car, to estimate the effects of shakedown on the levels of residual stress near the weldments that occurs during service. It was assumed that immediately after application of the weldments prior to any service operation the levels of residual stress near the weldments in this car would have been similar to that measured in the first car.

3.0 INSTRUMENTATION

The blind-hole drilling strain gage technique, as described in the American Society of Testing Materials (ASTM) specification E837-85, was used to determine the state of residual stress in the two tank shells. The technique consists of drilling a hole in the center of a strain gage rosette and measuring the relaxed strains. Model UM-06-062 strain gages, manufactured by Measurements Group, Incorporated, were used at all measurement locations. A digital strain indicator and a switch and balance unit, manufactured by Vishay, having a resolution of

1 microstrain were used to measure the strain. Figure 1 shows the Vishay strain indicator. Hole depth was measured using the micrometer feed control on the drill. Hole diameter was measured using a microscope grid.

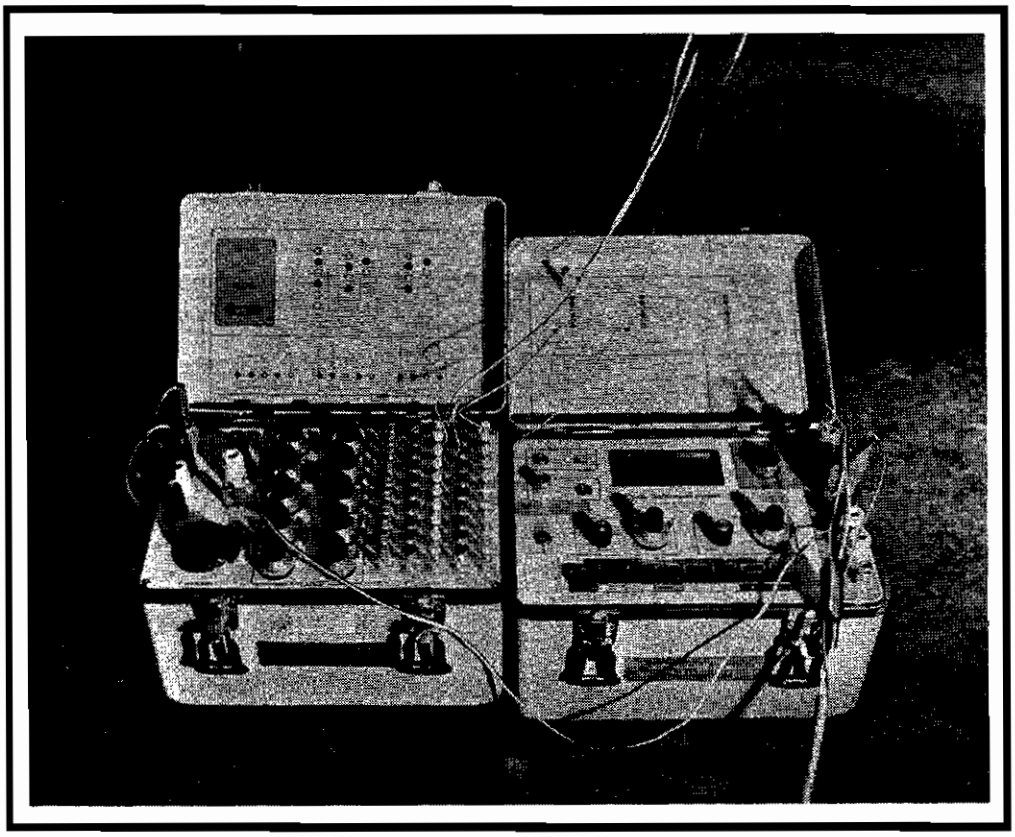


Figure 1. Vishay Strain Indicator

4.0 PROCEDURES

Residual stress measurements were made on two tank cars. The first car, GATX 92202, had been used in revenue service for approximately 5 years after the stiffener beam retrofit was applied. The stiffener beam retrofit was only recently applied to the second car, GATX 10360. The following subsections describe the methods used to select the measurement locations, and collect and analyze the strain data.

4.1 MEASUREMENT LOCATION SELECTION

The stiffener beam fillet weld measurement locations were selected based upon the variation of weldment from those set forth in the AAR R17.01 specification published in Section C Part III of the AAR's *Manual of Standards and Recommended Practices*, weldment conformance to the R17.01 specification, weldment radius, and weldment location on the tank shell. The R17.01 specification states that:

> *"Exterior or interior brackets, supports, and reinforcement bar pads may be fillet welded to tank shells, without post-weld heat treatment, provided the welds do not exceed 3 inches in length for an intermittent welding (skip or stepback welding permitted) and the total lineal welds do not exceed 24 inches per bracket, support, or reinforcing bar pad. Throat thickness of welds must not exceed 0.25 inch."*

Figure 2 shows the layout of the welds that were applied to the two test cars. Figures 3 and 4 show the measurement locations on tank car GATX 92202 and GATX 10360 respectively.

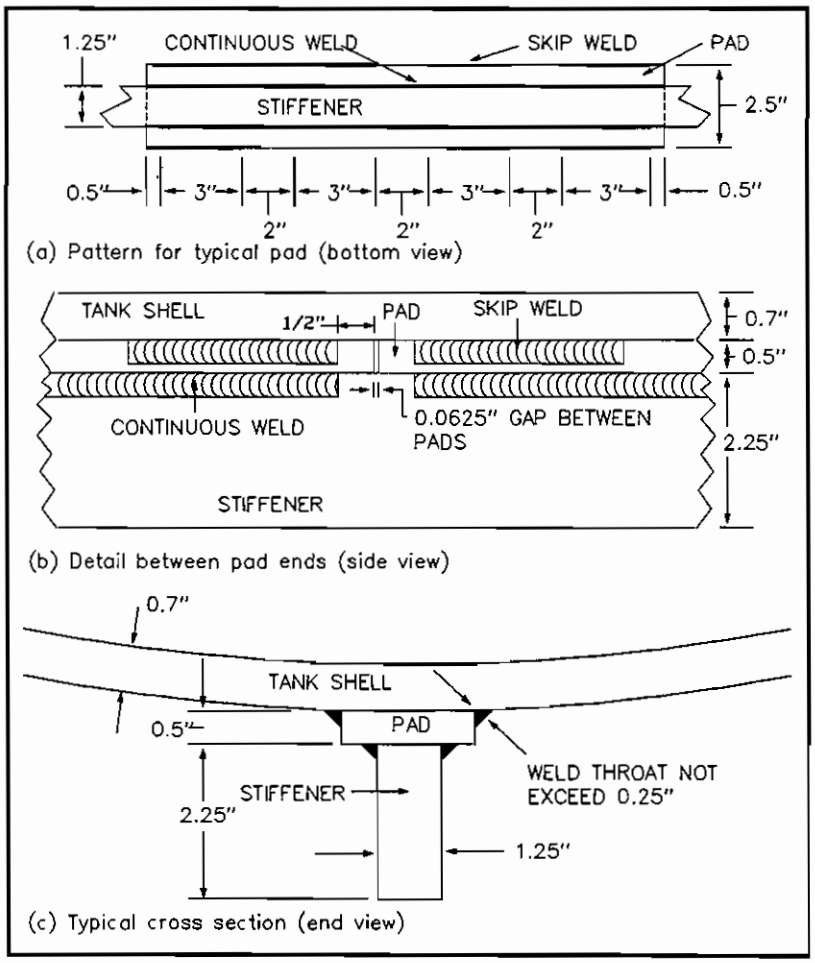


Figure 2. Stiffener Weld Layout

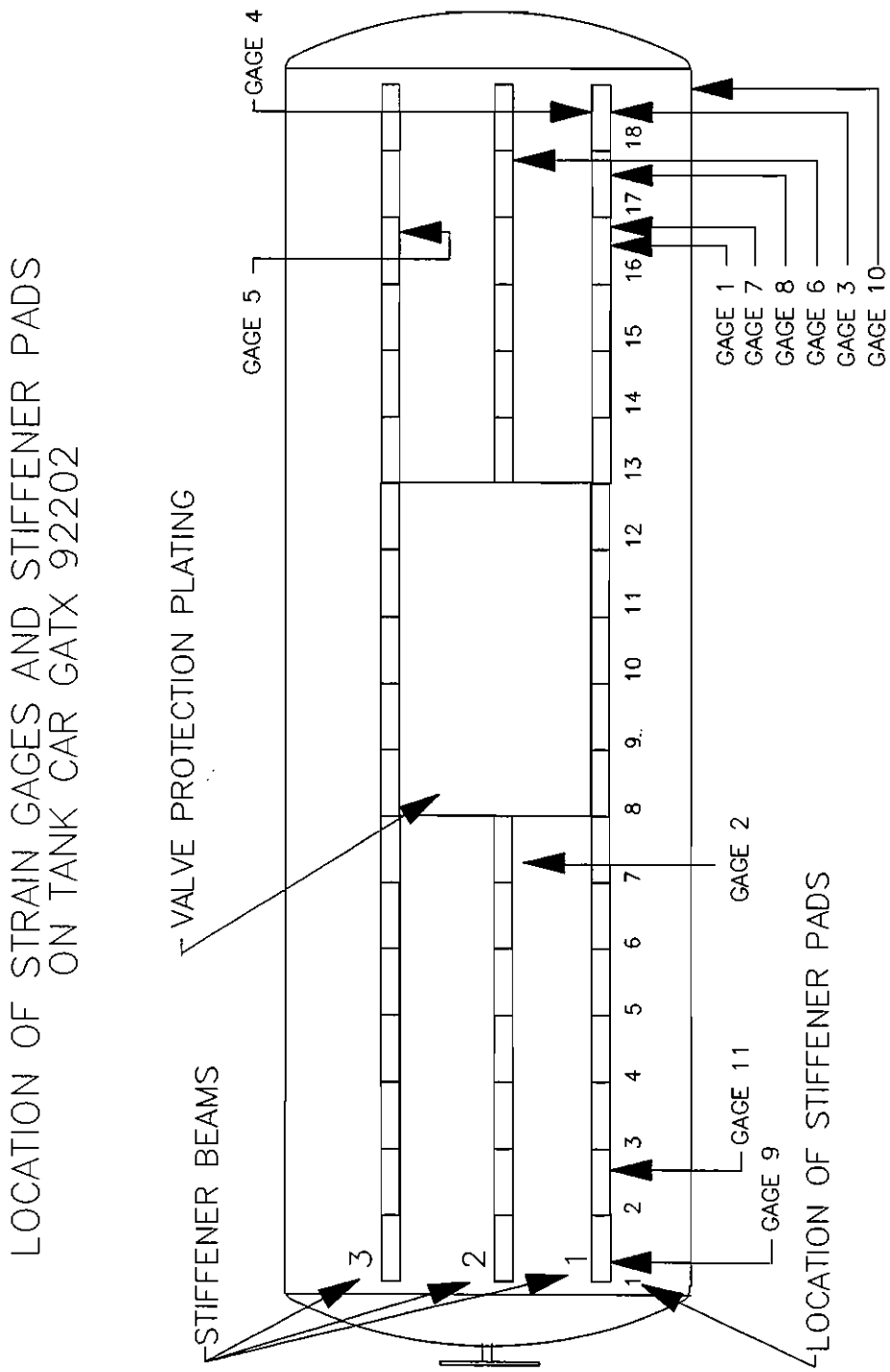


Figure 3. Measurement Locations on GATX 92202

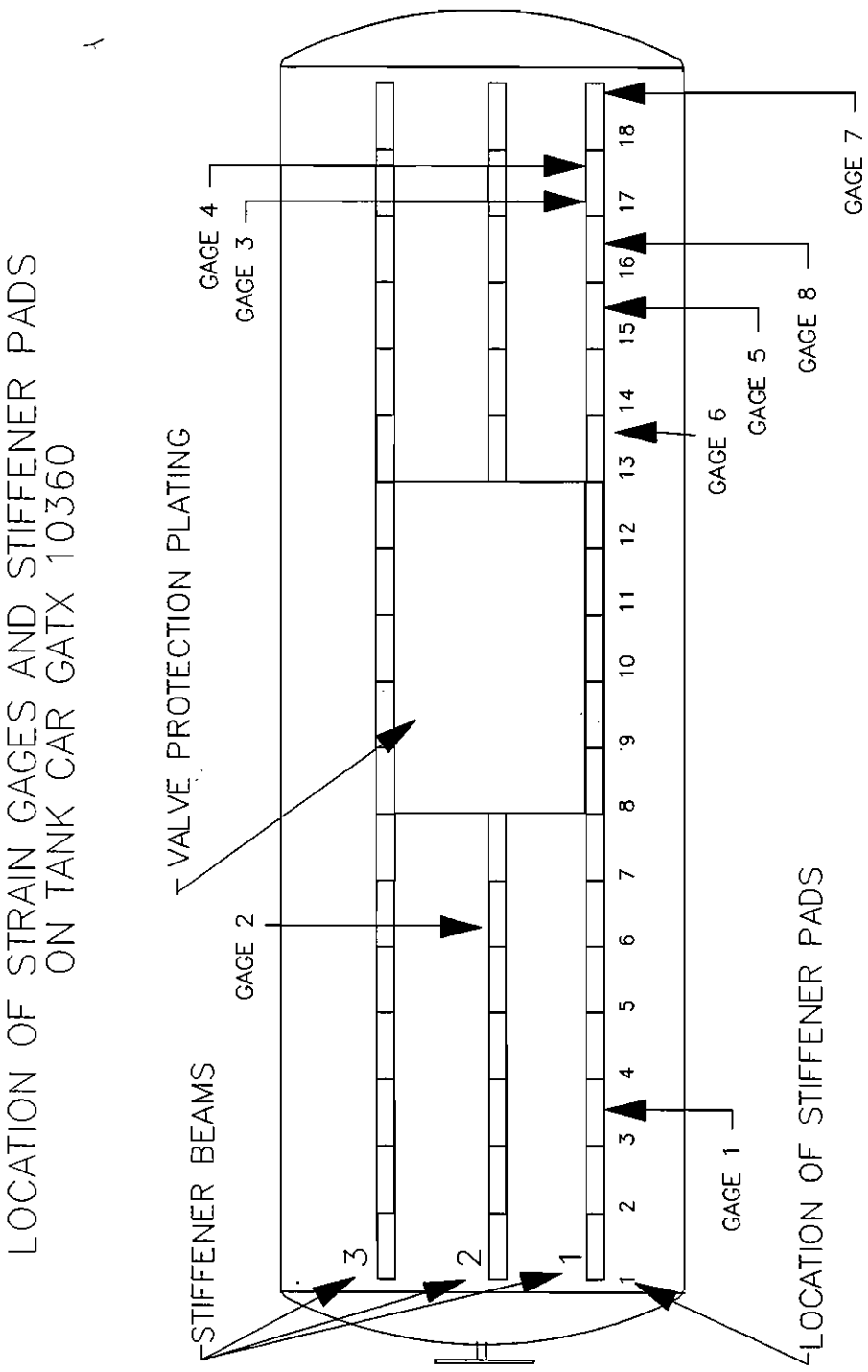


Figure 4. Measurement Locations on GATX 10360

Tables 1 and 2 provide a summary of the selection criteria for each measurement location for GATX 92202 and GATX 10360 respectively.

Table 1. Measurement Location and Selection Criteria - GATX 92202

MEASUREMENT LOCATION	SELECTION CRITERIA
1	Throat thickness of the weld exceeded 0.25 inch
2	Throat thickness of the weld exceeded 0.25 inch
3	Length of the weld exceeded 3 inches
4	Spacing between two welds was less than 2 inches
5	Stiffener pads butted together
6	Gap between stiffener pad and tank shell
7	Weld was in conformance to the specification
8	Weld was in conformance to the specification
9	Weld was in conformance to the specification
10A	2 inch radius weld on side strut
10B	8 inch radius on side strut
11	Spacing between two welds was 2 inches

Table 2. Measurement Location and Selection Criteria - GATX 10360

MEASUREMENT LOCATION	SELECTION CRITERIA
1	Throat thickness of the weld exceeded 0.25 inch
2	Throat thickness of the weld exceeded 0.25 inch
3	Spacing between two welds was less than 2 inches
4	Spacing between two welds was less than 2 inches
5	Weld was in conformance to the specification
6	Weld was in conformance to the specification
7	Weld was in conformance to the specification
8	Spacing between two welds was 2 inches

4.2 STRAIN DATA COLLECTION

The following procedures were followed in collecting the residual stress data for each measurement location:

1. The measurement location was prepared by lightly grinding the tank shell, followed by hand polishing and cleaning with solvent.
2. Scribe lines were marked and the strain gage rosette was bonded to the tank shell with adhesive.
3. Lead wires were soldered to the rosette and attached to the switch and balance unit and digital strain indicator.
4. The milling fixture (Figure 5) was attached to the stiffener beam.
5. The sliding plate in the milling fixture was moved to align the high speed drill approximately with the center line of the strain gage.
6. The milling guide tripod feet were adjusted to align the high speed drill with an axis perpendicular to the surface of the tank.
7. The alignment microscope was installed in the milling guide and the fine adjustment screws on the milling guide were used to precisely align the center line of the cross hairs of the microscope with the center line of the strain gage rosette.
8. The high speed drill equipped with an end mill was installed in the milling guide and rotated by hand while applying a light pressure to drill the center portion of the strain gage and expose the surface of the tank.
9. The strain balancing unit was adjusted to provide an initial reading of zero for each of the rosette strain gages.
10. The micrometer feed adjustment on the high speed drill was set to zero.
11. The drill was powered and the micrometer feed was rotated to drill the hole in 0.01 inch increments to a depth of 0.10 inch. At each increment, the drilling was stopped and a strain measurement was recorded for each rosette strain gage.
12. At the completion of the drilling operation the diameter of the hole was measured using a graduated scale on the microscope.

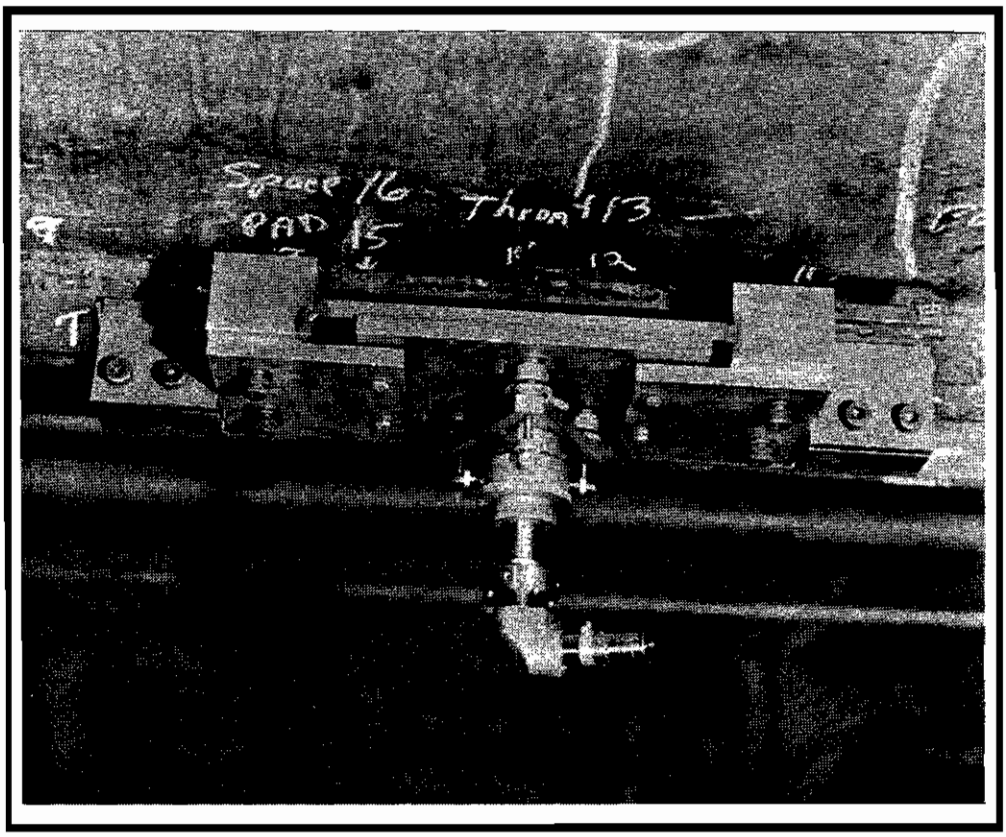


Figure 5. Milling Fixture with Alignment Microscope Installed

4.3 STRAIN DATA ANALYSIS

The blind-hole drilling strain gage technique is a semi-destructive method for determining the near surface residual stresses of an isotropic, elastic material. The technique involves applying a strain gage to the surface of the specimen, drilling a hole in the vicinity of the gage to a depth greater than its diameter, and measuring the change in surface strain with hole depth. The introduction of the hole in the specimen relaxes the stresses at the location. For the blind-hole technique, when the hole depth approaches 1.2 times the hole diameter nearly all of the relaxation is complete. Figure 6 shows a diagram of a typical strain gage arrangement.

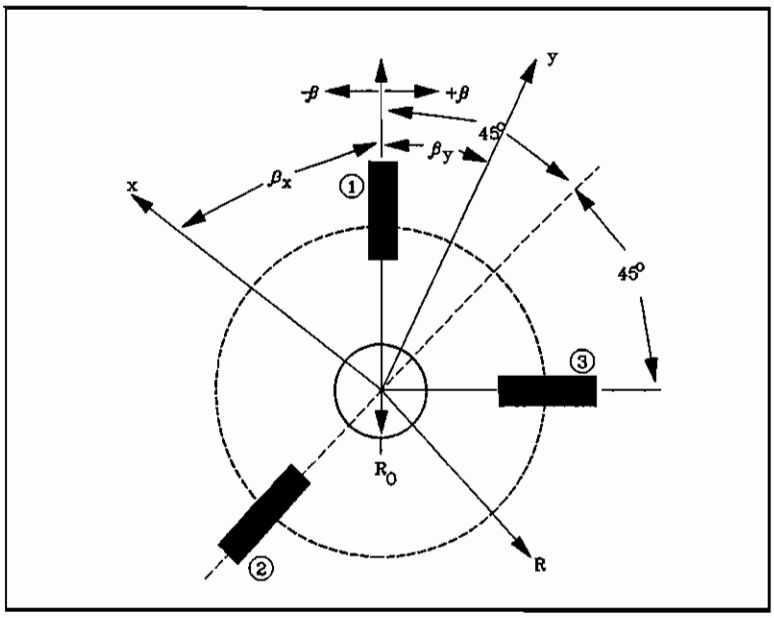


Figure 6. Typical Strain Gage Arrangement

The principal stresses can be determined from the measured strains by the following relationships:

$$\sigma_x = \frac{\epsilon_1 + \epsilon_3}{4\overline{A}} + \frac{\sqrt{2}}{4\overline{B}}\sqrt{(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2}$$

$$\sigma_y = \frac{\epsilon_1 + \epsilon_3}{4\overline{A}} - \frac{\sqrt{2}}{4\overline{B}}\sqrt{(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2}$$

where:

$$\overline{A} = \frac{1 + \mu}{2E} \cdot \overline{a}$$

$$\overline{B} = \frac{1}{2E} \cdot \overline{b}$$

μ = Poisons Ratio

E = Modulus of Elasticity

ϵ_1 = The strain measured at gage location 1

ϵ_2 = The strain measured at gage location 2

ϵ_3 = The strain measured at gage location 3

$\overline{a}, \overline{b}$ were obtained from the graph shown in Figure 7

and:

$$\beta = \left(\tan^{-1} \left(\frac{\epsilon_1 - 2\epsilon_2 + \epsilon_3}{\epsilon_3 - \epsilon_1} \right) \right) / 2$$

Where the direction angle β is referenced to gage 1 and the clockwise direction is positive and:

$\beta = \beta_x \quad if \quad \epsilon_3 < \epsilon_1$

$\beta = \beta_y \quad if \quad \epsilon_3 > \epsilon_1$

$\beta = 45^\circ \quad if \quad \epsilon_1 = \epsilon_3$

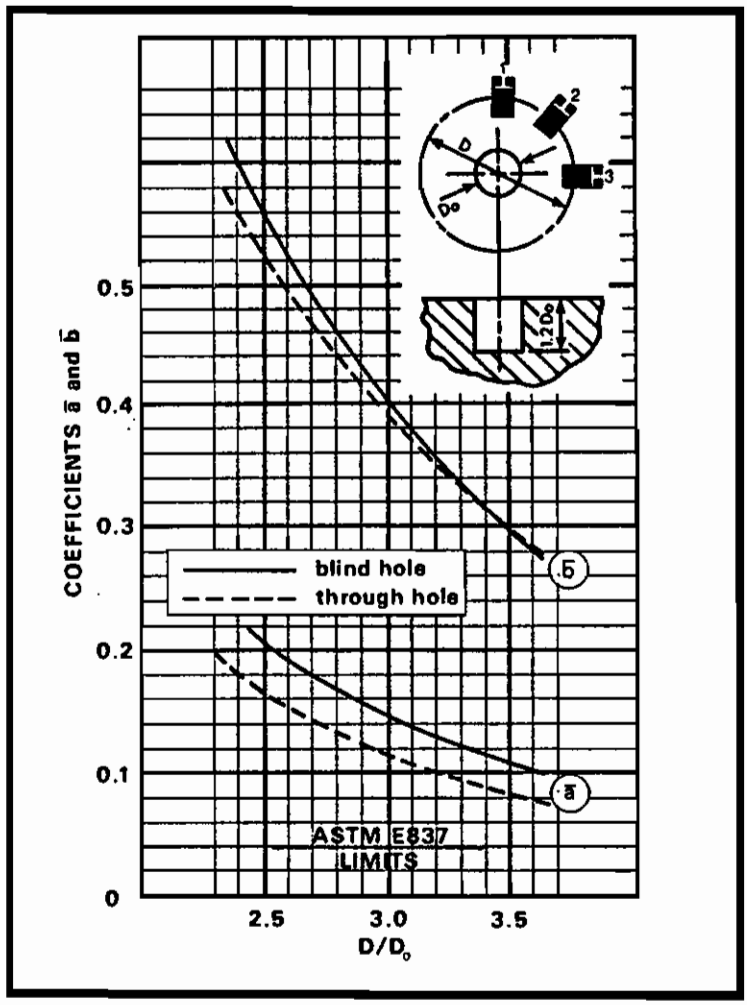


Figure 7. Data Reduction Coefficients $\bar{a}$ and $\bar{b}$ for UM Gages

These relationships only produce accurate results when the residual stresses are uniform throughout the drilling depth. In order to estimate the uniformity of the stresses throughout the drilling depth, the percent strain relieved is plotted against the ratio of the hole depth to the hole diameter and compared to the specified scatter band published in the ASTM specification E837-85. Graphs showing percent strain relieved versus the ratio of hole depth to hole diameter for each measurement location are provided in Appendix C.

5.0 RESULTS

The calculated stresses for each measurement location for tank cars GATX 92202 and GATX 10360 are provided in Tables 3 and 4, respectively. The values listed in the table correspond to a hole depth of 0.09 inch (approximately 1.2 times the hole diameter). The measurement locations for which the residual stresses were not uniform throughout the hole depth are indicated with an asterisk.

Table 3. Residual Stresses for Tank Car GATX 92202

GAGE	SELECTION CRITERIA	MIN STRESS (ksi)	MAX STRESS (ksi)	LONG STRESS (ksi)	TRANS STRESS (ksi)	BETA+	BETA AXIS
1	WIDTH > .25"	-4.5	33.9	31.9	-2.5	13°	MAX
2	WIDTH > .25"	-20.5	27.8	26.8	-19.4	8°	MAX
3*	LENGTH > 3"	-1.4	31.8	13.0	17.4	-41°	MIN
4*	SPACING < 2"	-13.6	24.4	24.4	-13.6	44°	MIN
5	LOCATION	-8.3	28.0	27.2	-8.0	-5°	MIN
6*	LOCATION	-20.5	11.1	10.4	-19.8	-9°	MIN
7*	CONFORMANCE	-8.1	16.1	16.4	-8.1	-1°	MAX
8*	CONFORMANCE	-1.0	17.9	16.5	0.4	16°	MAX
9	CONFORMANCE	-15.2	16.8	11.4	-9.8	24°	MIN
10A	2" RADIUS	-6.4	30.0	29.1	-5.5	-9°	MIN
10B*	8" RADIUS	0.8	10.9	9.9	1.8	-18°	MIN
11*	SPACING = 2.2"	-27.5	21.8	21.8	-27.5	45°	MIN

+ Beta is the angle between the axis of strain gage 1 and the minimum or maximum stress axis (Clockwise = positive).

* Indicates residual stresses not uniform throughout the drilling depth.

Table 4. Residual Stresses for Tank Car GATX 10360

GAGE	SELECTION CRITERIA	MIN STRESS (ksi)	MAX STRESS (ksi)	LONG STRESS (ksi)	TRANS STRESS (ksi)	BETA+	BETA AXIS
1	WIDTH > .25"	-20.55	34.3	30.4	-16.5	-16°	MIN
2*	WIDTH > .25"	6.4	49.3	45.9	9.9	17°	MAX
3	SPACING < 2"	-50.5	-5.7	-5.8	-50.4	42°	MIN
4	SPACING < 2"	-48.8	0.9	-1.2	-48.6	41°	MIN
5A	CONFORMANCE	19.5	64.8	56.7	27.6	25°	MAX
5B*	CONFORMANCE	37.8	44.3	42.5	39.5	31°	MAX
5C*	CONFORMANCE	29.4	32.8	32.0	30.1	-28°	MAX
5D*	CONFORMANCE	-16.4	21.0	19.8	-15.1	-11°	MIN
5E	CONFORMANCE	-24.4	11.6	11.3	-24.1	5°	MAX
6	CONFORMANCE	-10.7	25.4	22.4	-7.7	-17°	MIN
7*	CONFORMANCE	-3.3	49.5	45.3	0.8	16°	MAX
8*	SPACING = 2"	-26.1	14.8	14.6	-26.0	-41°	MIN

+ Beta is the angle between the axis of strain gage 1 and the minimum or maximum stress axis (Clockwise = positive).

* Indicates residual stresses not uniform throughout the drilling depth.

An analysis of Tables 2 and 3 reveals that for locations where the residual stresses were uniform throughout the drilling depth the conformance fillet weld stresses were substantially higher for GATX 10360 than for GATX 92202, which supports the premise that revenue service operation may reduce weld related tank shell stresses. For example, the maximum stress measured in the conformance welds on GATX 10360 was 64.8 ksi while the maximum stress measured on GATX 92202 was 16.8 ksi. It should also be noted for both cars mentioned the stresses measured in the conformance welds were lower than those measured in the welds in which throat thickness exceeded the R17.01 specification.

6.0 CONCLUSIONS

The data obtained from the locations where the residual stress was uniform throughout the drilling depth supports the following conclusions concerning the state of residual stresses in these specific tank car designs:

- Weld induced tank shell stresses measured near conformance welds in the car recently retrofitted with the stiffener beam (GATX 10360) were substantially higher than those measured near conformance welds in the car that had been operated for 5 years in revenue service since the stiffener beam retrofit was applied (GATX 92202).
- Tank shell stresses on the order of 30 ksi were measured on GATX 92202 near welds where the throat thickness exceeded the R17.01 specification. Thus, while revenue service operation may result in a redistribution of weld induced stresses, a significant level of tensile residual stress remained in the tank shell.

7.0 RECOMMENDATIONS

The following recommendations are submitted for consideration by the FRA:

- Three additional tank cars with approximately 5 years or 200,000 miles of revenue service operation since the retrofit application should be tested to confirm the presence of high (30 ksi) tensile stresses in the vicinity of the stiffener beam fillet weld measurement locations.
- Destructive materials tests should be used to determine the fatigue life of heat treated and non-heat treated fillet welds for various applied load levels.

APPENDIX A

STRAIN GAGE POSITIONS, CALCULATED STRESSES, AND PHOTOGRAPHS

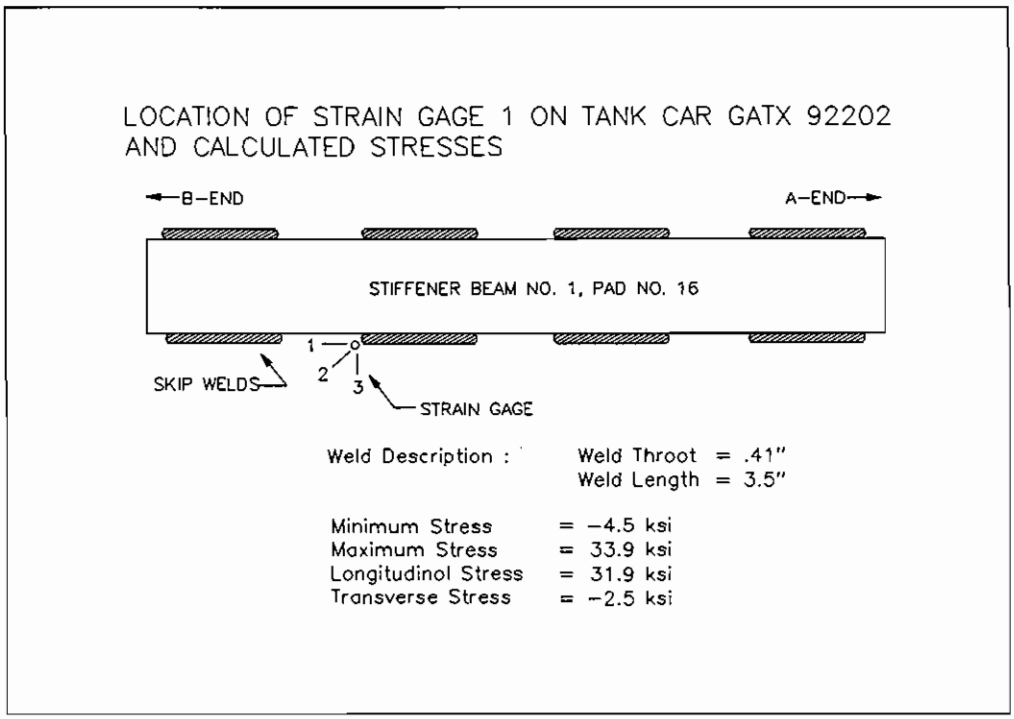


Figure A-1. Location of Strain Gage 1 on Tank Car GATX 92202 and Calculated Stresses

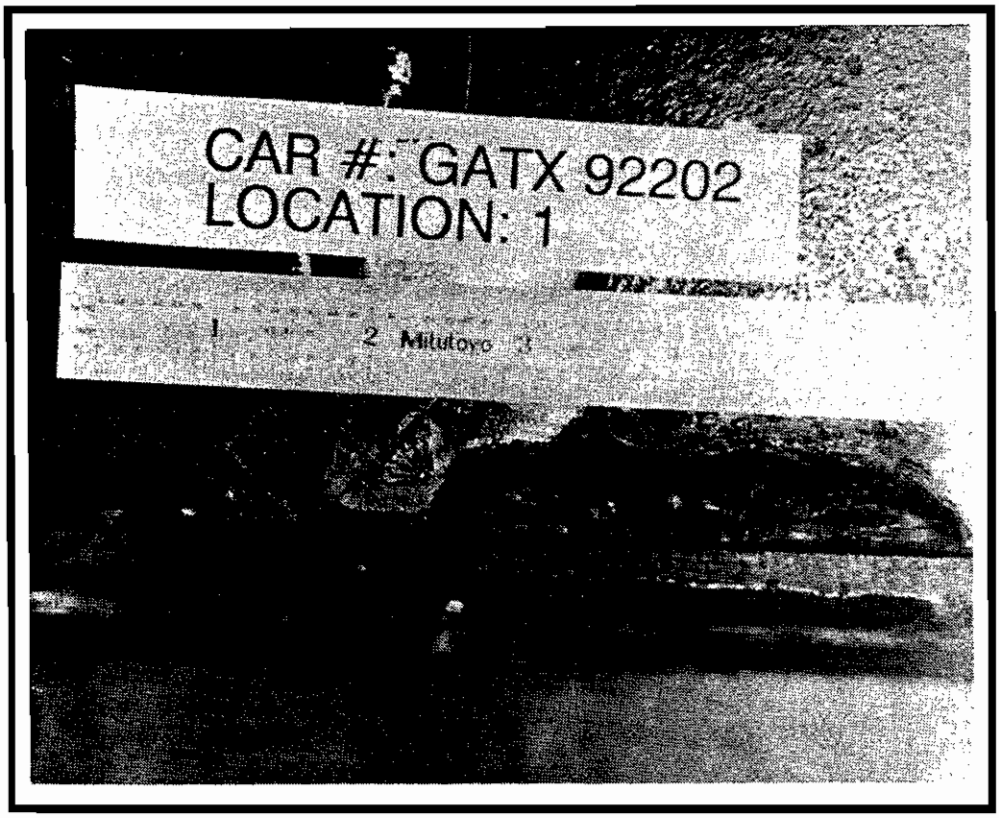


Figure A-2. View of Strain Gage 1 on Tank Car GATX 92202

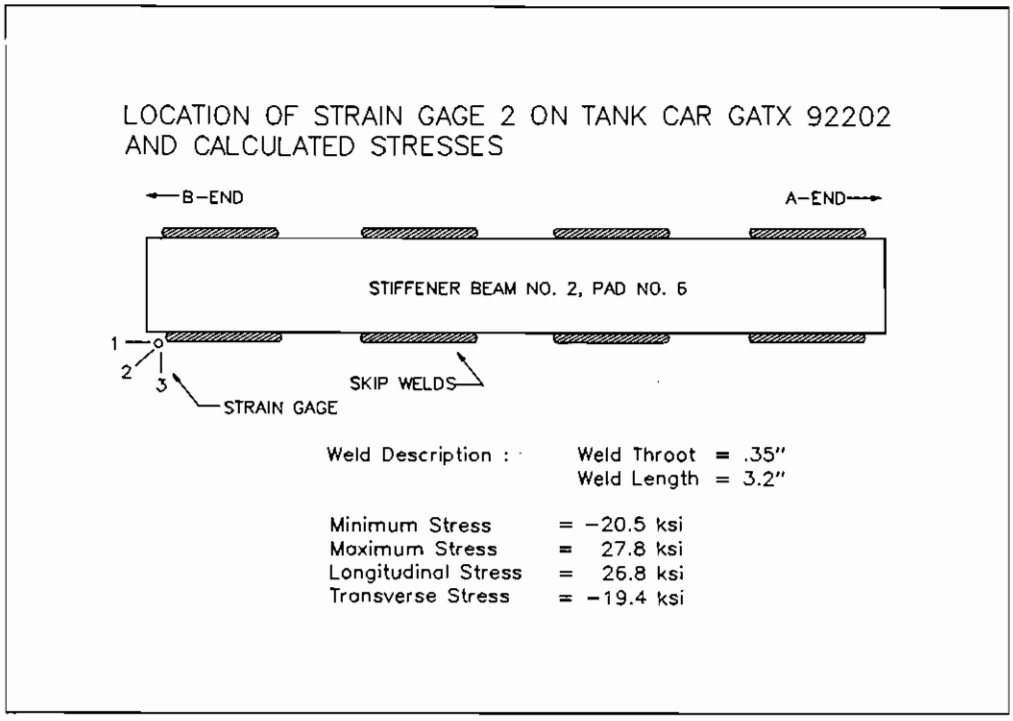


Figure A-3. Location of Strain Gage 2 on Tank Car GATX 92202 and Calculated Stresses

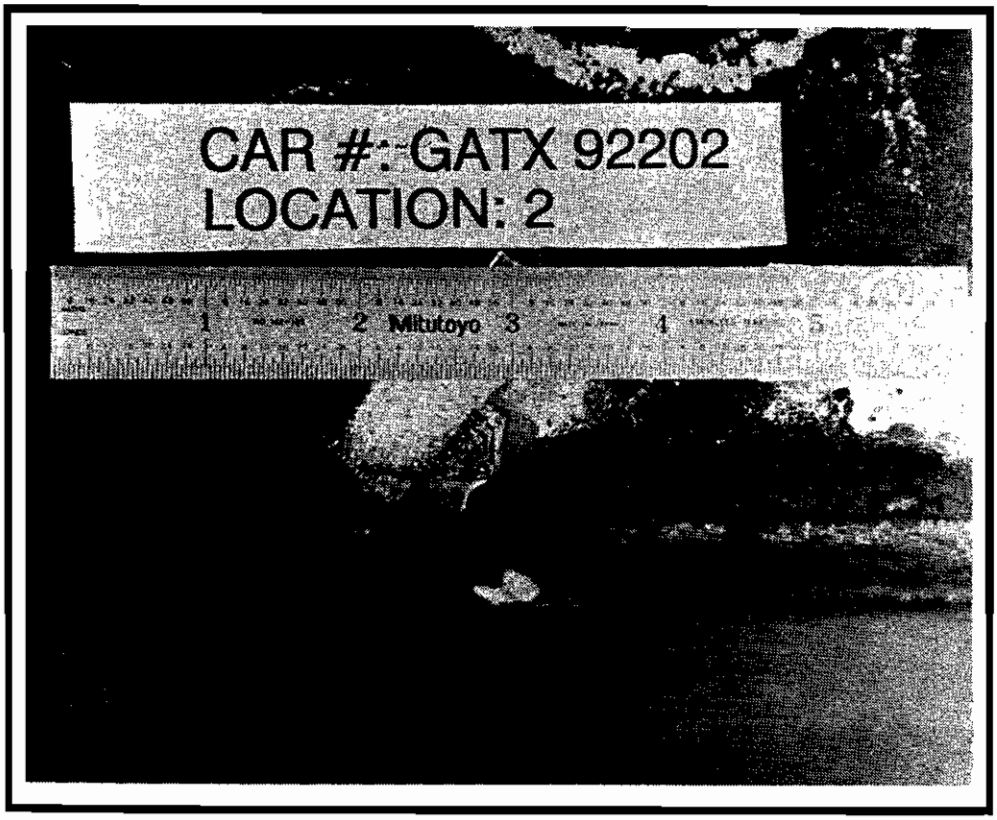


Figure A-4. View of Strain Gage 2 on Tank Car GATX 92202

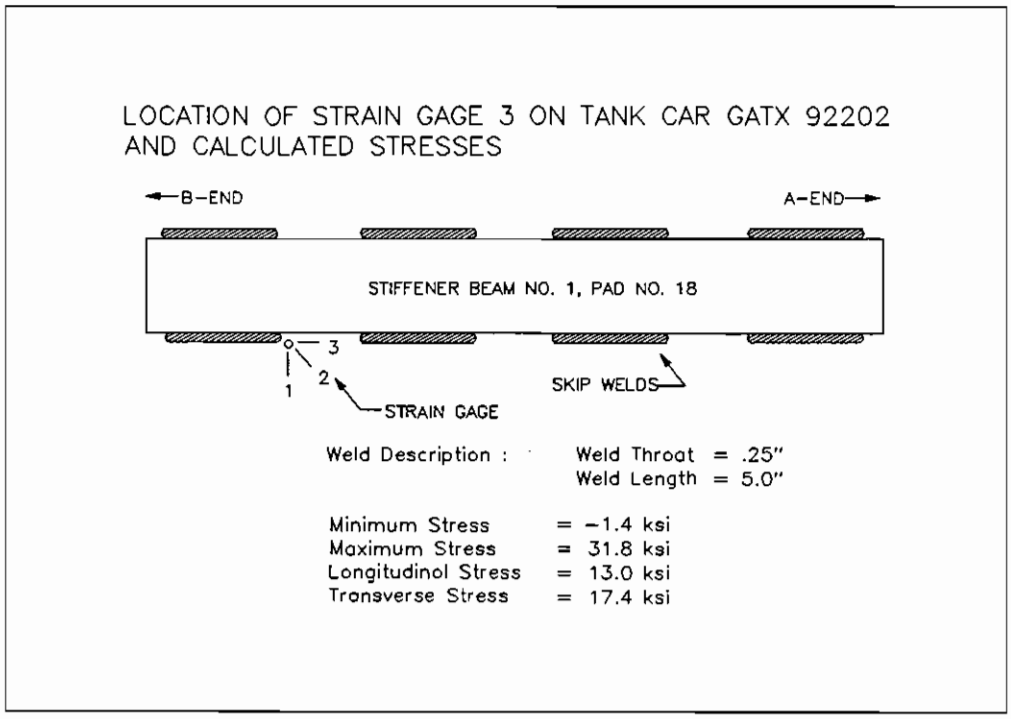


Figure A-5. Location of Strain Gage 3 on Tank Car GATX 92202 and Calculated Stresses

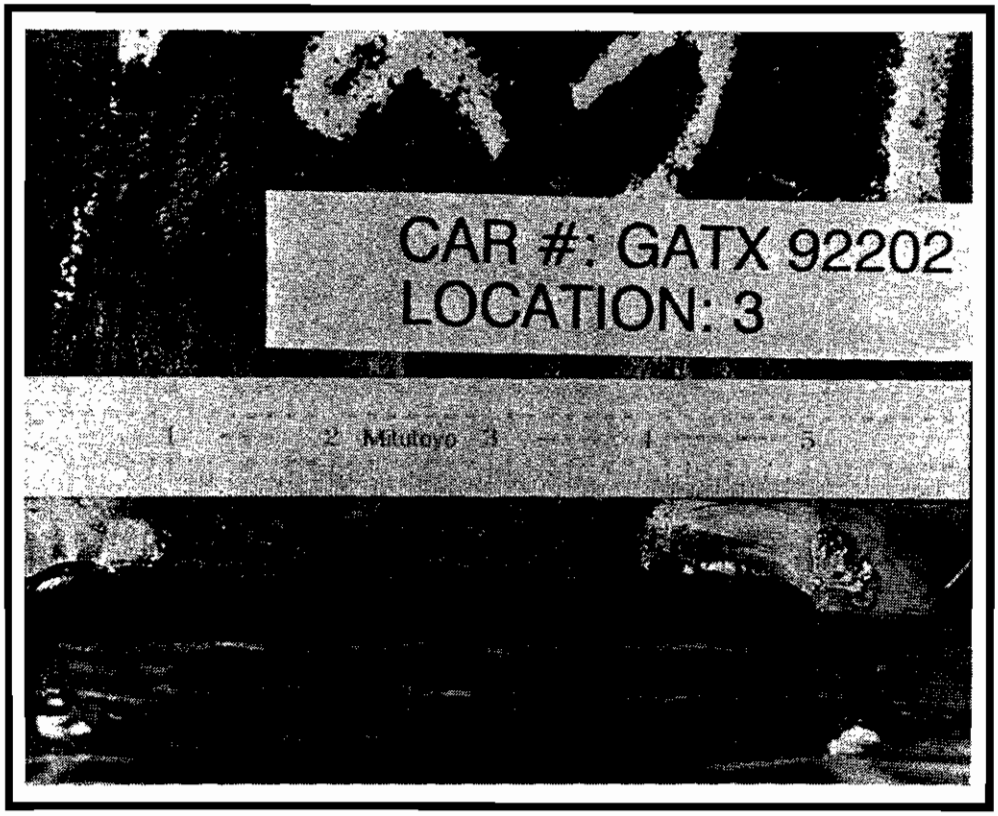


Figure A-6. View of Strain Gage 3 on Tank Car GATX 92202

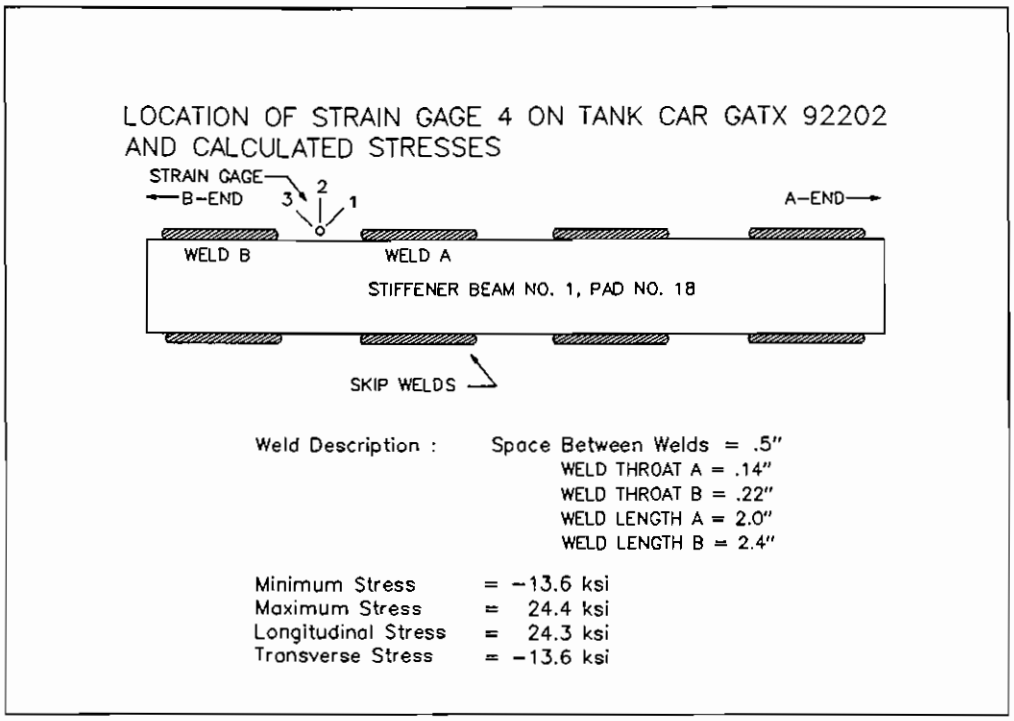


Figure A-7. Location of Strain Gage 4 on Tank Car GATX 92202 and Calculated Stresses

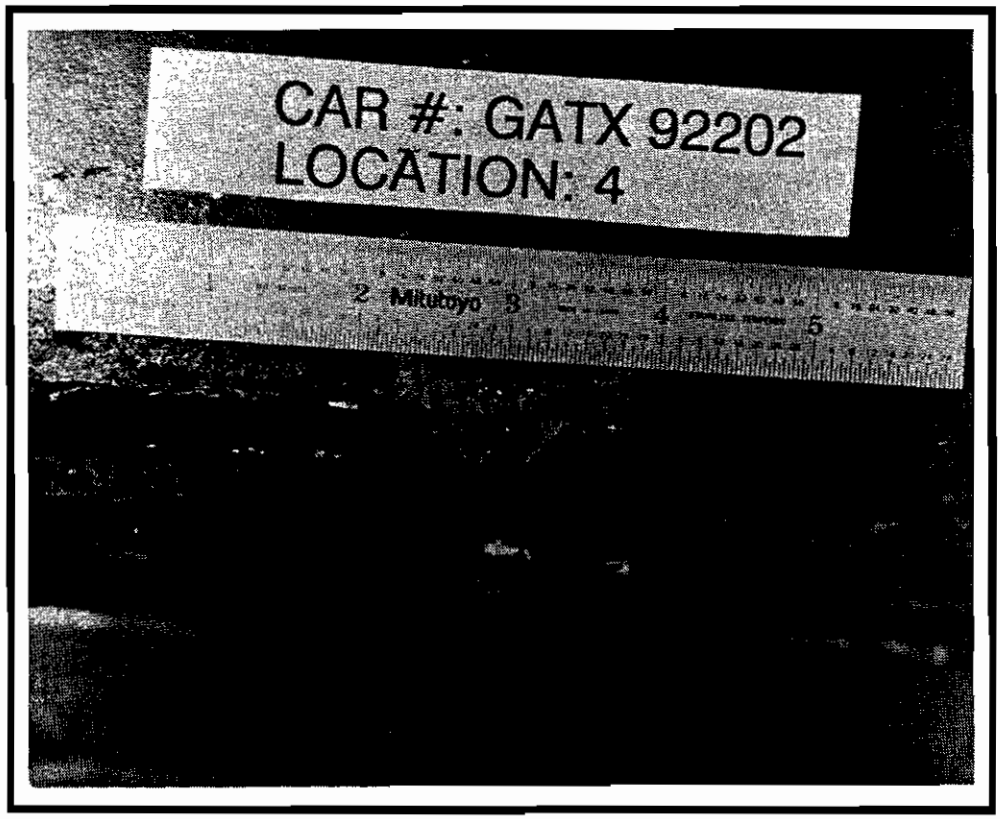


Figure A-8. View of Strain Gage 4 on Tank Car GATX 92202

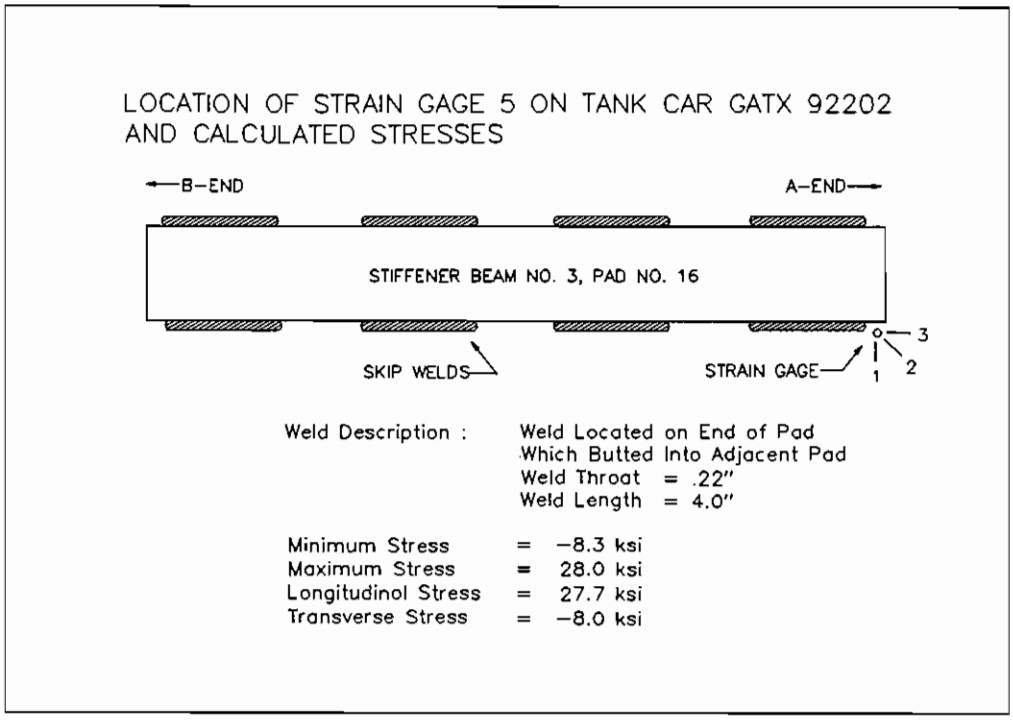


Figure A-9. Location of Strain Gage 5 on Tank Car GATX 92202 and Calculated Stresses

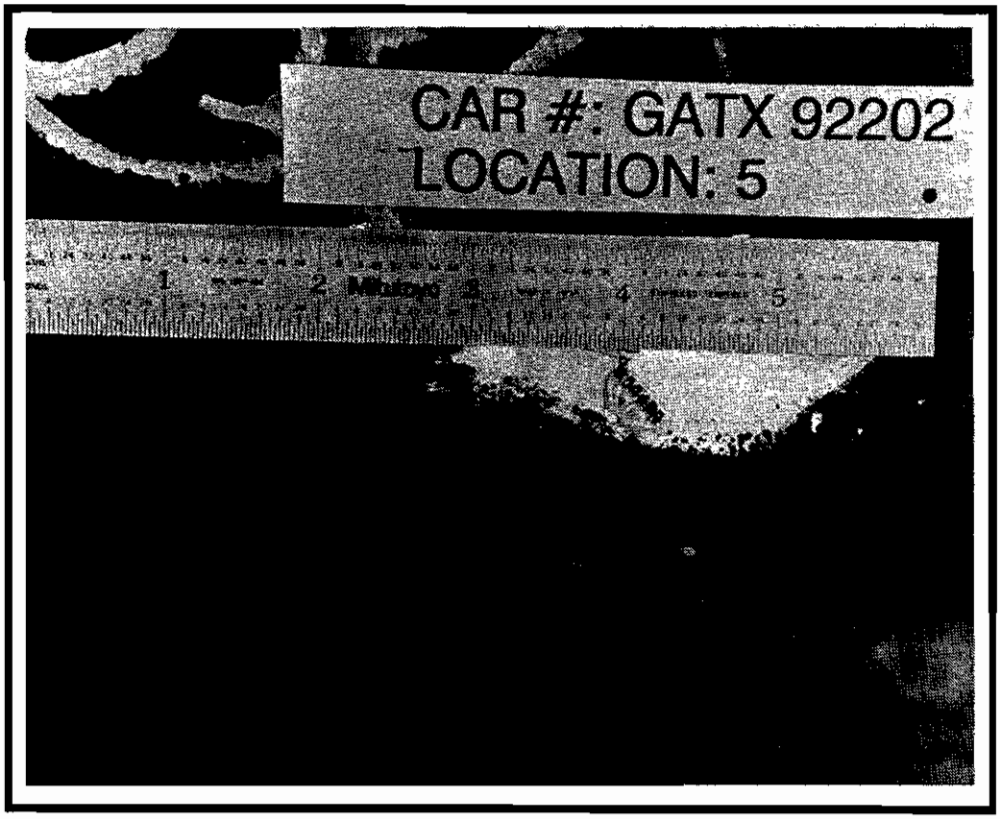


Figure A-10. View of Strain Gage 5 on Tank Car GATX 92202

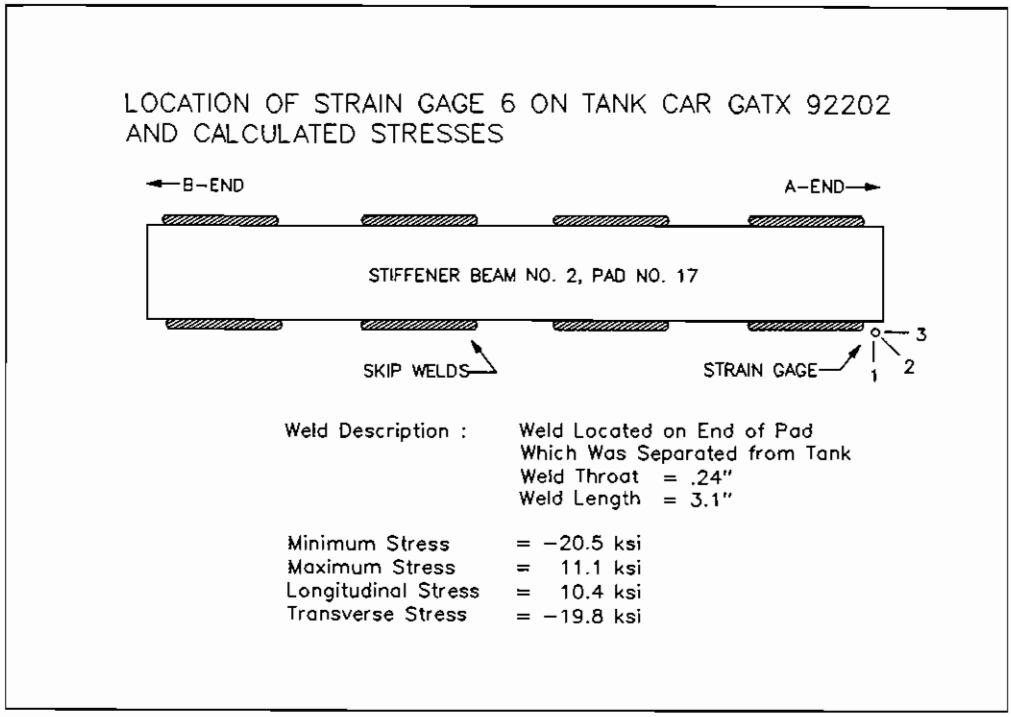


Figure A-11. Location of Strain Gage 6 on Tank Car GATX 92202 and Calculated Stresses

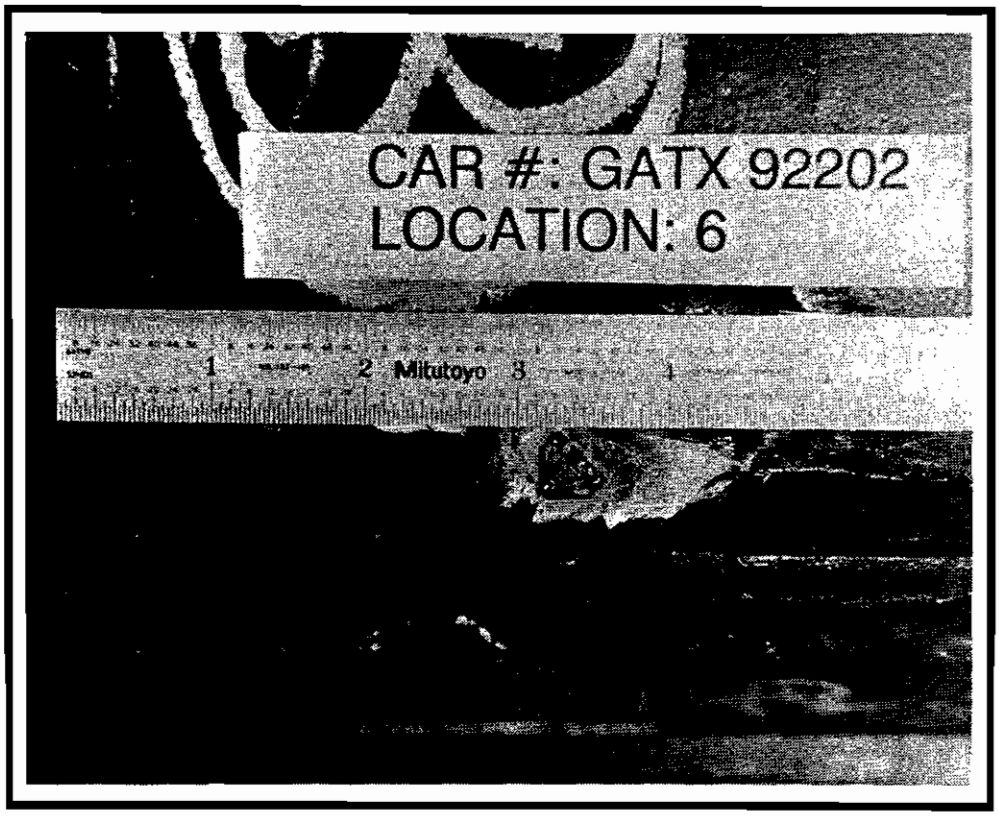


Figure A-12. View of Strain Gage 6 on Tank Car GATX 92202

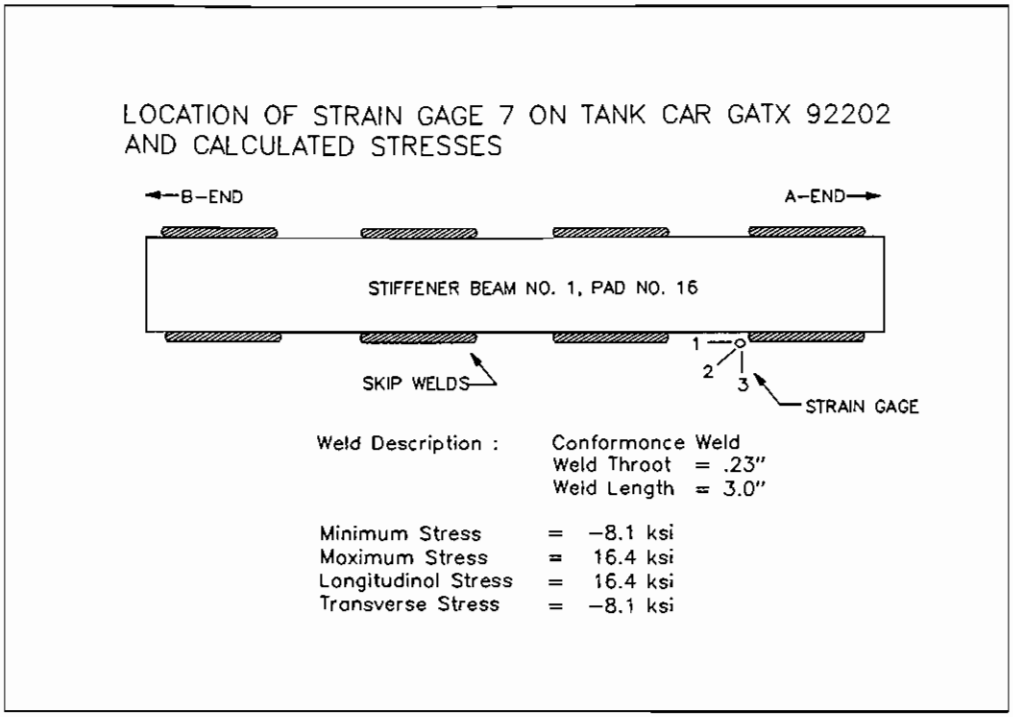


Figure A-13. Location of Strain Gage 7 on Tank Car GATX 92202 and Calculated Stresses

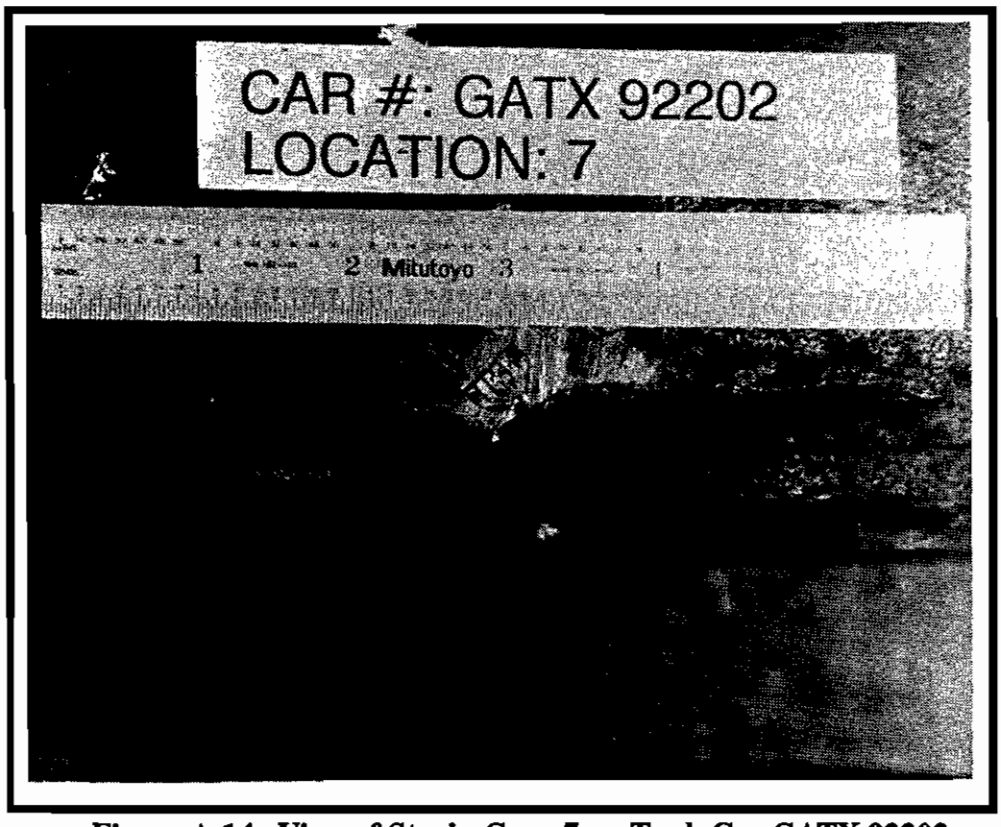


Figure A-14. View of Strain Gage 7 on Tank Car GATX 92202

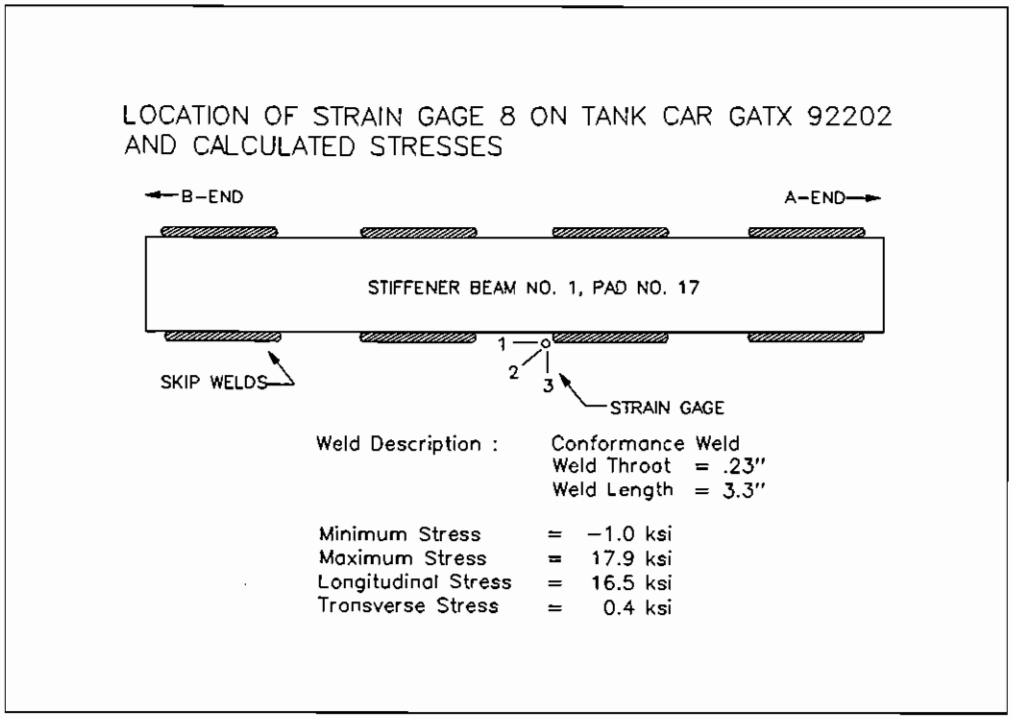


Figure A-15. Location of Strain Gage 8 on Tank Car GATX 92202 and Calculated Stresses

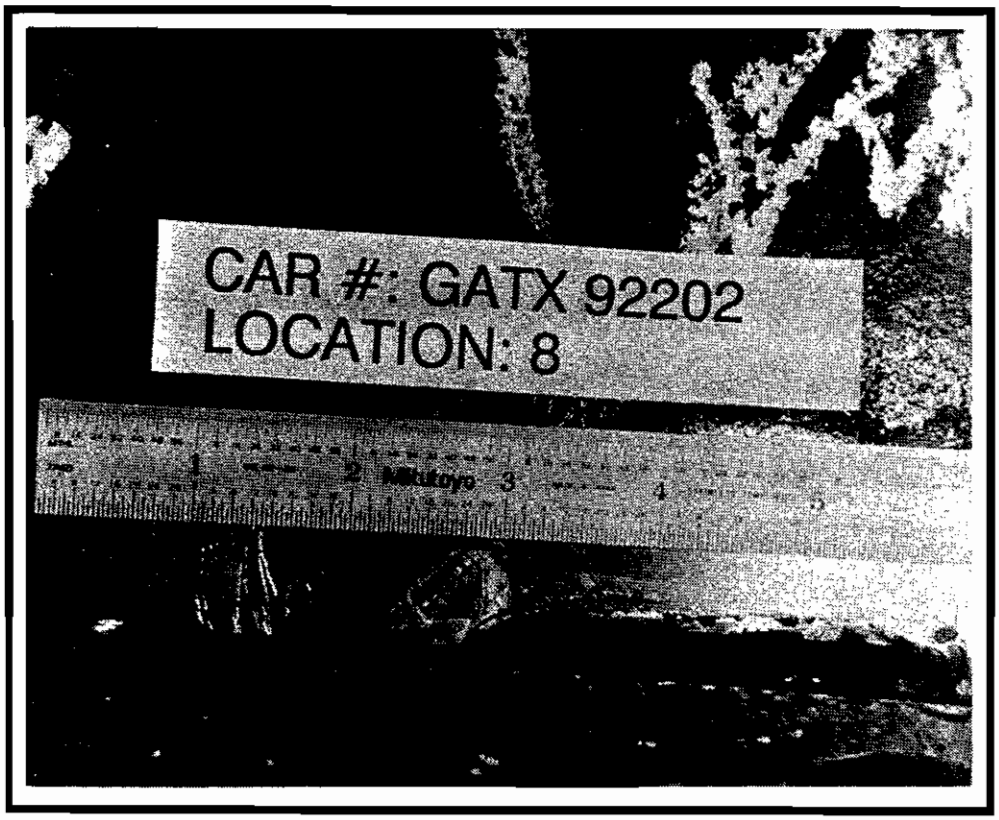


Figure A-16. View of Strain Gage 8 on Tank Car GATX 92202

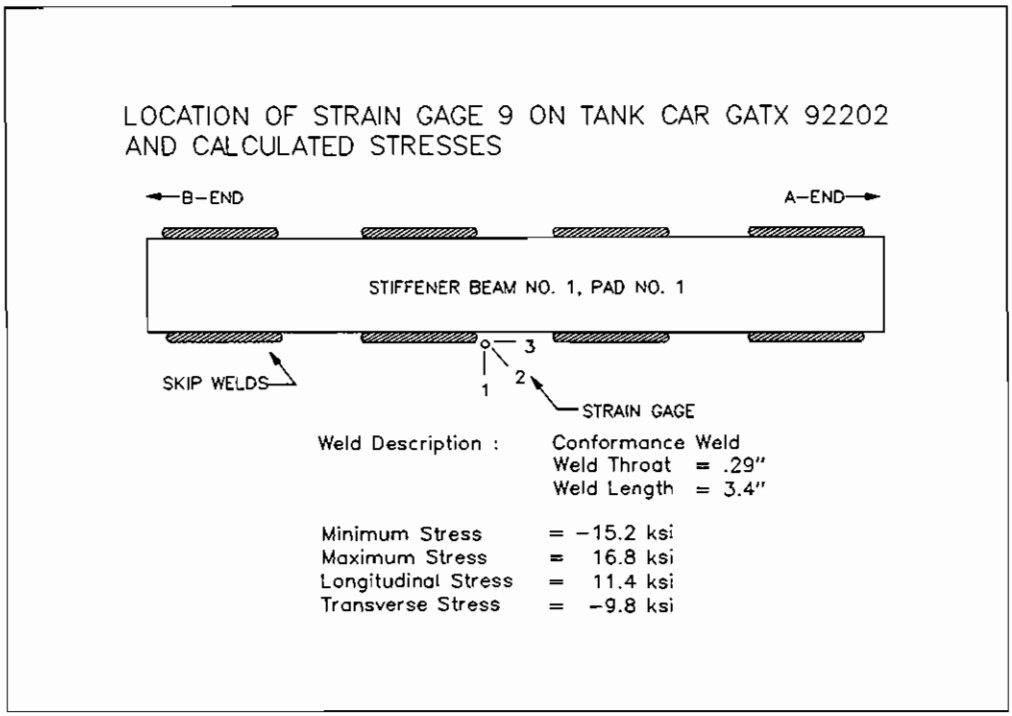


Figure A-17. Location of Strain Gage 9 on Tank Car GATX 92202 and Calculated Stresses

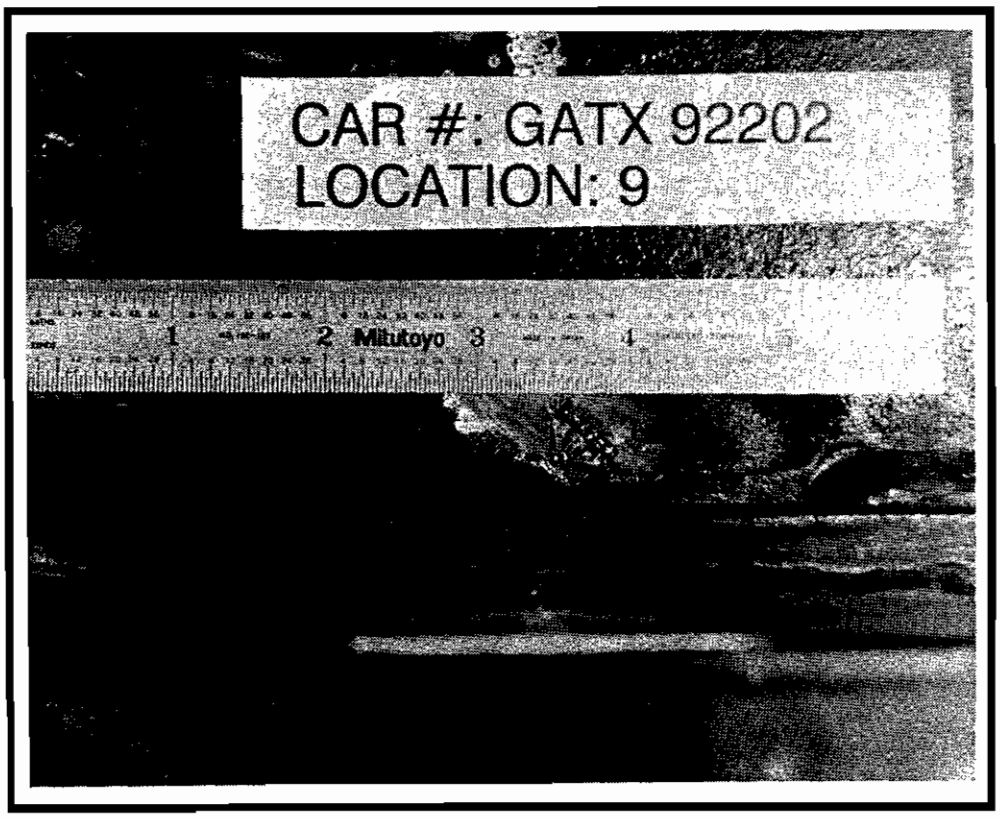


Figure A-18. View of Strain Gage 9 on Tank Car GATX 92202

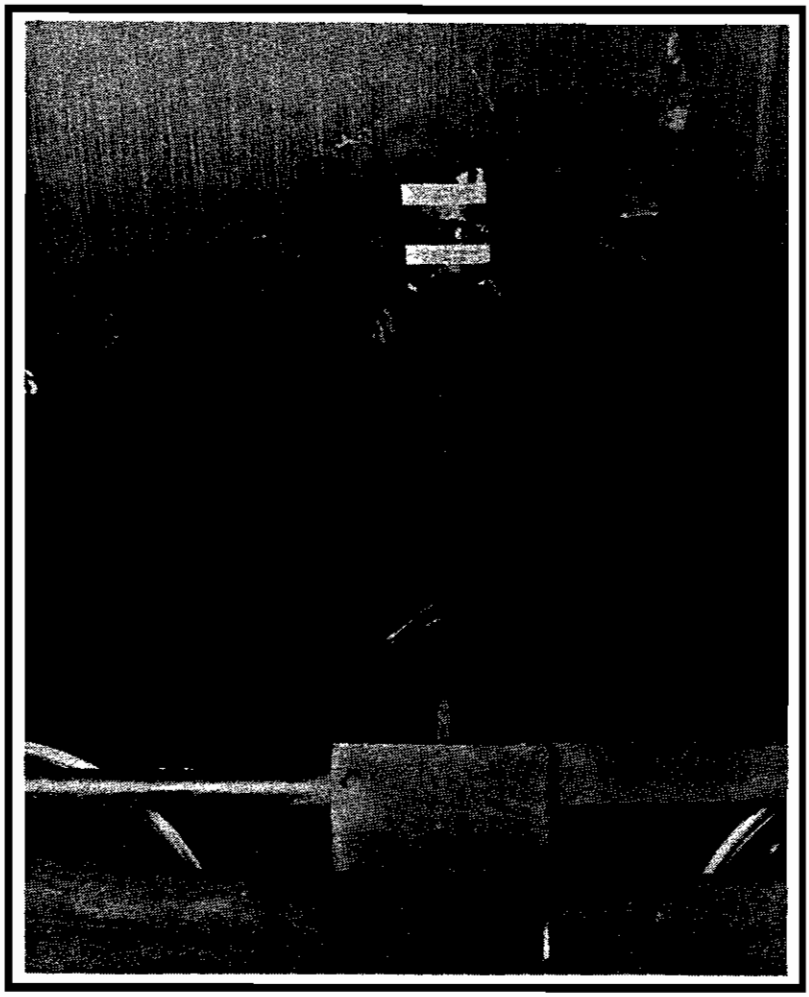


Figure A-19. View of Strain Gage 10A and 10B on Tank Car GATX 92202

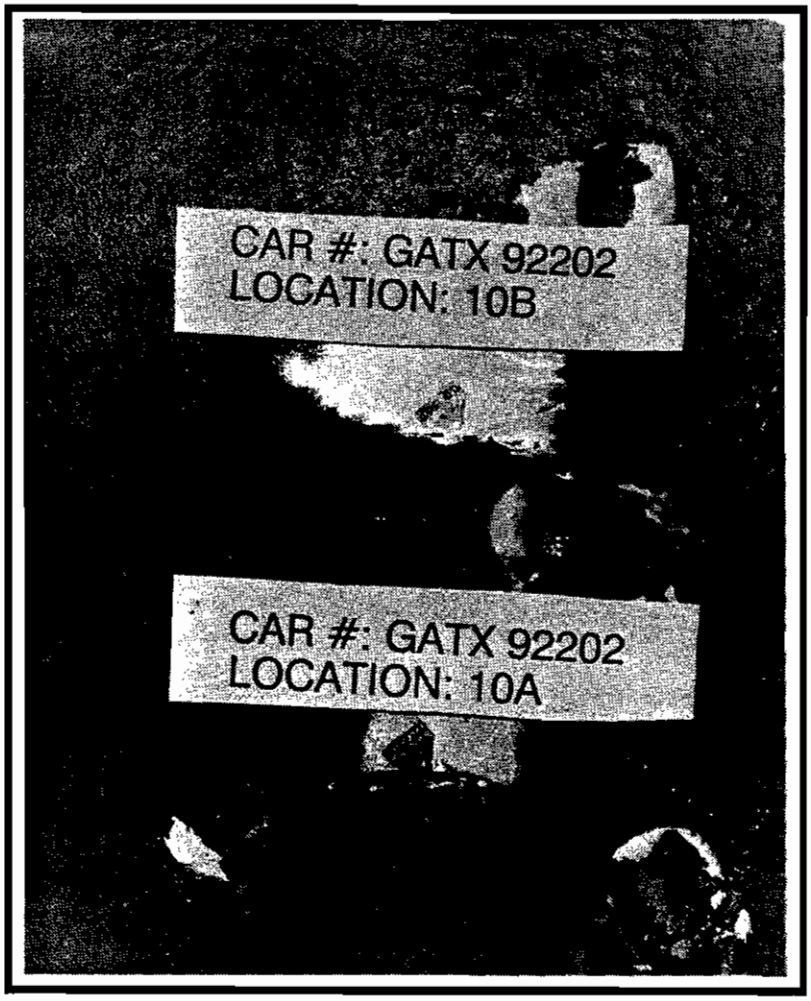


Figure A-20. View of Strain Gage 10A and 10B on Tank Car GATX 92202

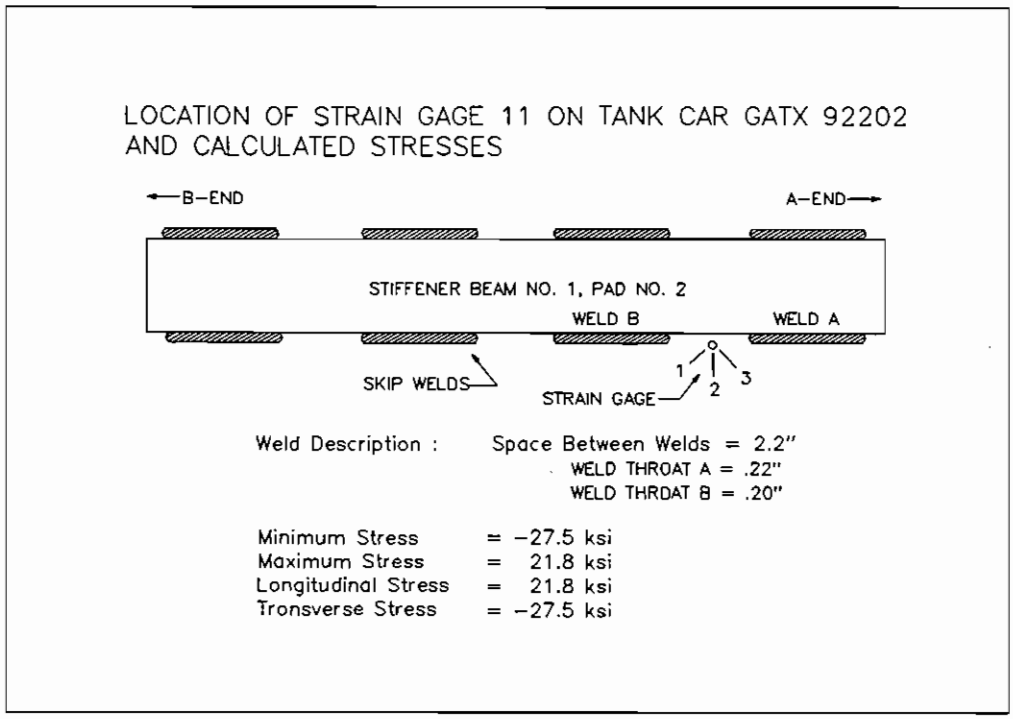


Figure A-21. Location of Strain Gage 11 on Tank Car GATX 92202 and Calculated Stresses

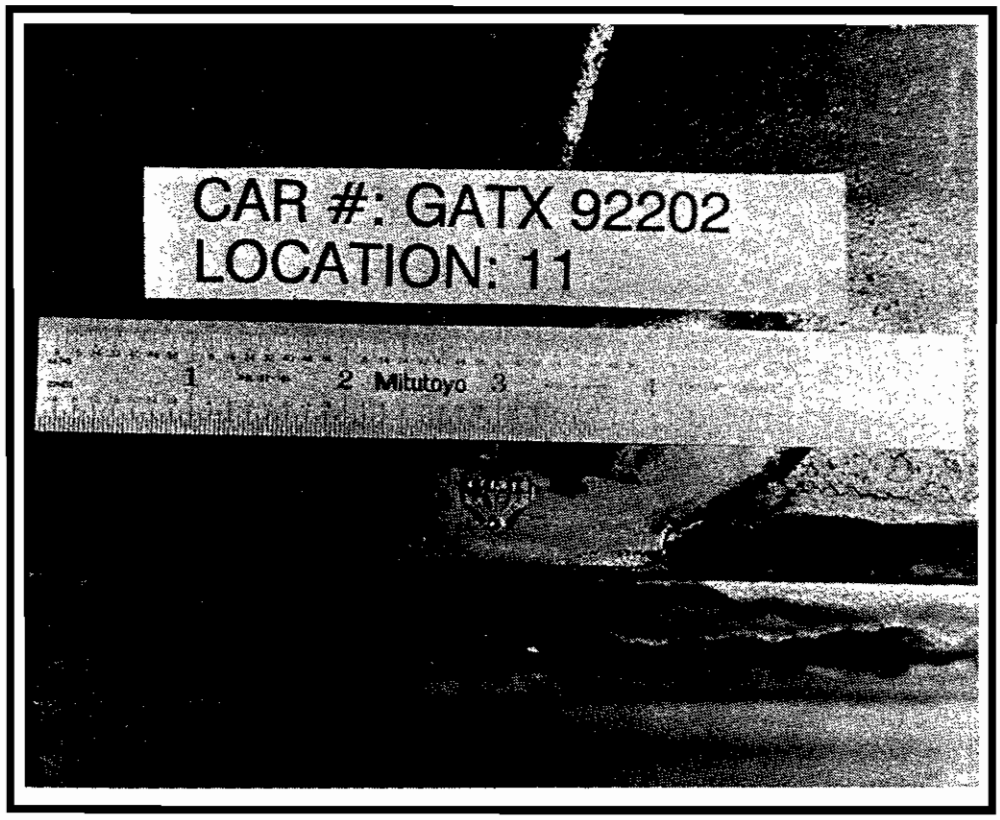


Figure A-22. View of Strain Gage 11 on Tank Car GATX 92202

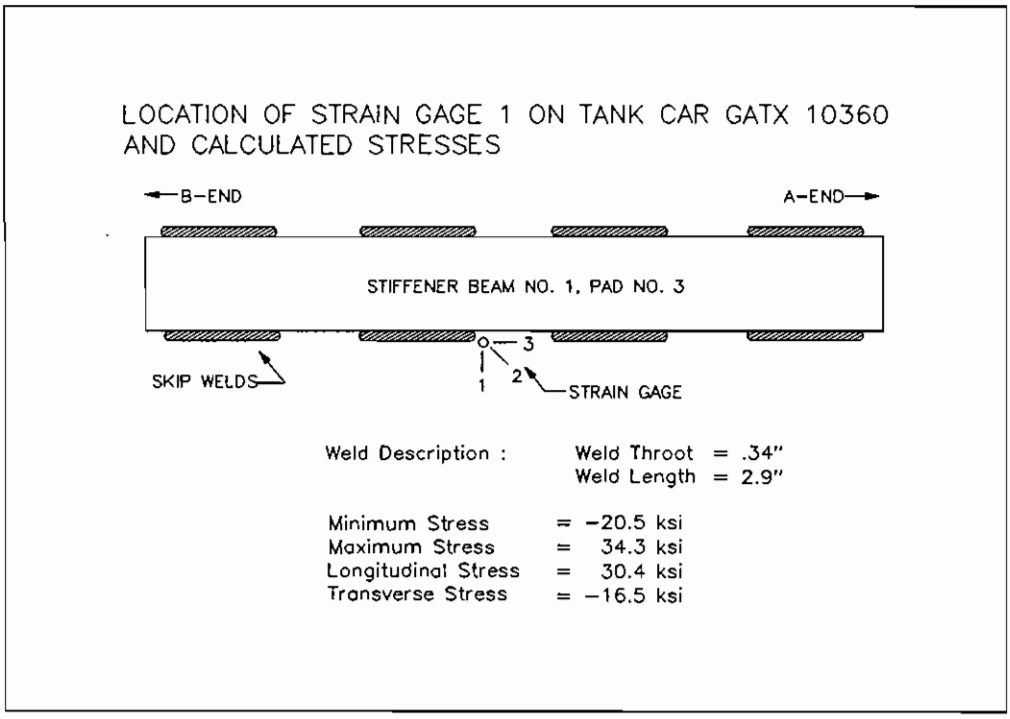


Figure A-23. Location of Strain Gage 1 on Tank Car GATX 10360 and Calculated Stresses

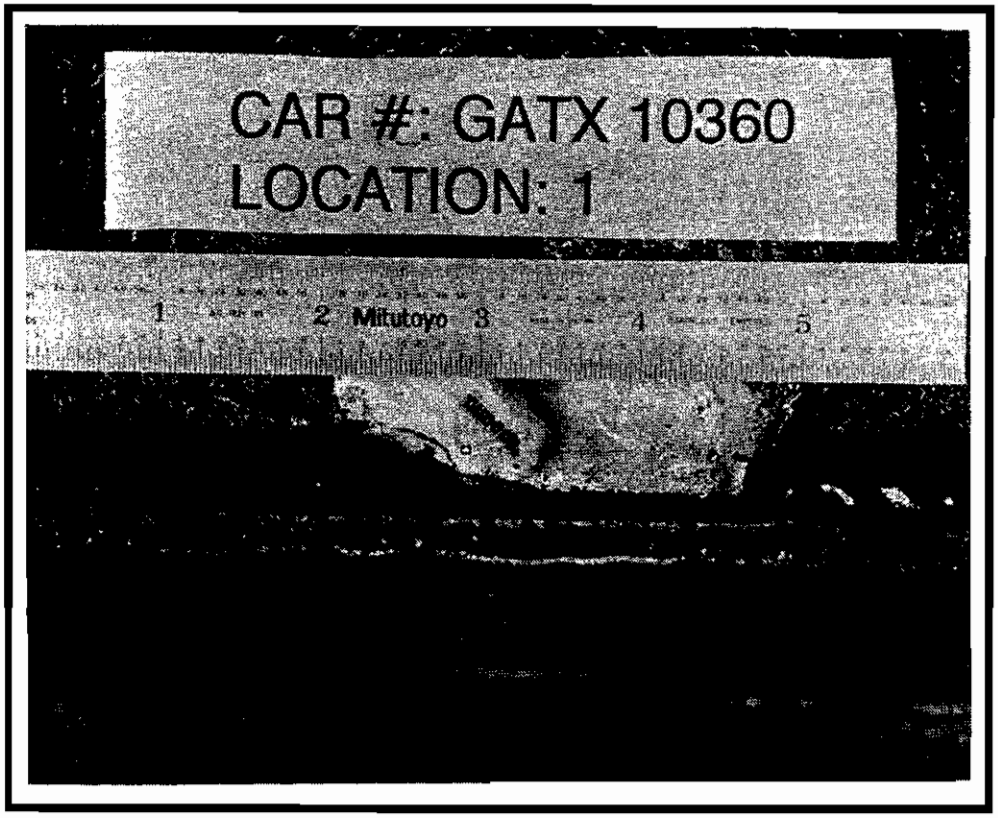


Figure A-24. View of Strain Gage 1 on Tank Car GATX 10360

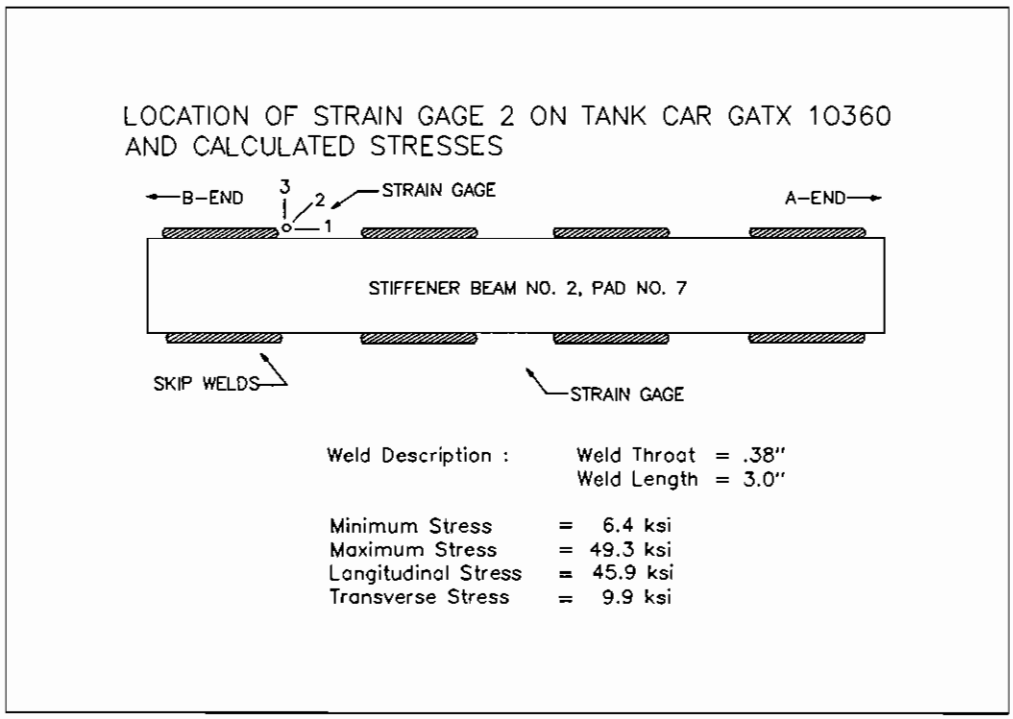


Figure A-25. Location of Strain Gage 2 on Tank Car GATX 10360 and Calculated Stresses

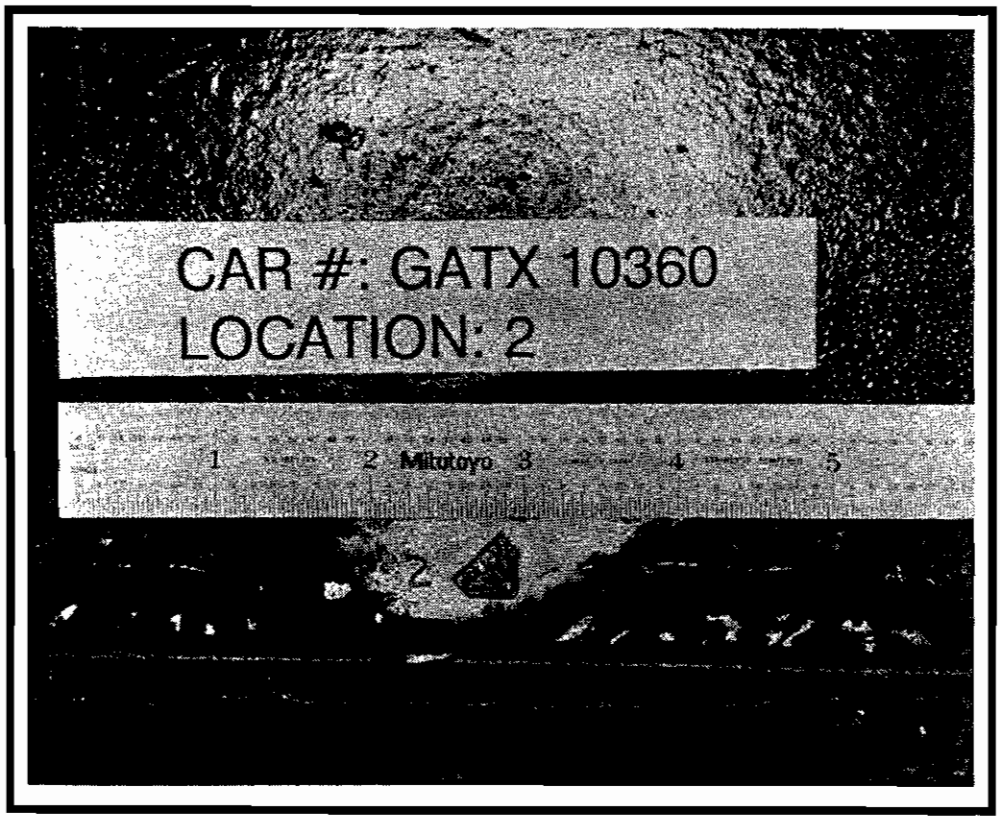


Figure A-26. View of Strain Gage 2 on Tank Car GATX 10360

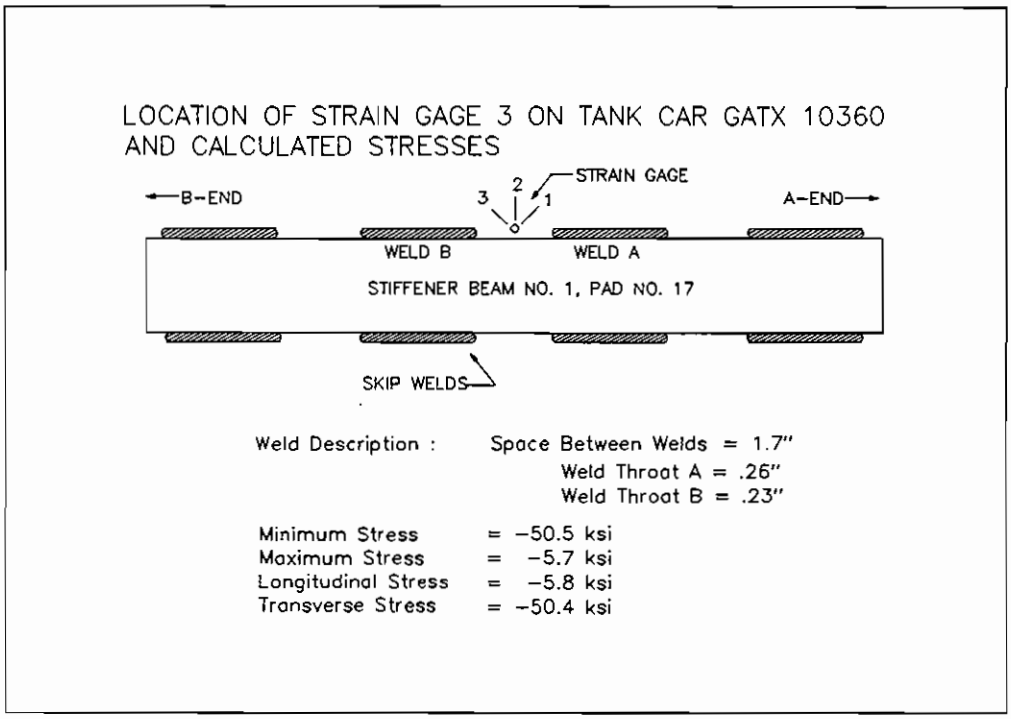


Figure A-27. Location of Strain Gage 3 on Tank Car GATX 10360 and Calculated Stresses

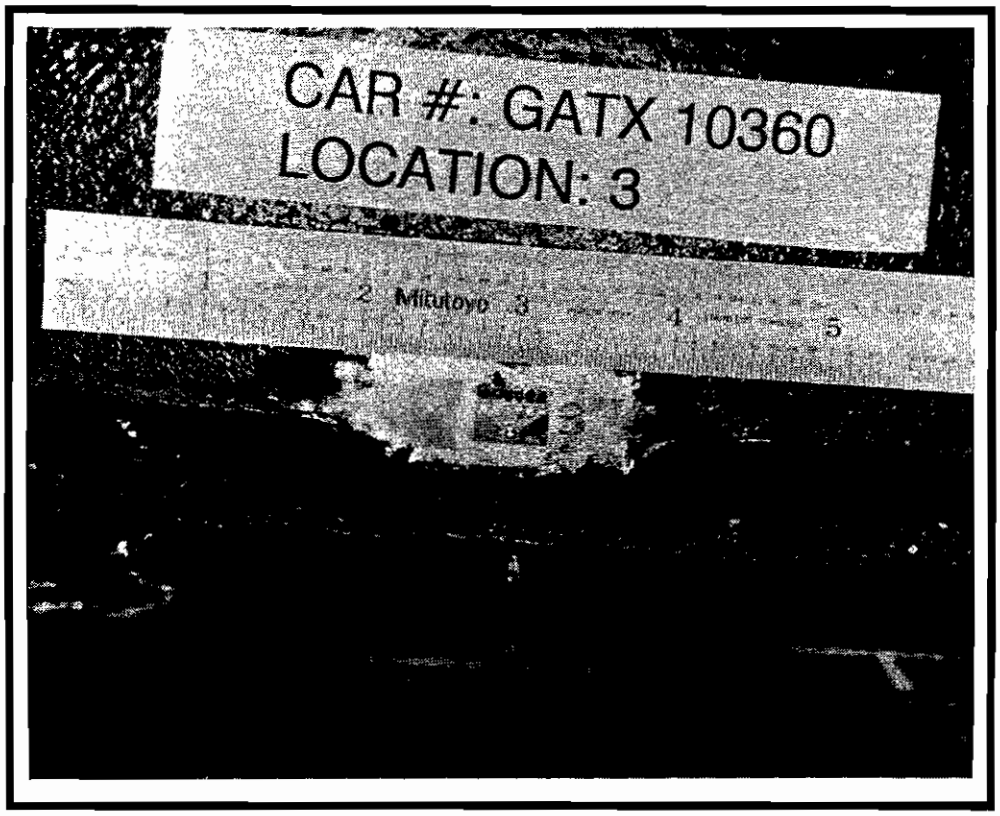


Figure A-28. View of Strain Gage 3 on Tank Car GATX 10360

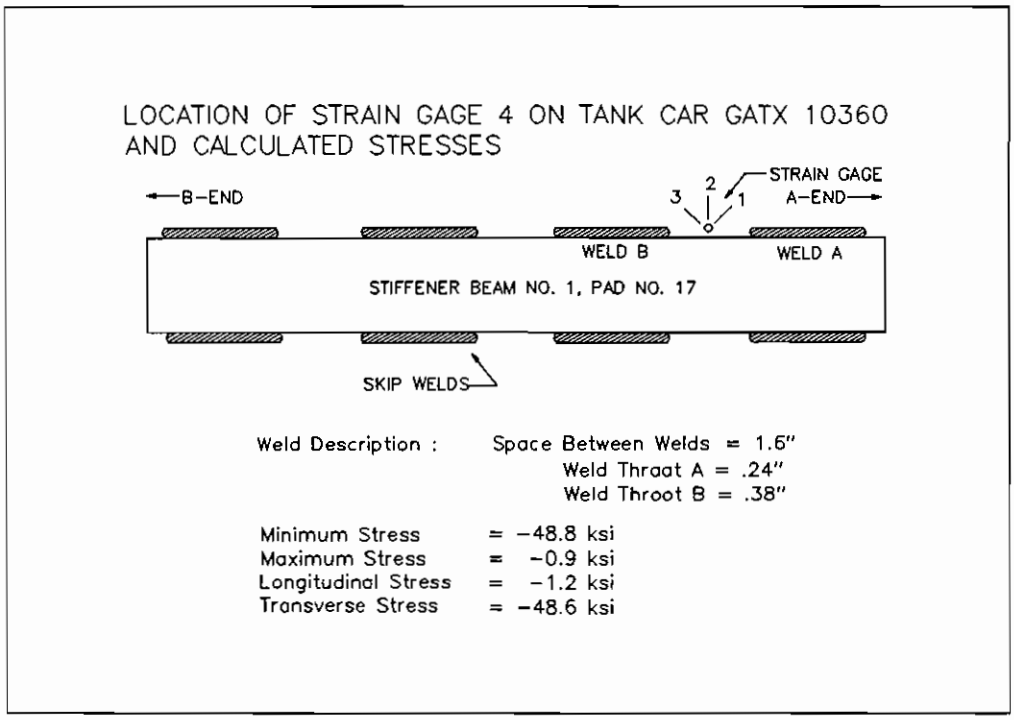


Figure A-29. Location of Strain Gage 4 on Tank Car GATX 10360 and Calculated Stresses

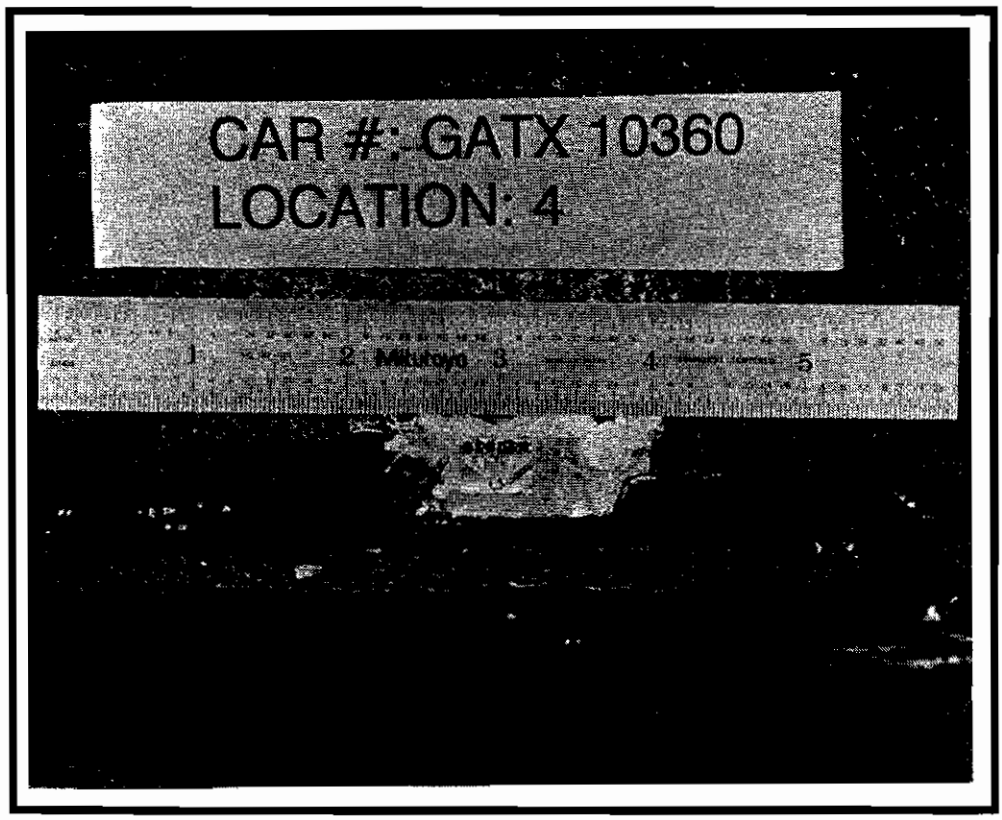


Figure A-30. View of Strain Gage 4 on Tank Car GATX 10360

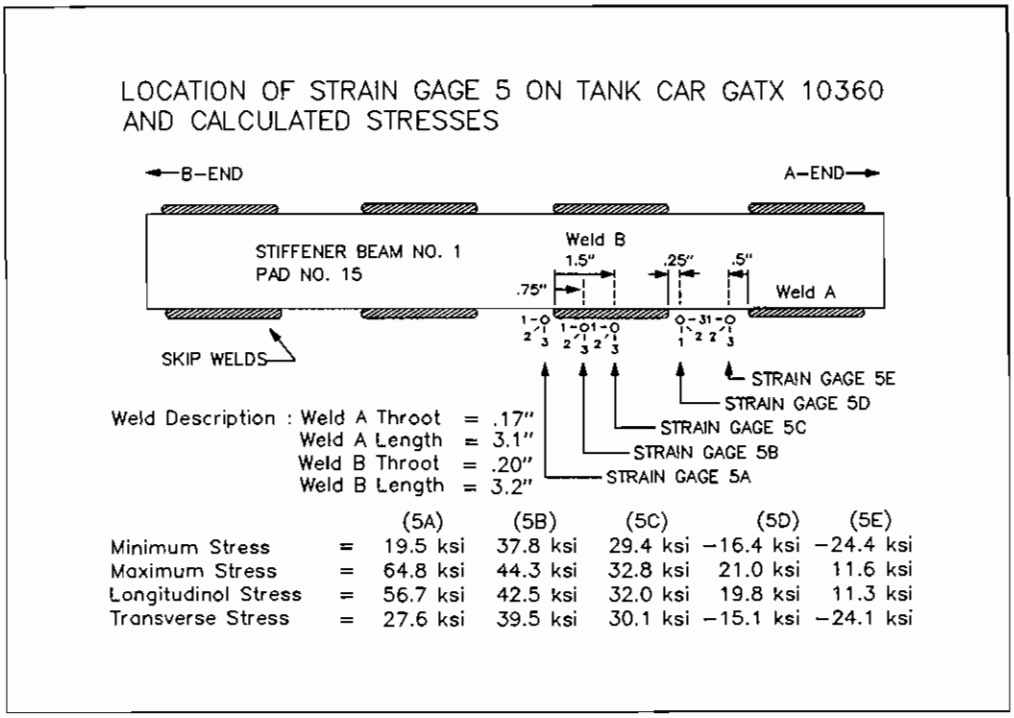


Figure A-31. Location of Strain Gages 5A - 5E on Tank Car GATX 10360 and Calculated Stresses

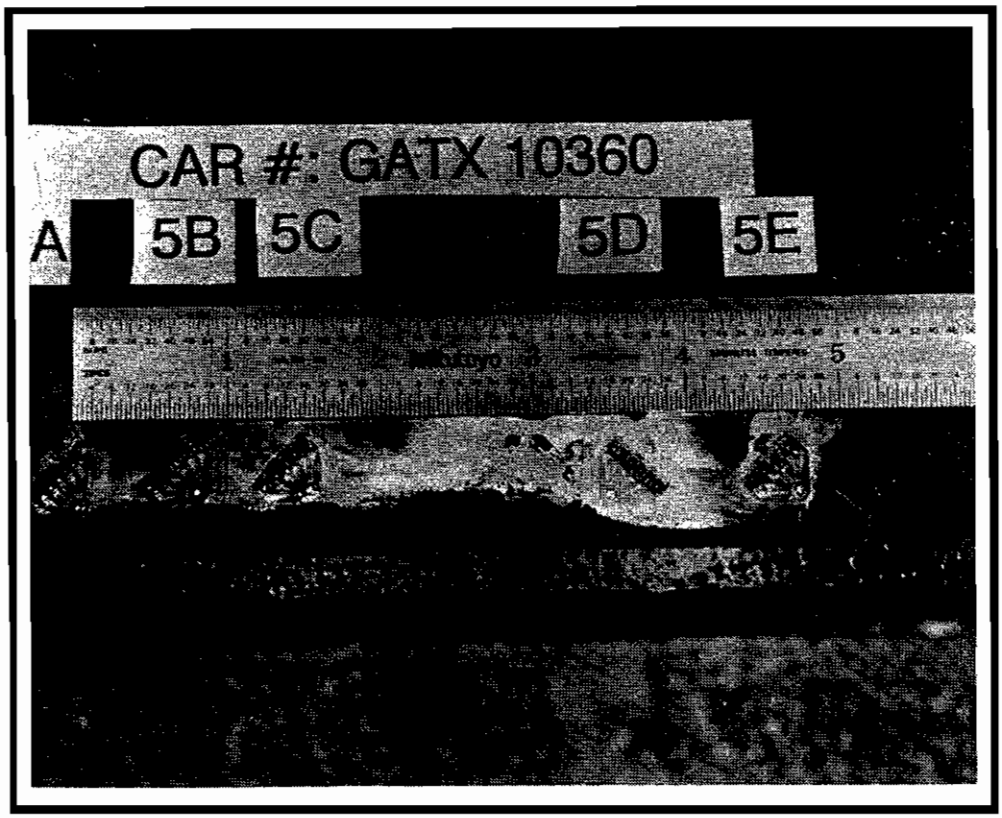


Figure A-32. View of Strain Gages 5A - 5E on Tank Car GATX 10360

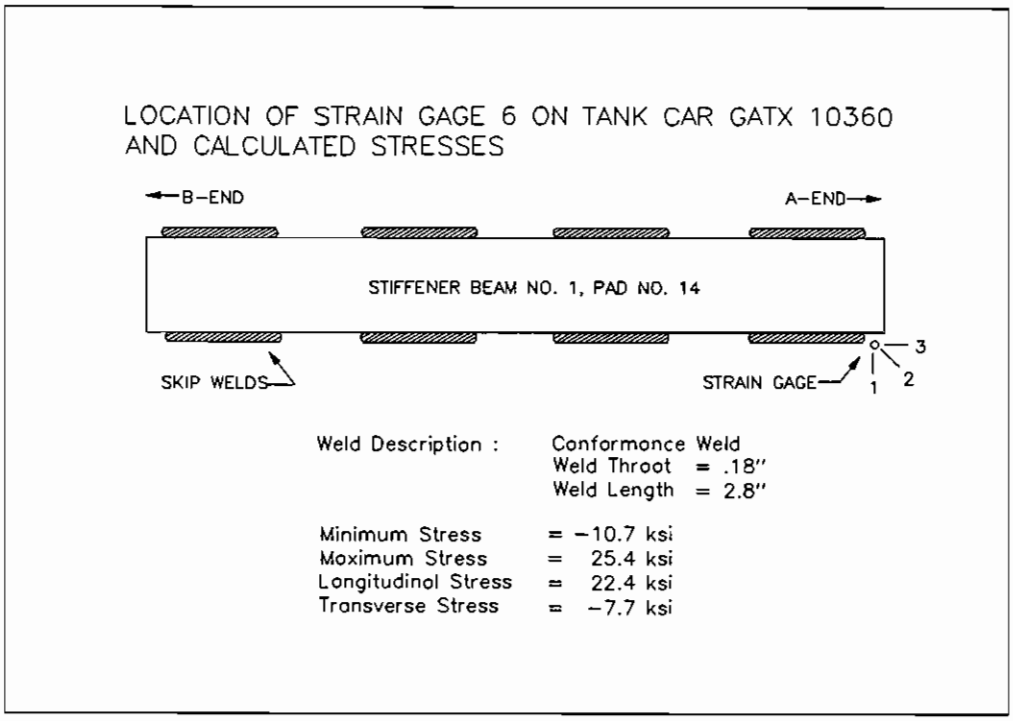


Figure A-33. Location of Strain Gage 6 on Tank Car GATX 10360 and Calculated Stresses

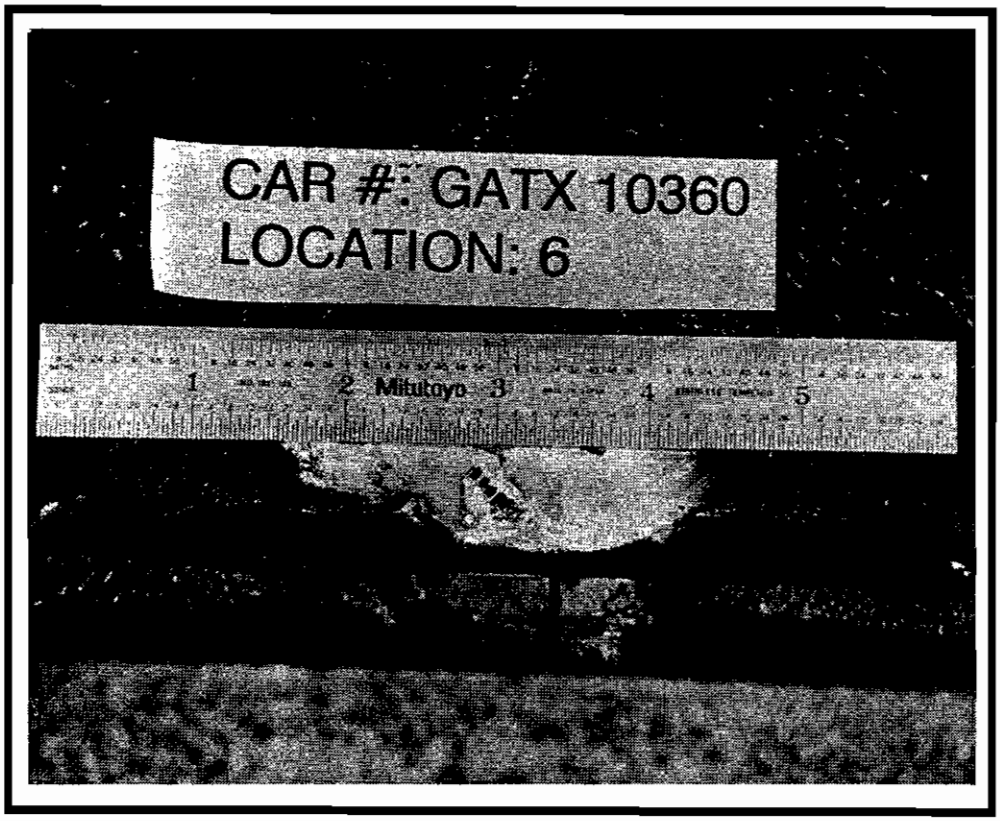


Figure A-34. View of Strain Gage 6 on Tank Car GATX 10360

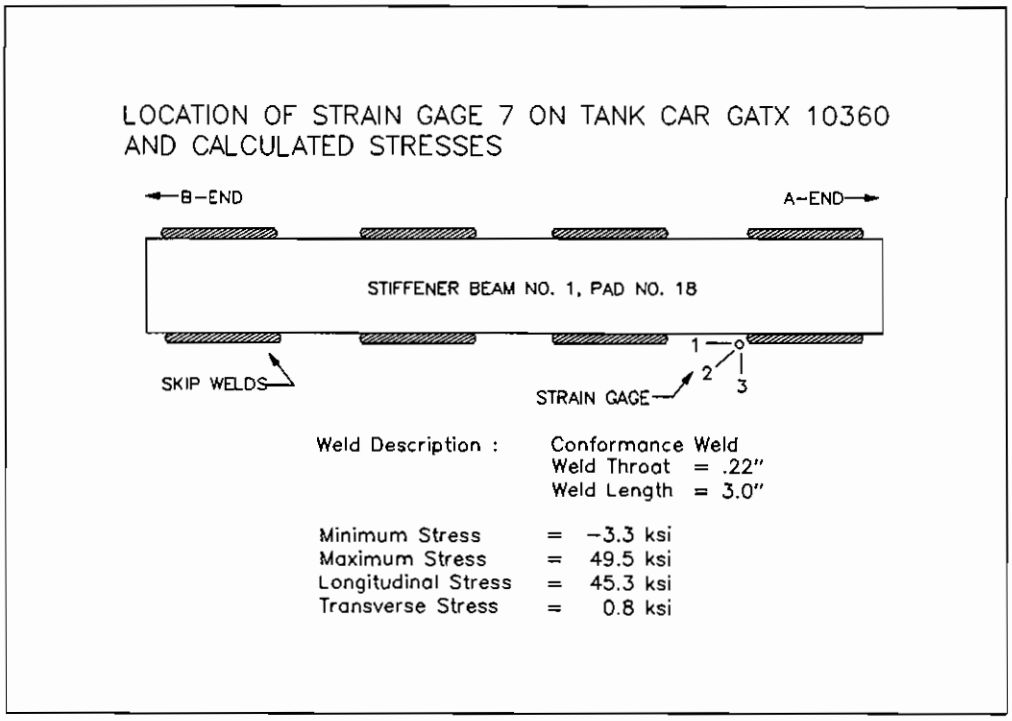


Figure A-35. Location of Strain Gage 7 on Tank Car GATX 10360 and Calculated Stresses

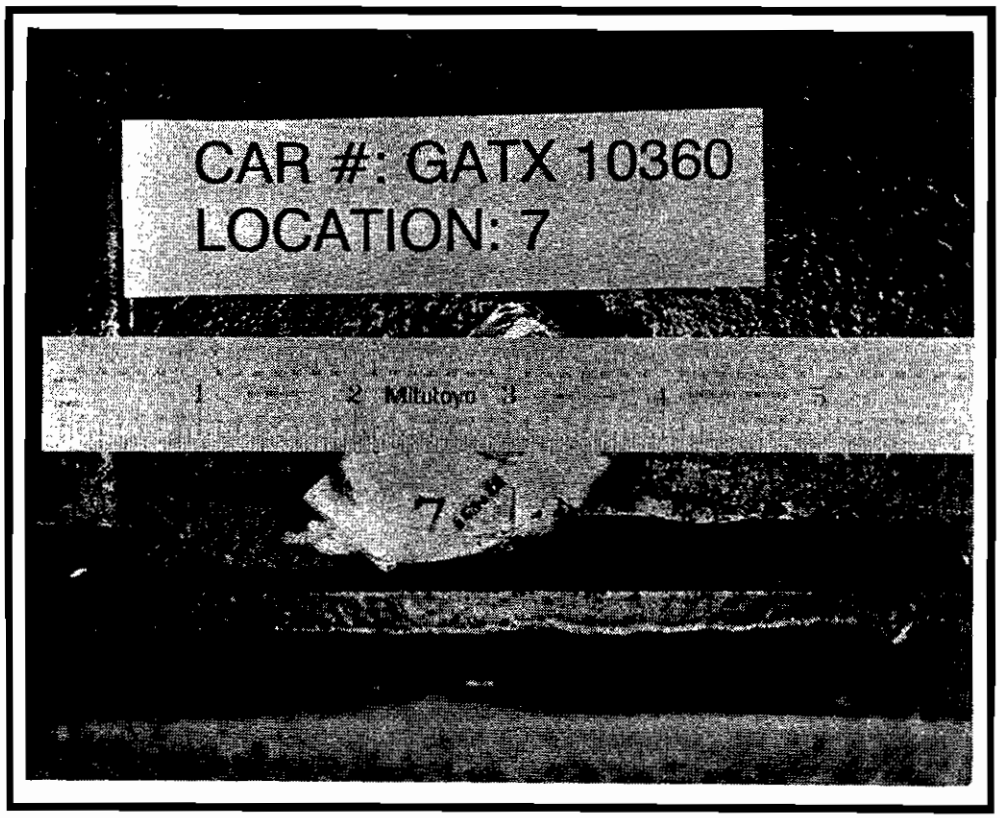


Figure A-36. View of Strain Gage 7 on Tank Car GATX 10360

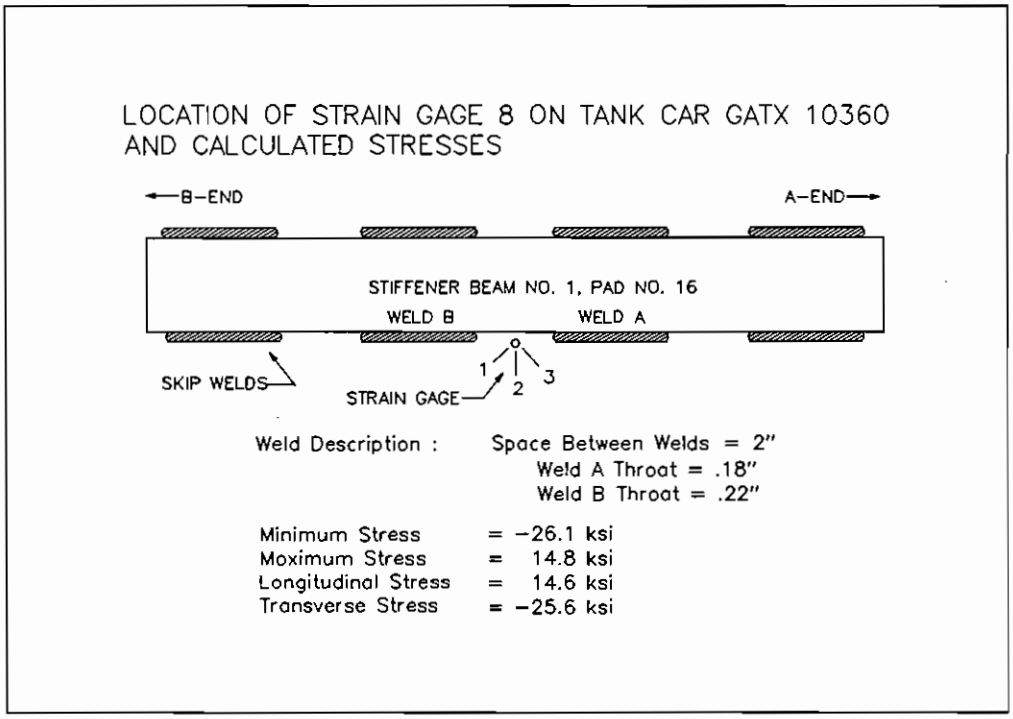


Figure A-37. Location of Strain Gage 8 on Tank Car GATX 10360 and Calculated Stresses

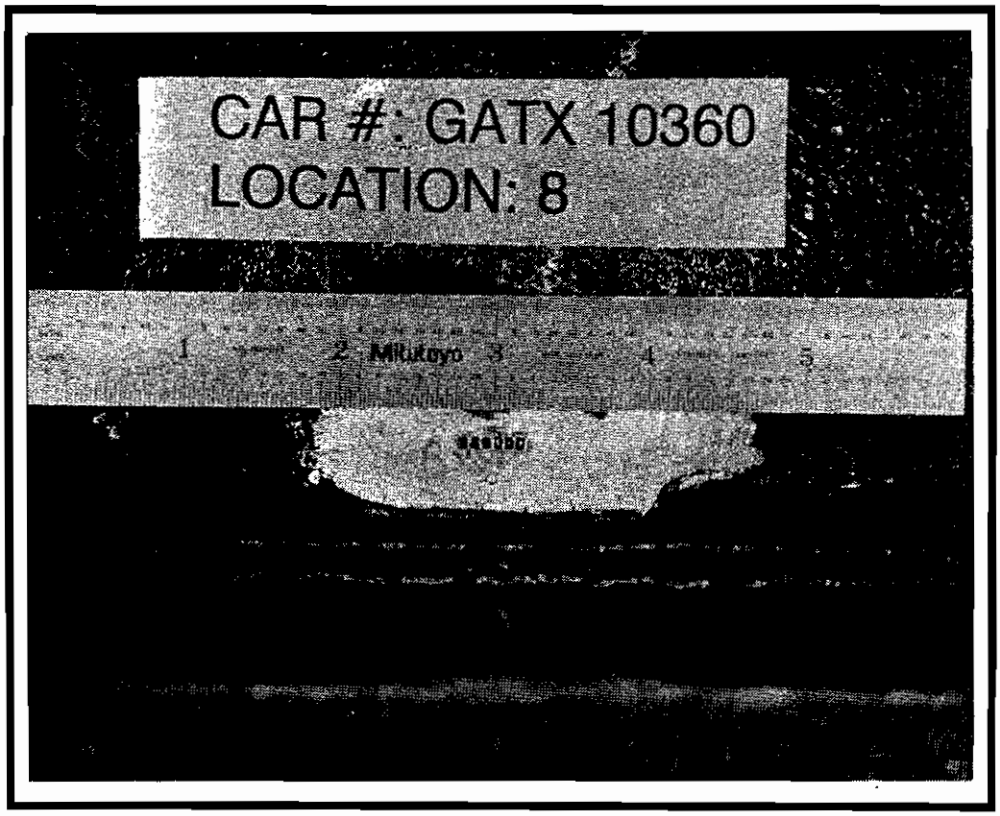


Figure A-38. View of Strain Gage 8 on Tank Car GATX 10360

APPENDIX B

CALCULATED STRESSES FOR EACH .01 INCH DEPTH INCREMENT

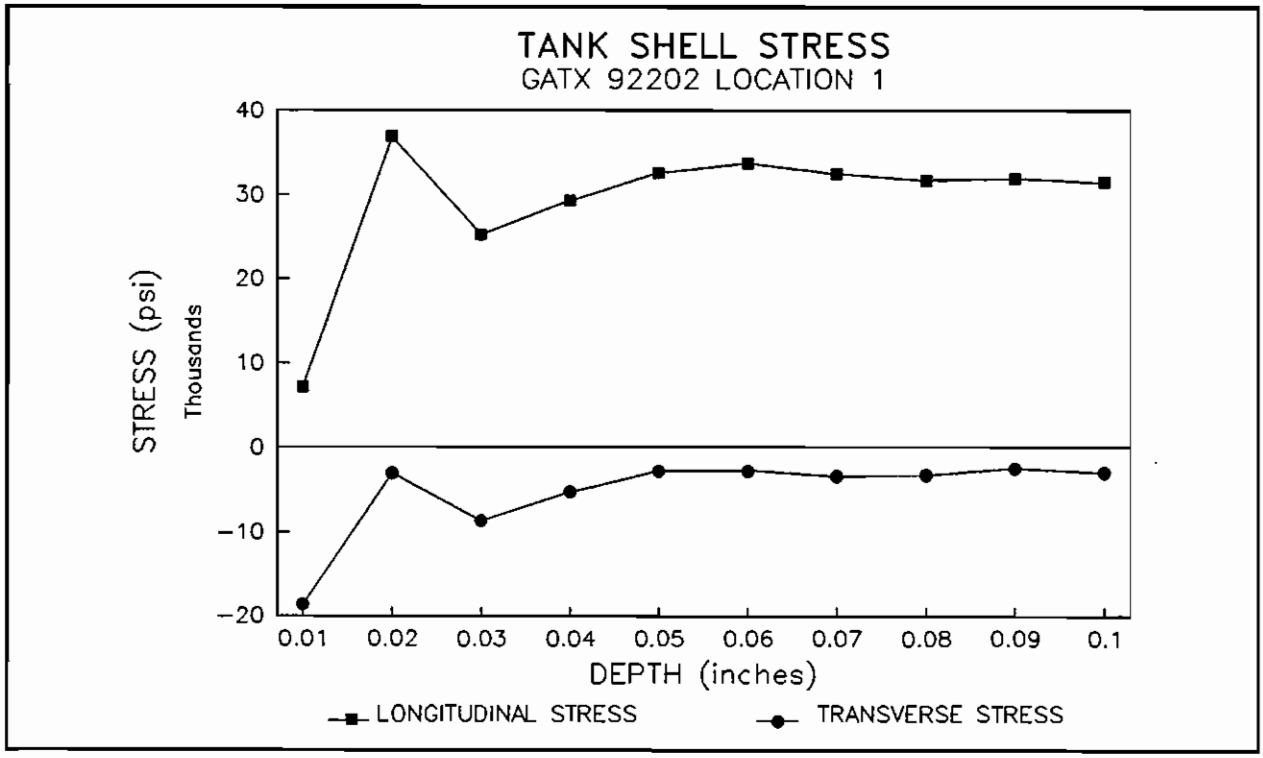


Figure B-1. Longitudinal and Transverse Stresses Measured at Location 1 on GATX 92202

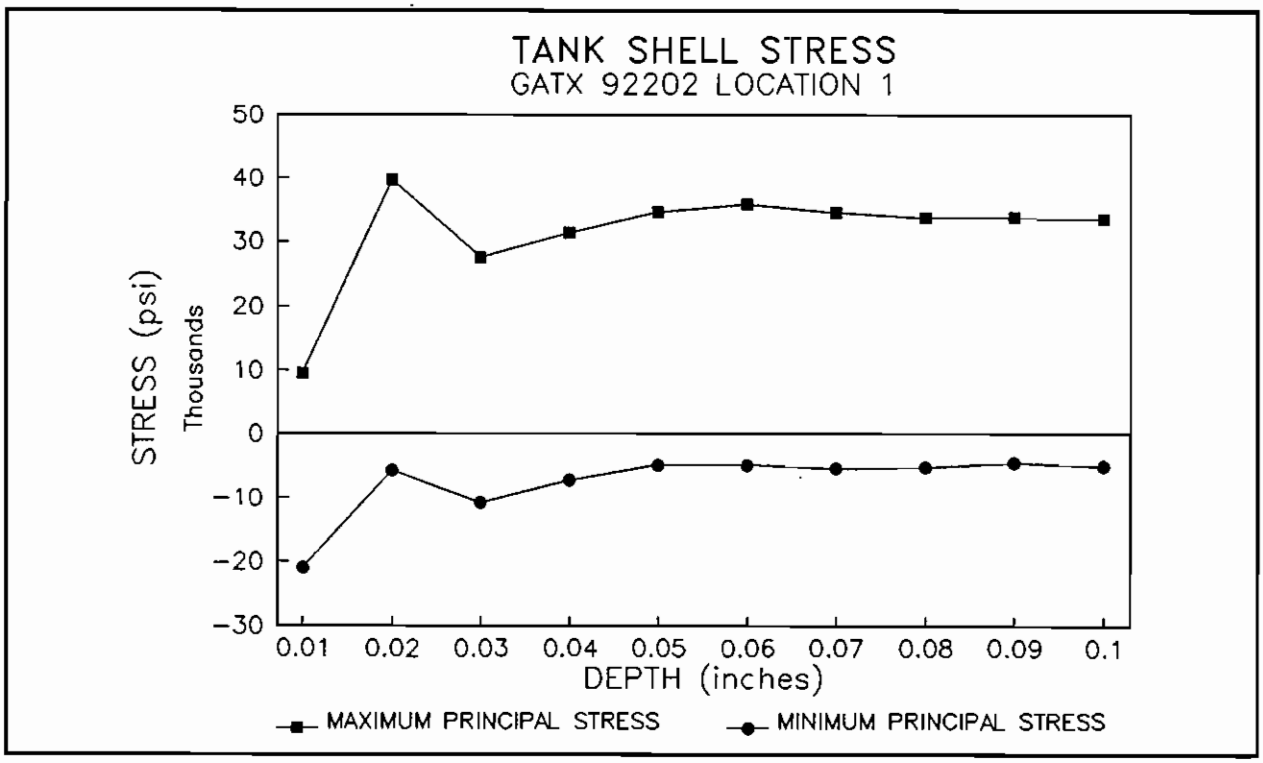


Figure B-2. Principal Stresses Measured at Location 1 on GATX 92202

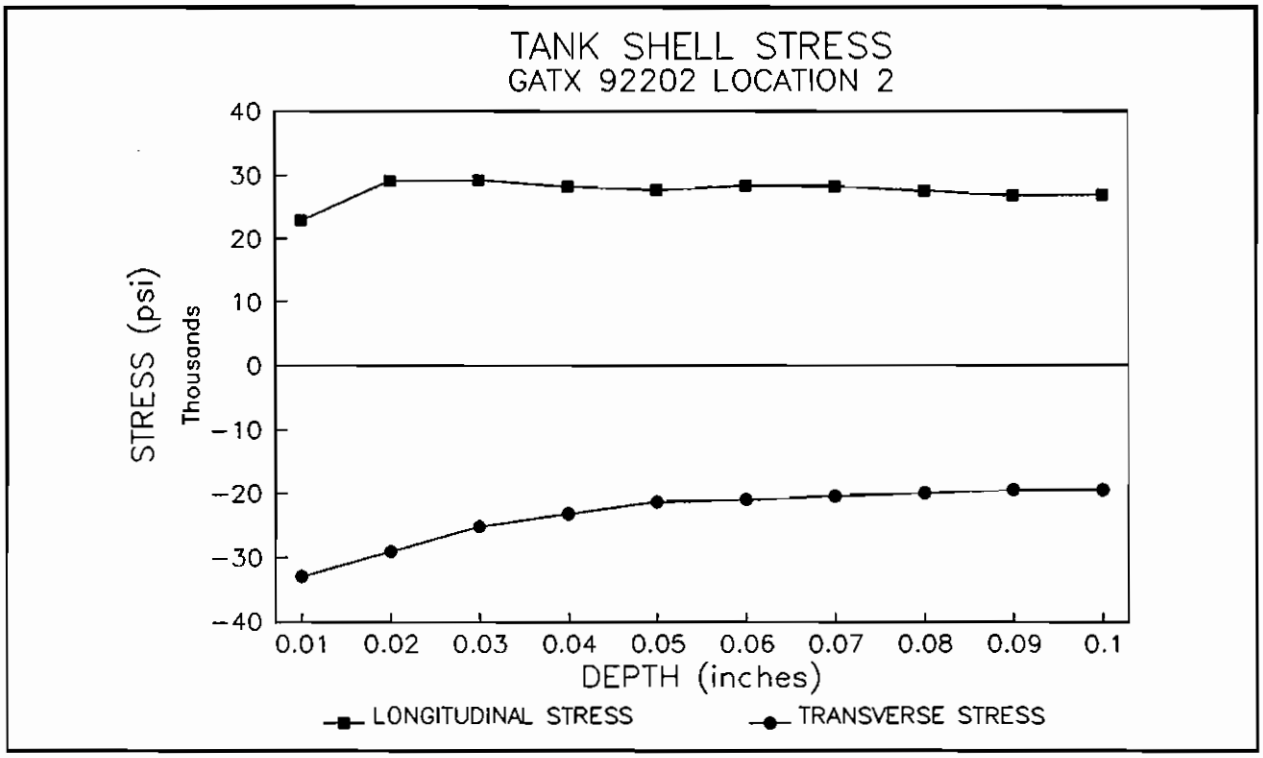


Figure B-3. Longitudinal and Transverse Stresses Measured at Location 2 on GATX 92202

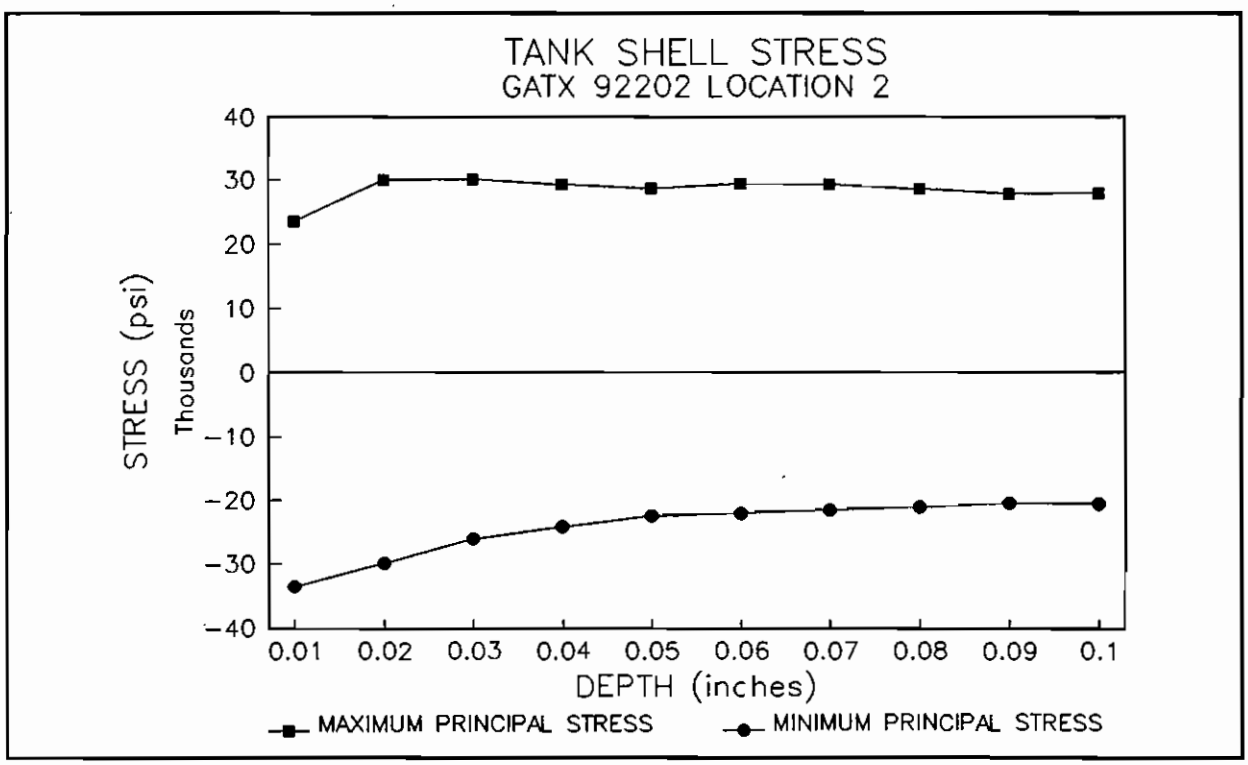


Figure B-4. Principal Stresses Measured at Location 2 on GATX 92202

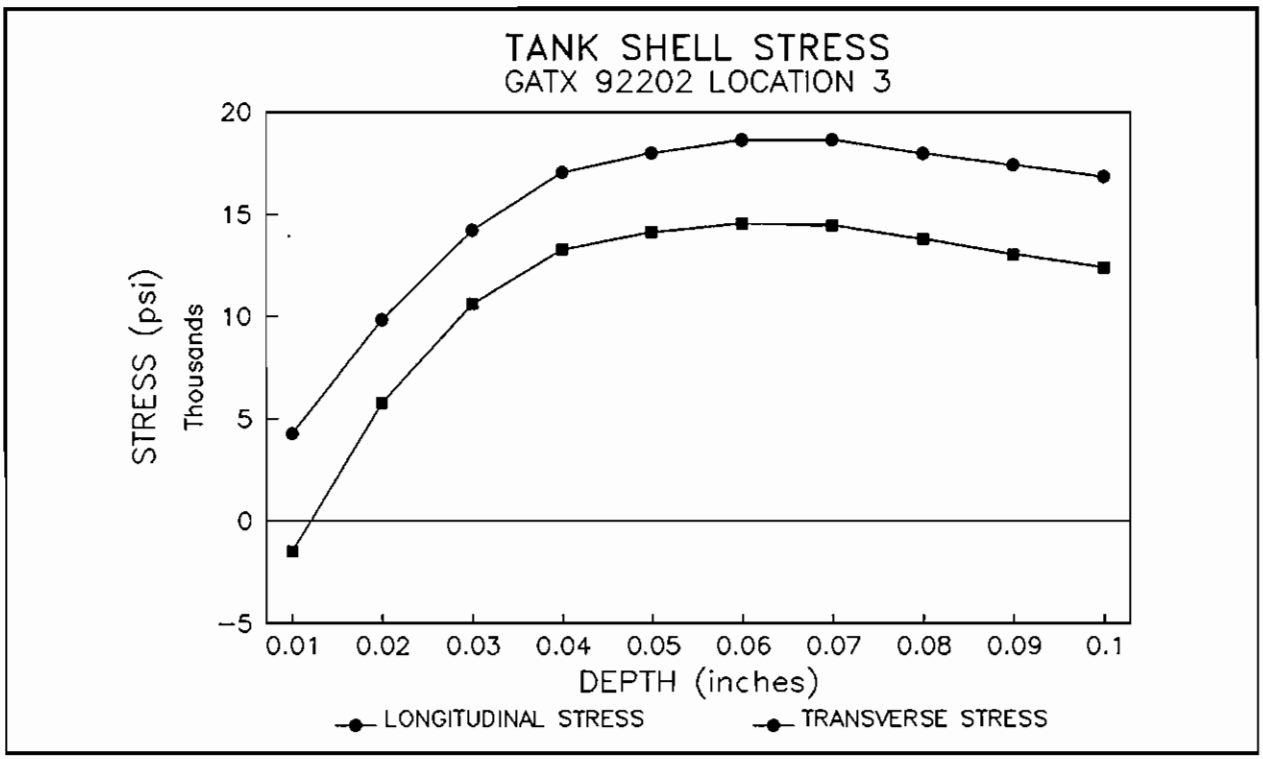


Figure B-5. Longitudinal and Transverse Stresses Measured at Location 3 on GATX 92202

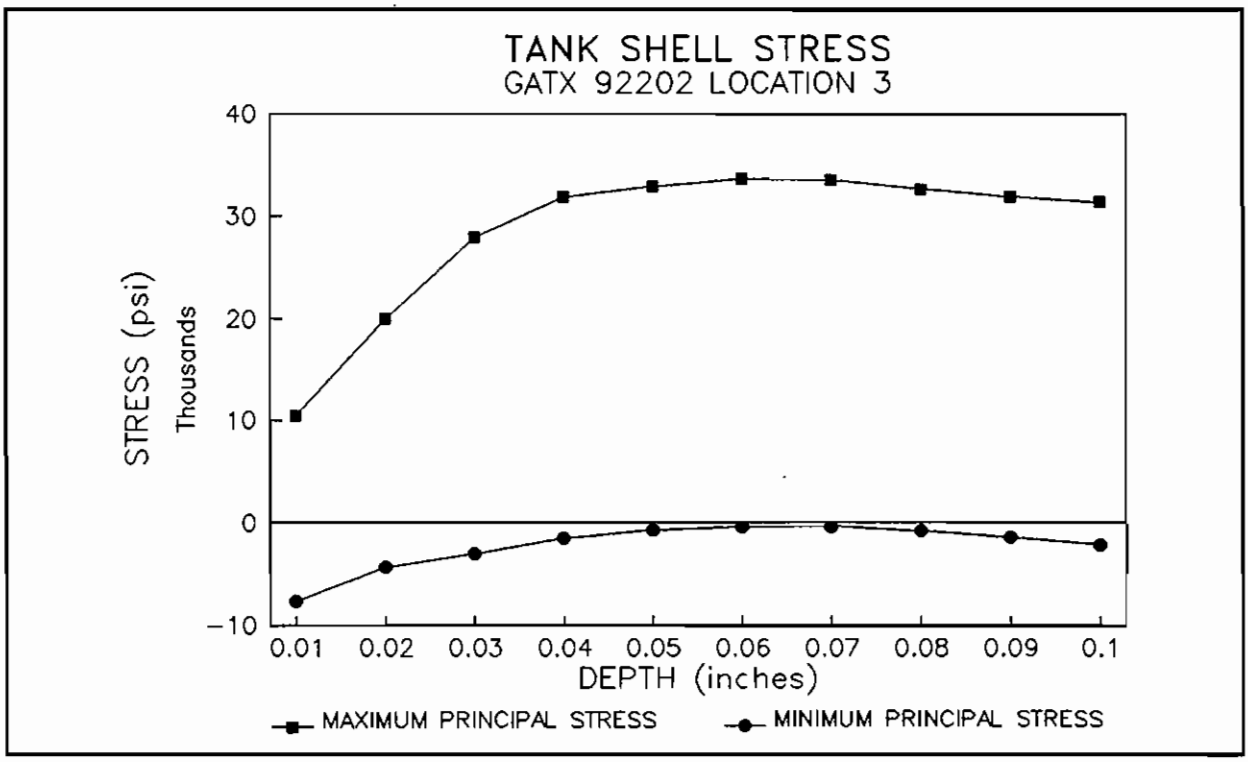


Figure B-6. Principal Stresses Measured at Location 3 on GATX 92202

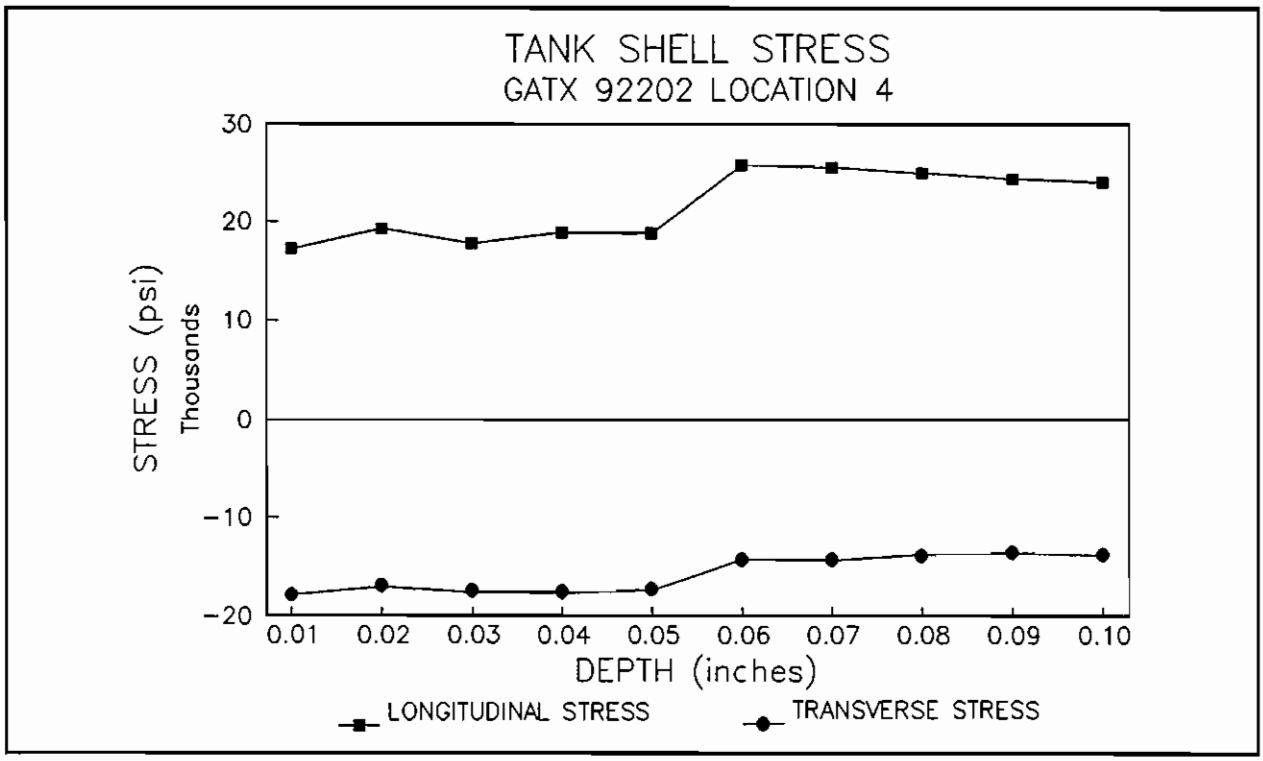


Figure B-7. Longitudinal and Transverse Stresses Measured at Location 4 on GATX 92202

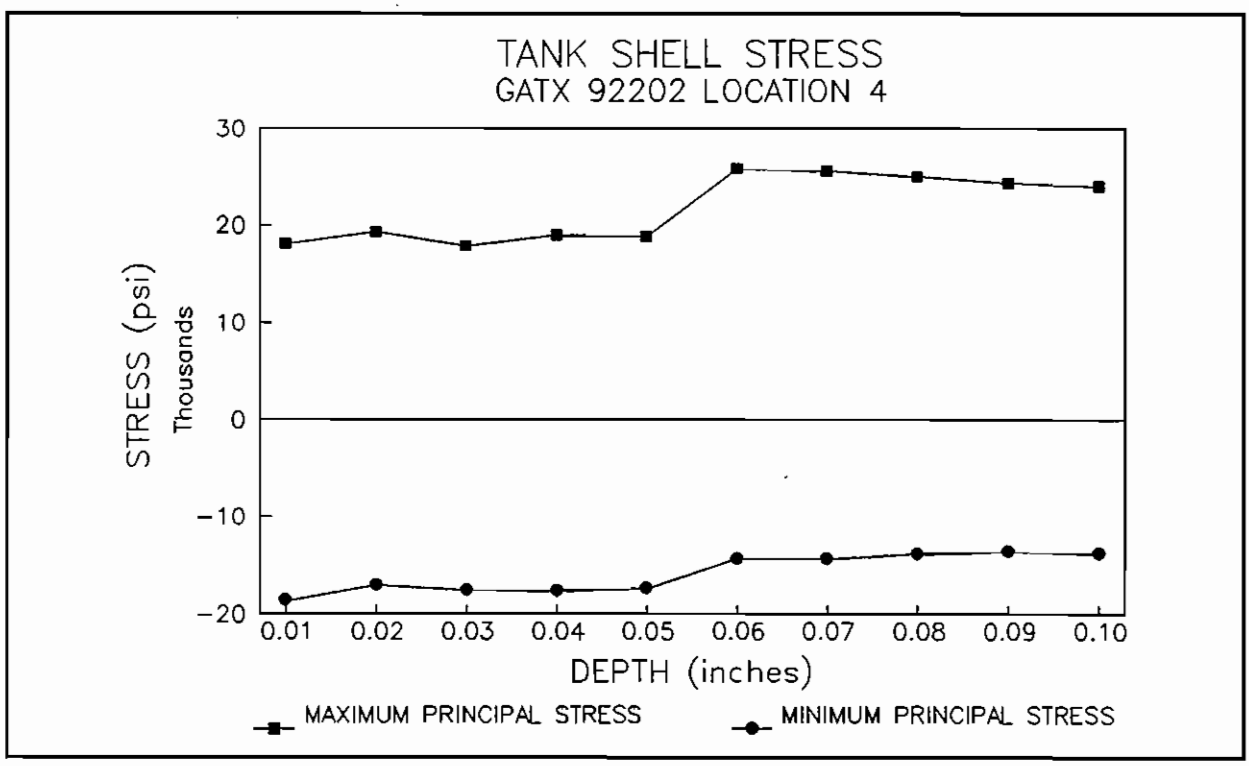


Figure B-8. Principal Stresses Measured at Location 4 on GATX 92202

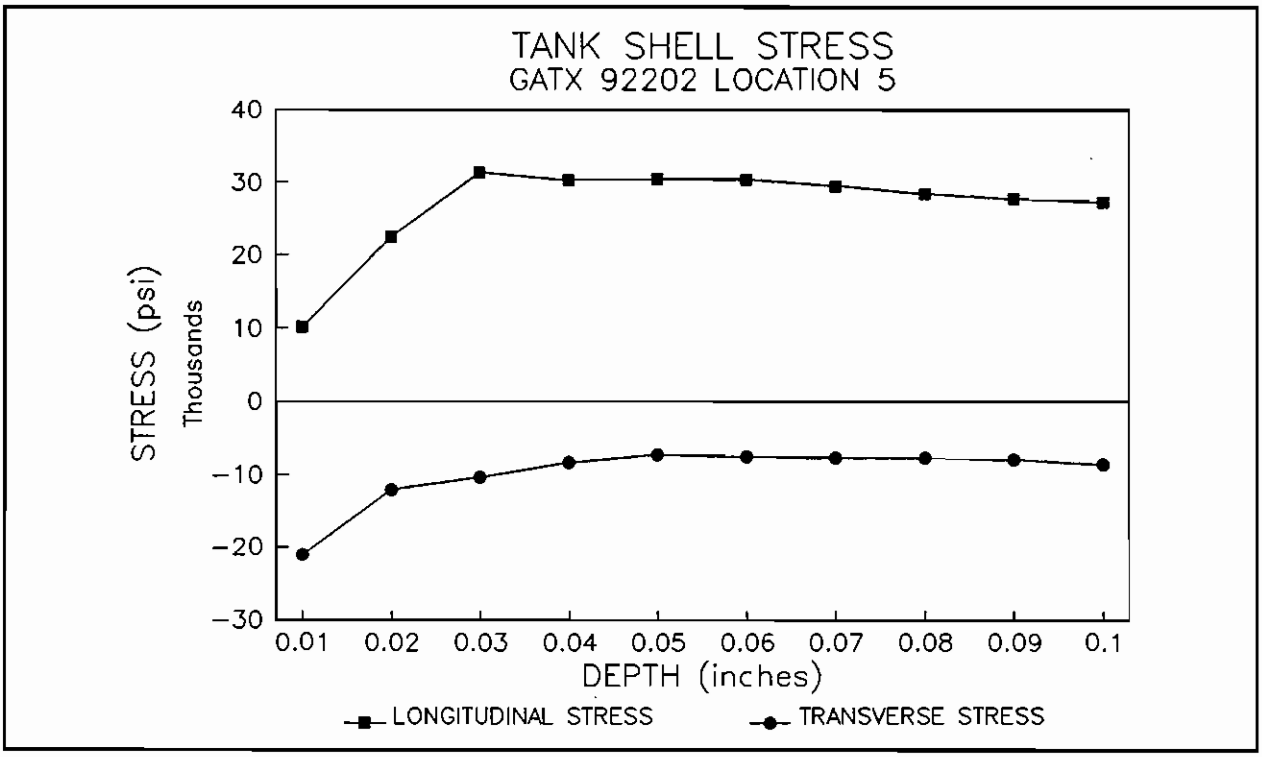


Figure B-9. Longitudinal and Transverse Stresses Measured at Location 5 on GATX 92202

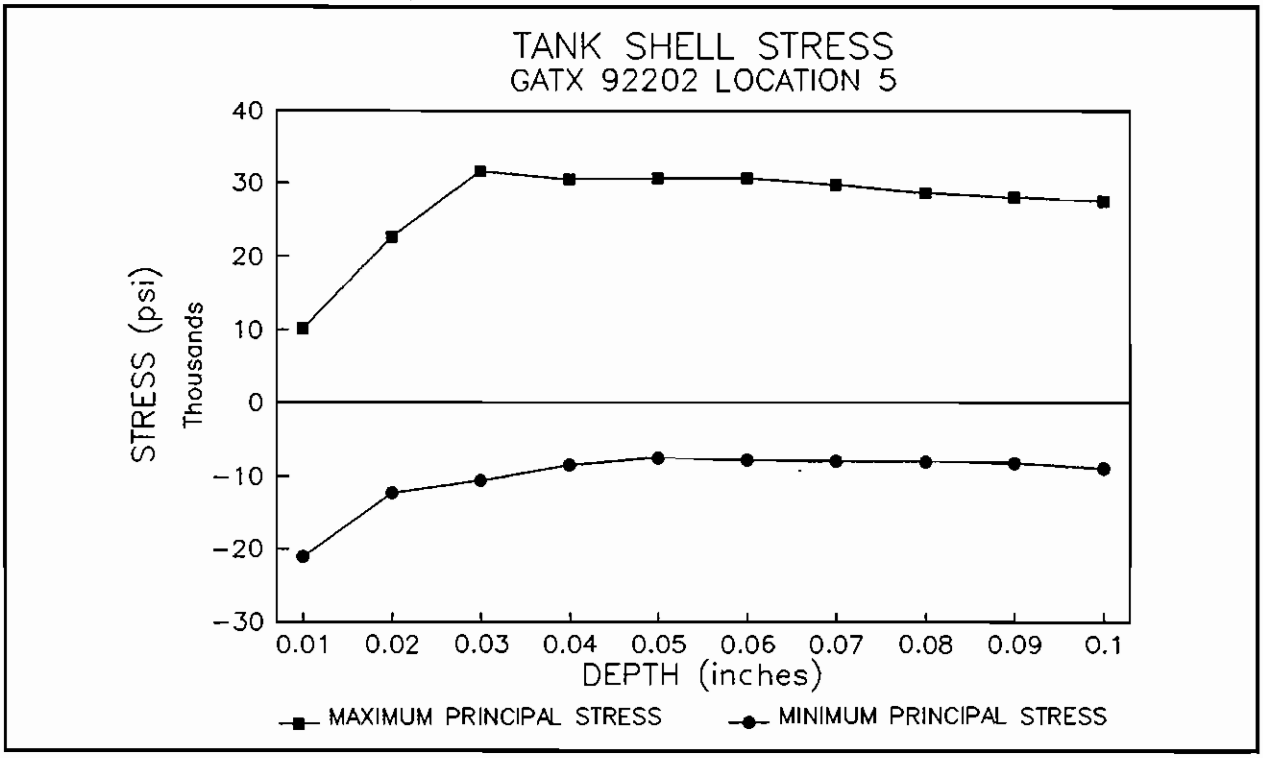


Figure B-10. Principal Stresses Measured at Location 5 on GATX 92202

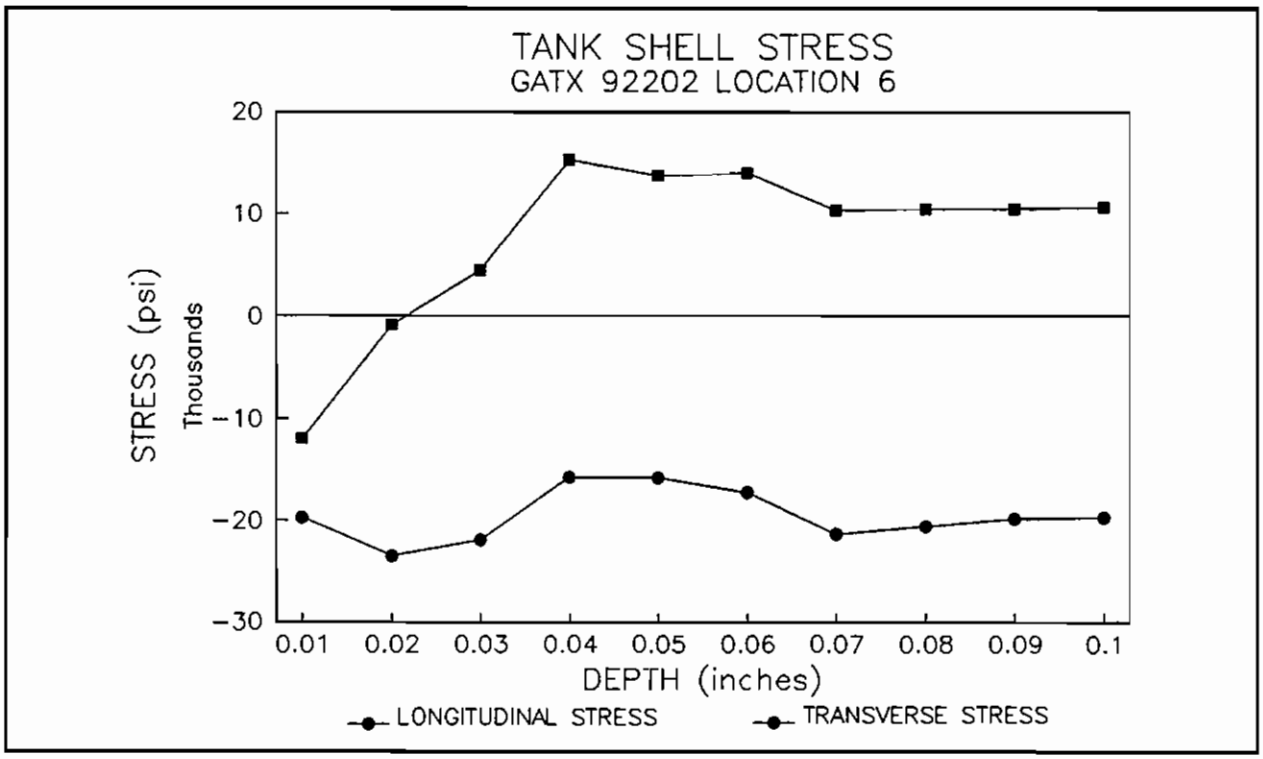


Figure B-11. Longitudinal and Transverse Stresses Measured at Location 6 on GATX 92202

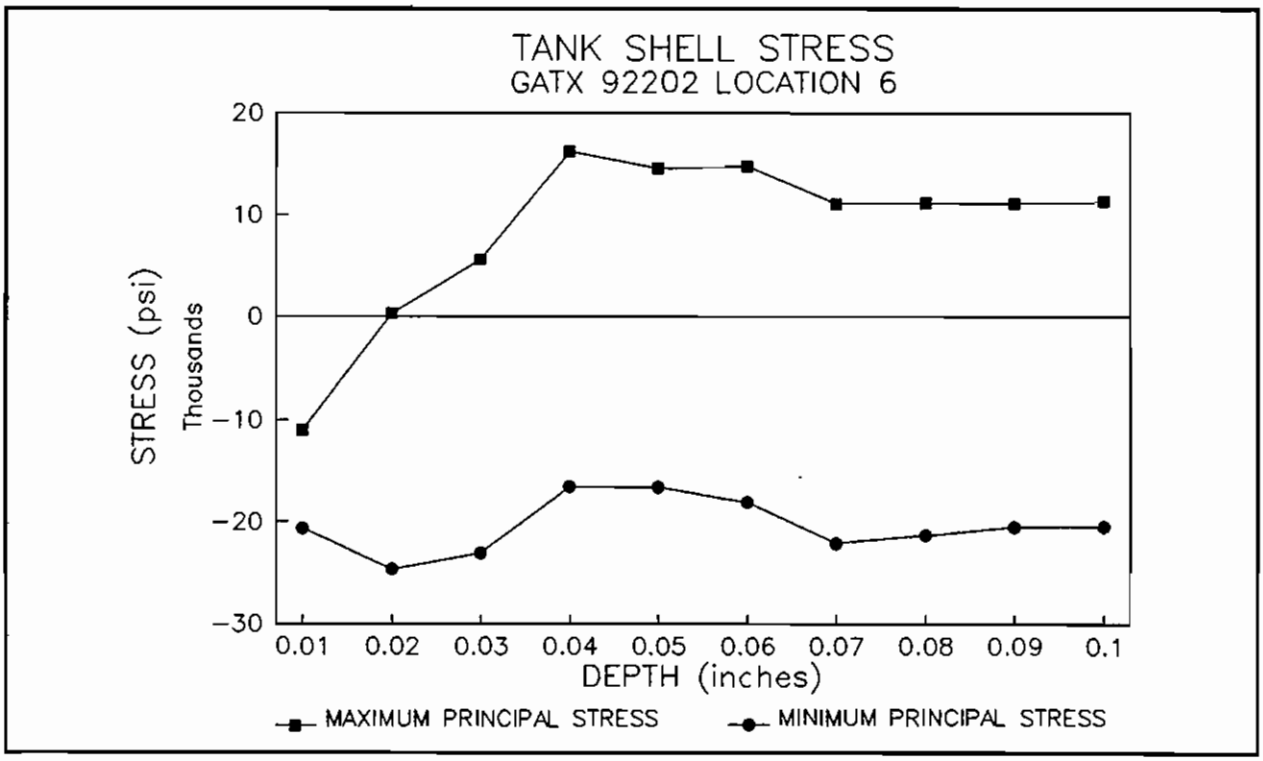


Figure B-12. Principal Stresses Measured at Location 6 on GATX 92202

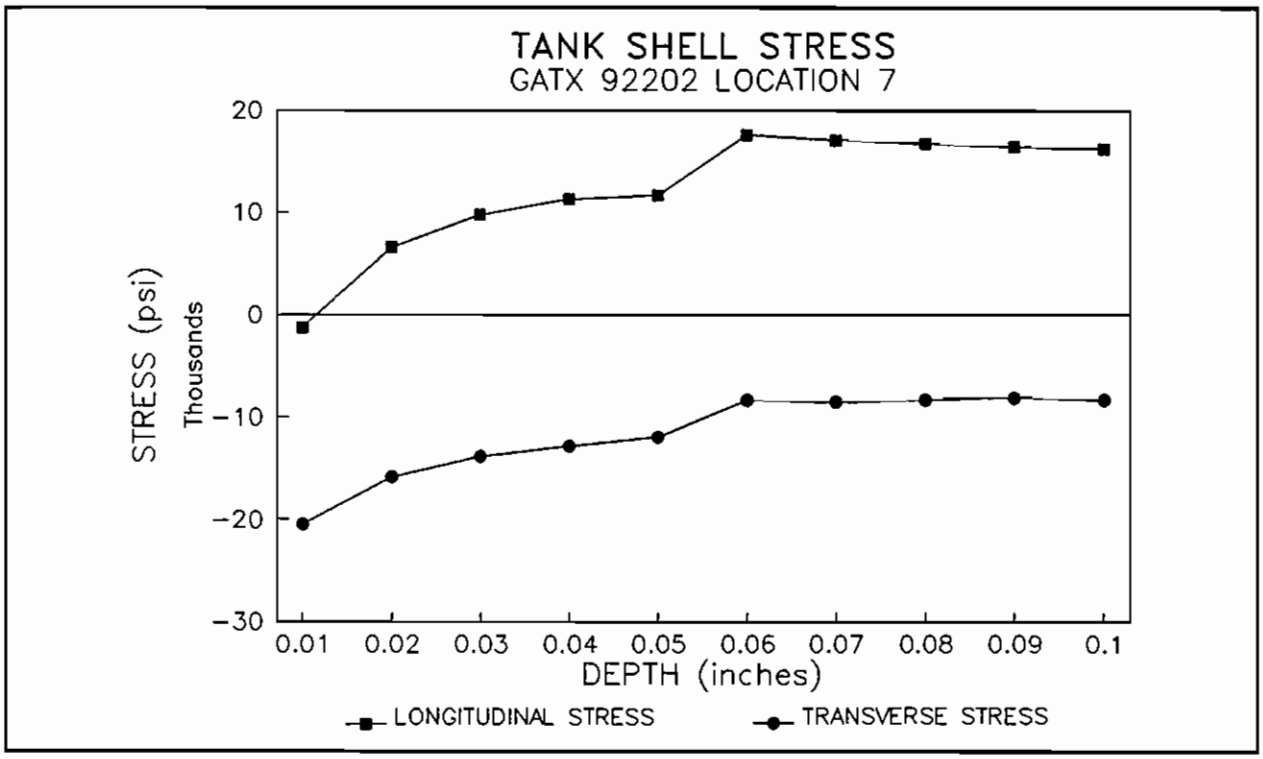


Figure B-13. Longitudinal and Transverse Stresses Measured at Location 7 on GATX 92202

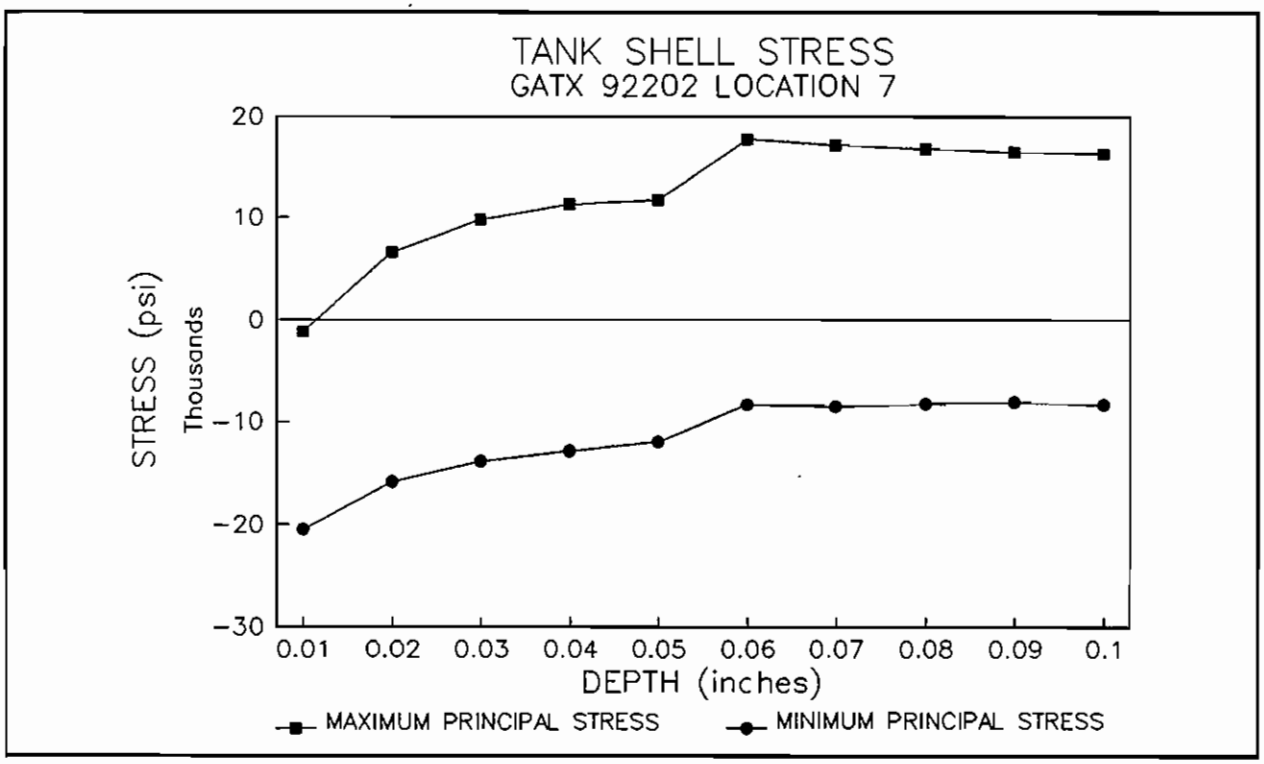


Figure B-14. Principal Stresses Measured at Location 7 on GATX 92202

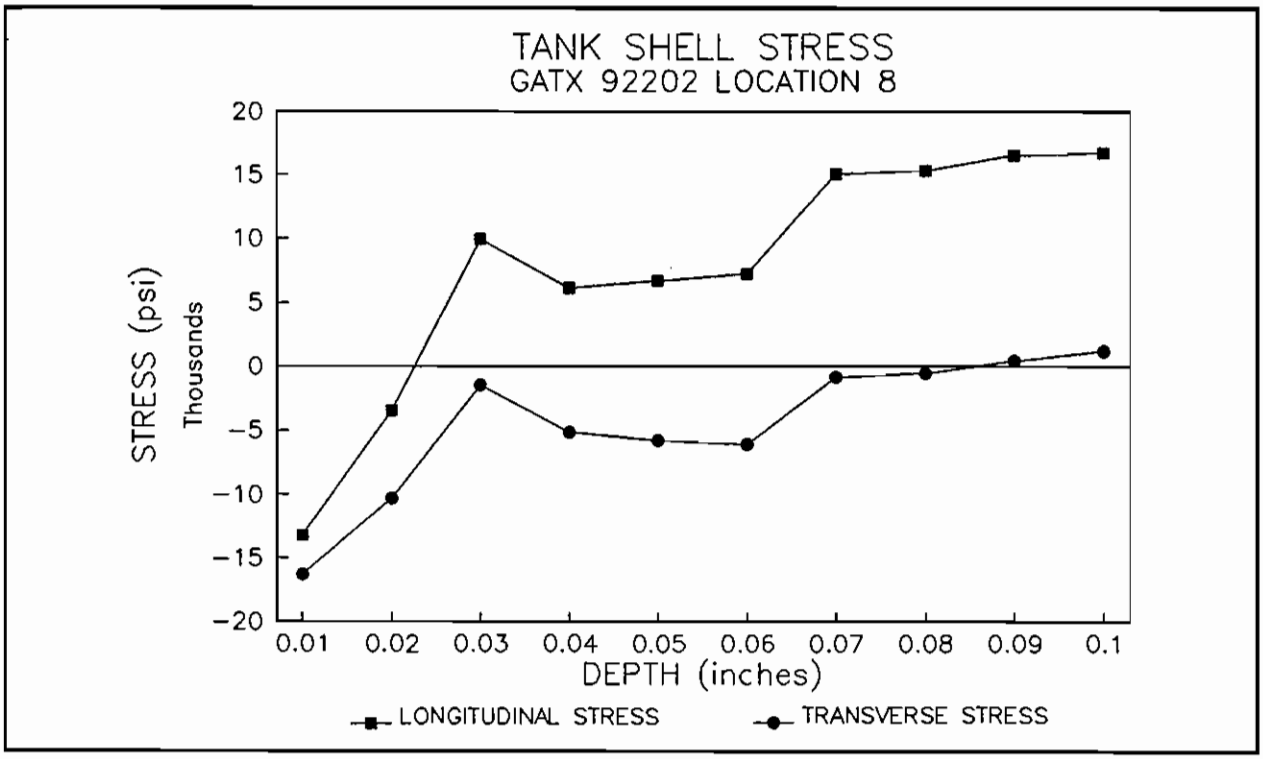


Figure B-15. Longitudinal and Transverse Stresses Measured at Location 8 on GATX 92202

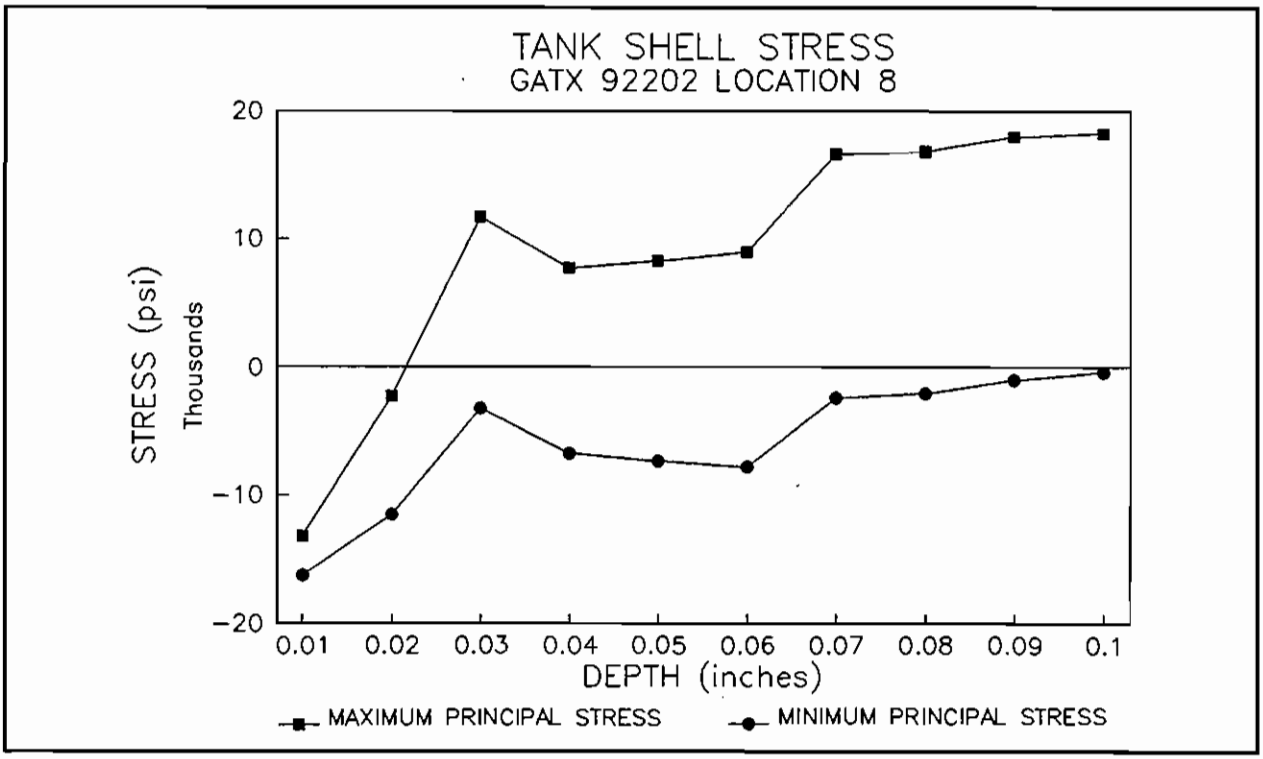


Figure B-16. Principal Stresses Measured at Location 8 on GATX 92202

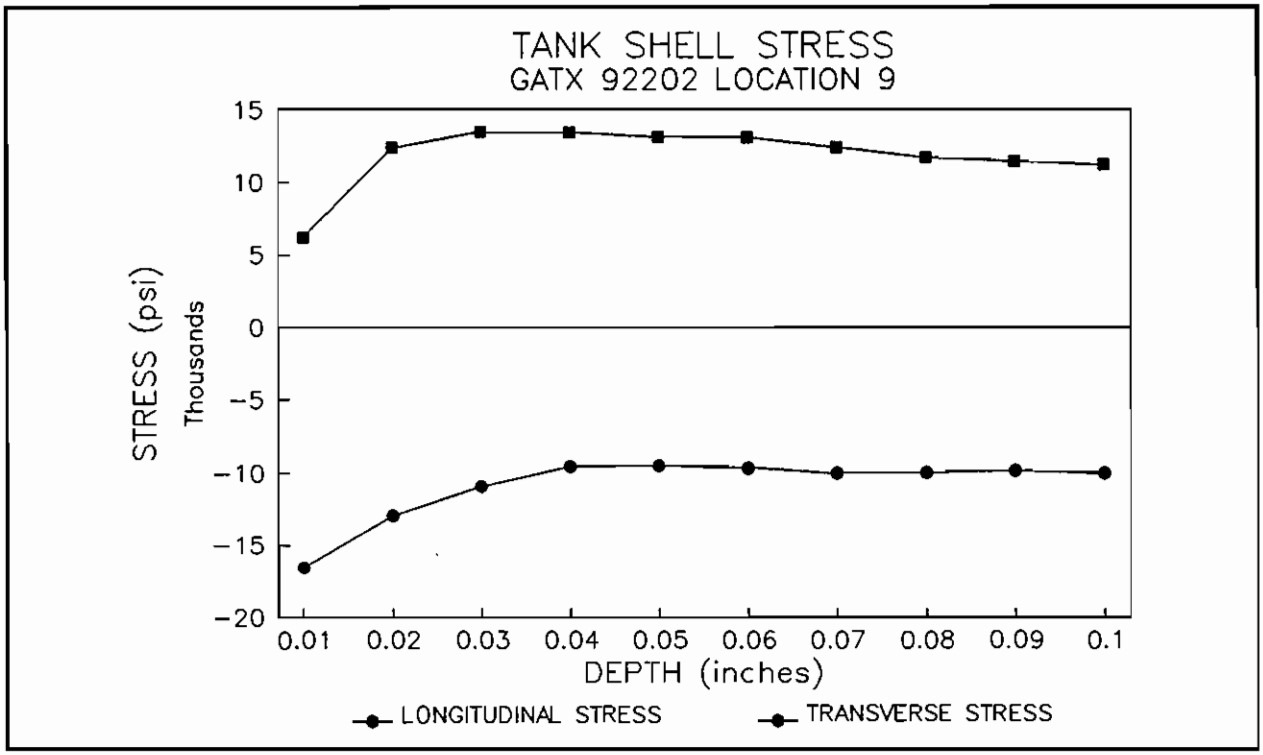


Figure B-17. Longitudinal and Transverse Stresses Measured at Location 9 on GATX 92202

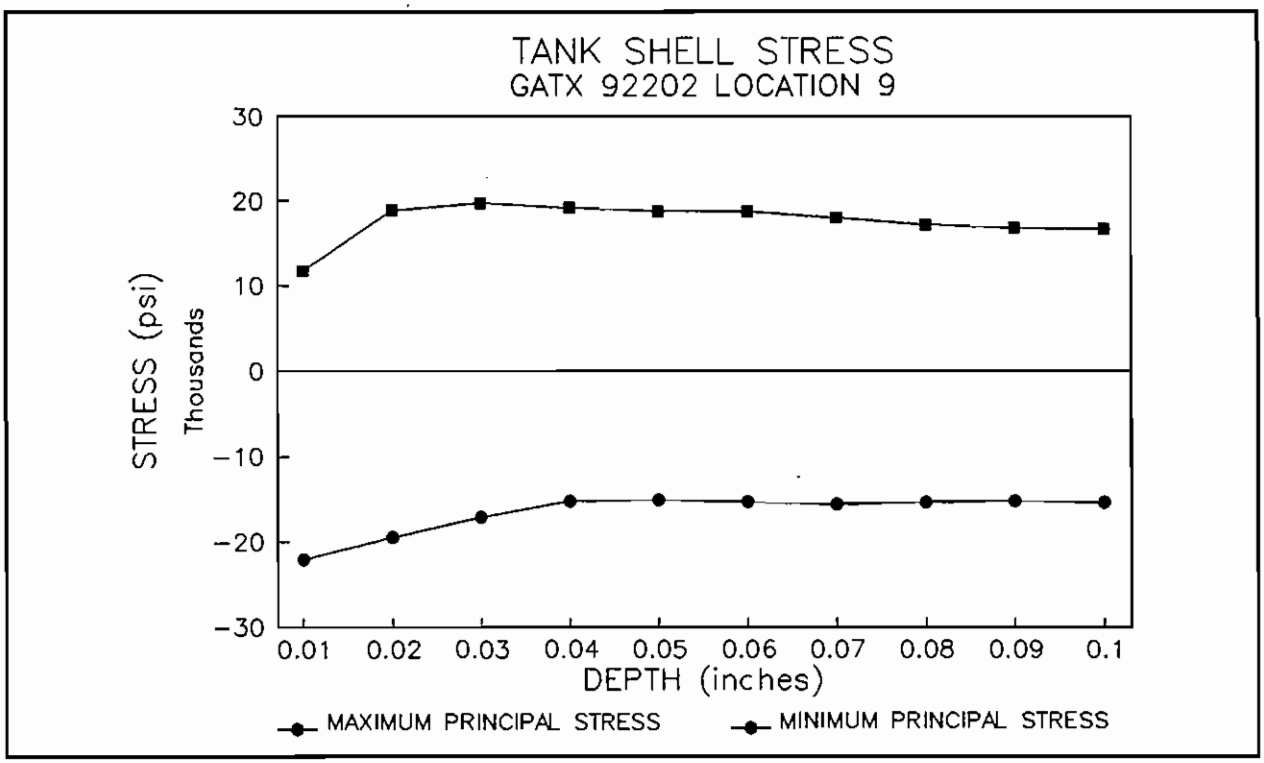


Figure B-18. Principal Stresses Measured at Location 9 on GATX 92202

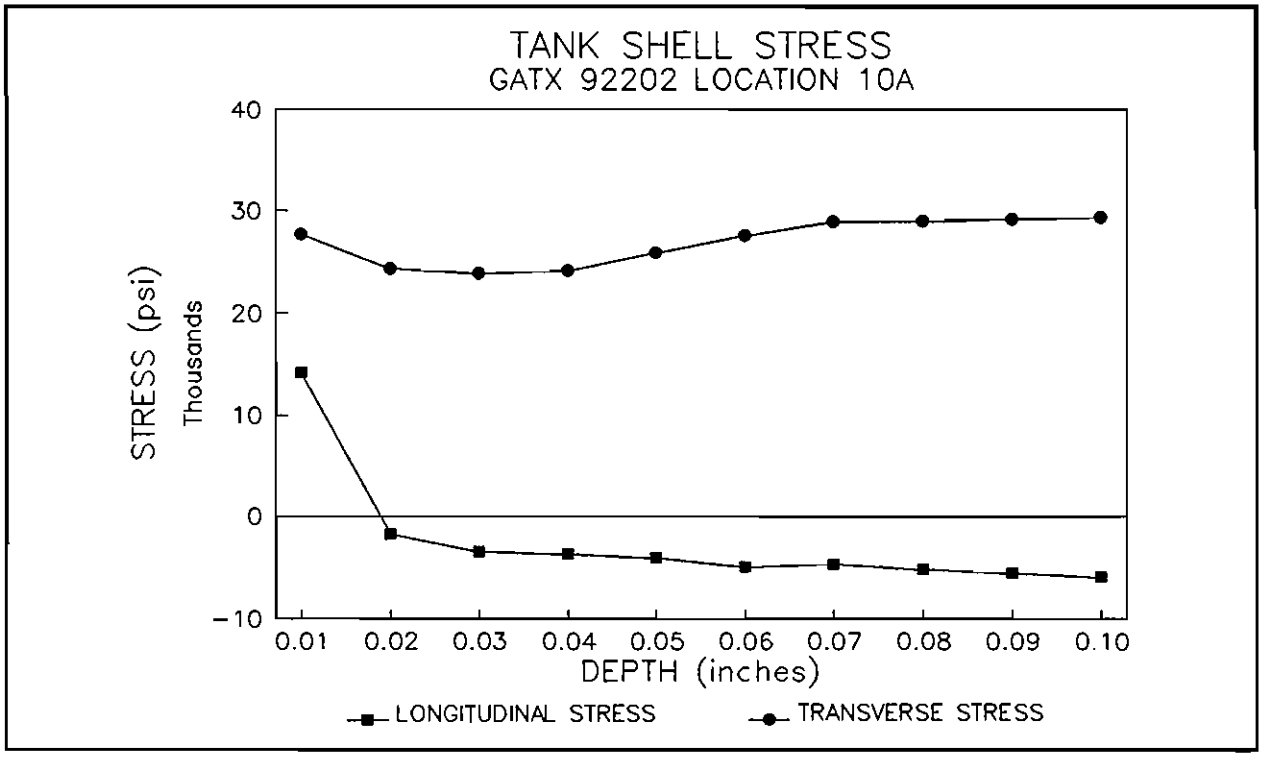


Figure B-19. Longitudinal and Transverse Stresses Measured at Location 10 on GATX 92202

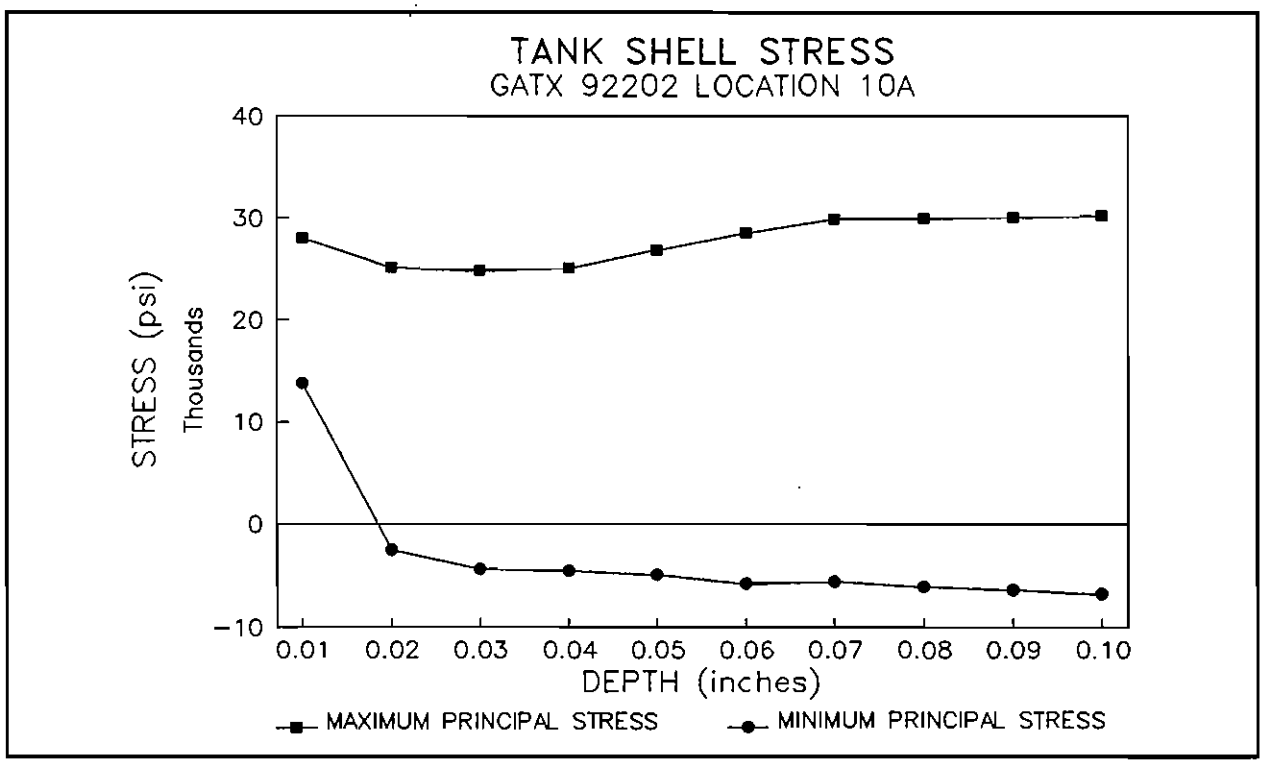


Figure B-20.Principal Stresses Measured at Location 10 on GATX 92202

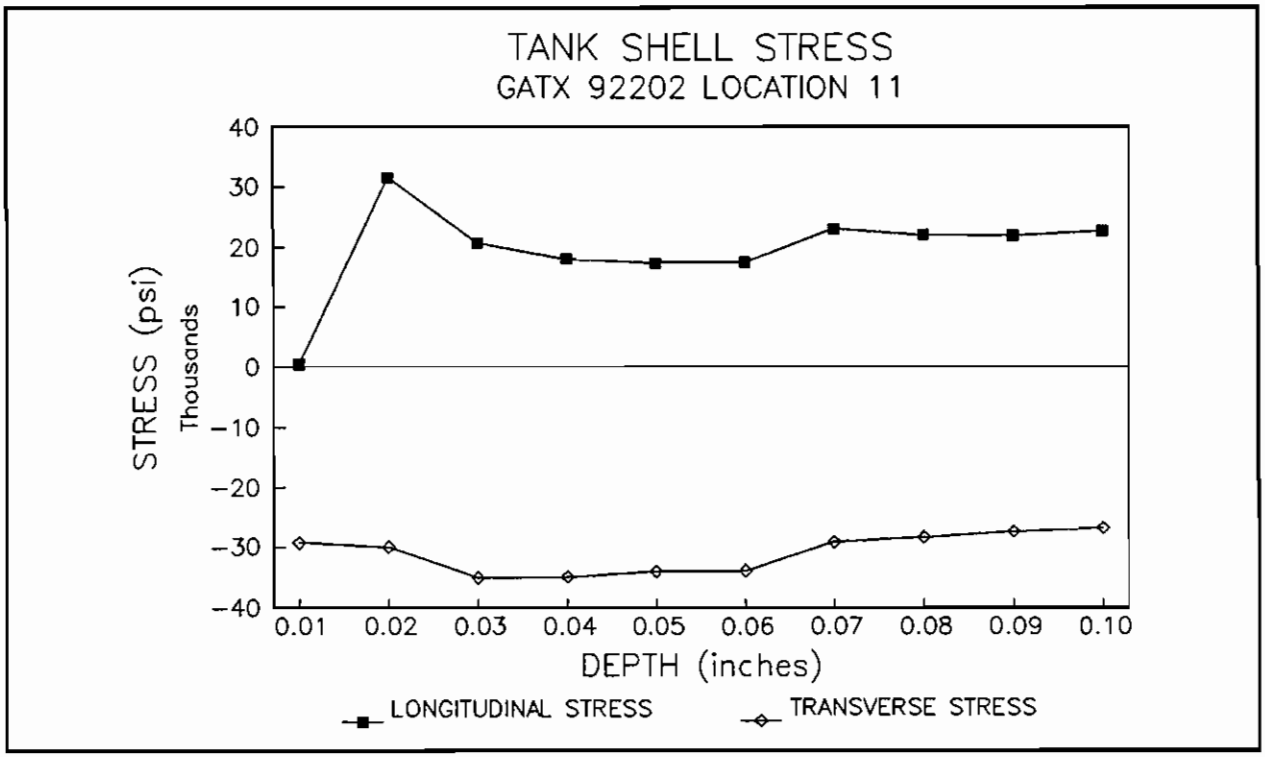


Figure B-21. Longitudinal and Transverse Stresses Measured at Location 11 on GATX 92202

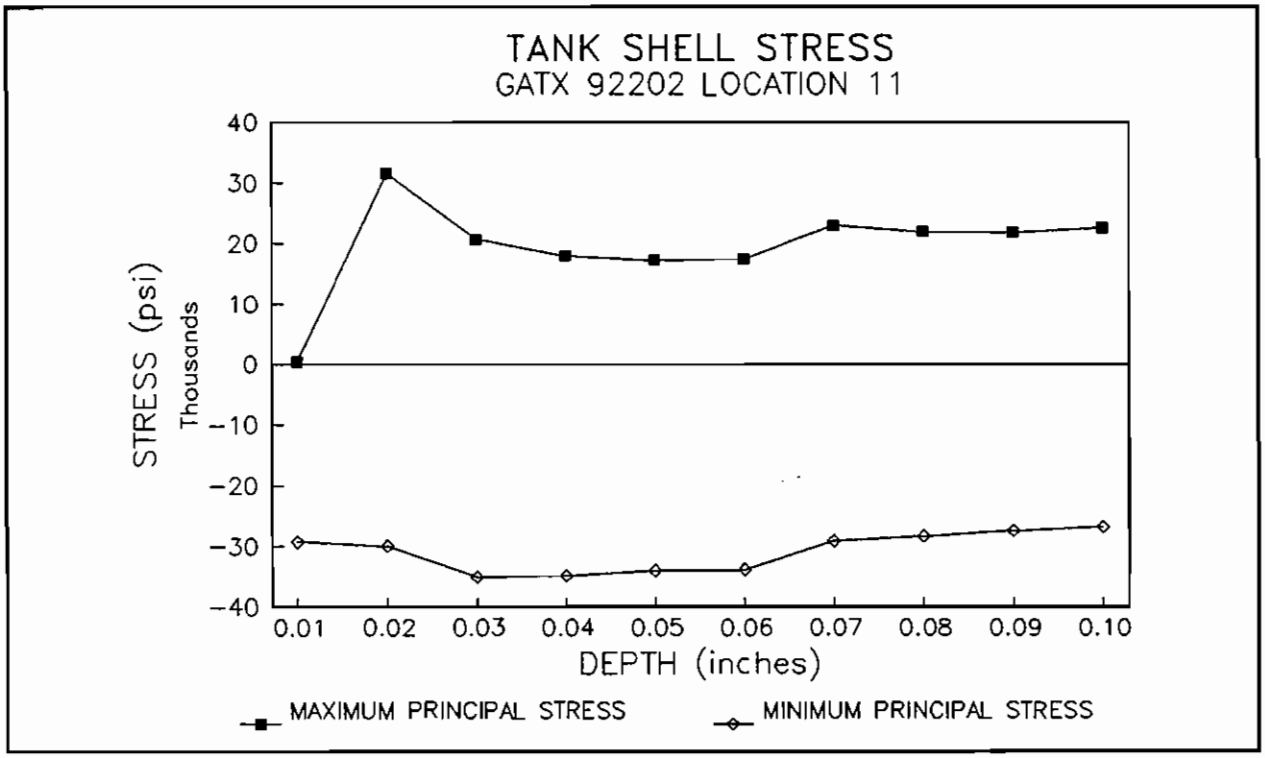


Figure B-22. Principal Stresses Measured at Location 11 on GATX 92202

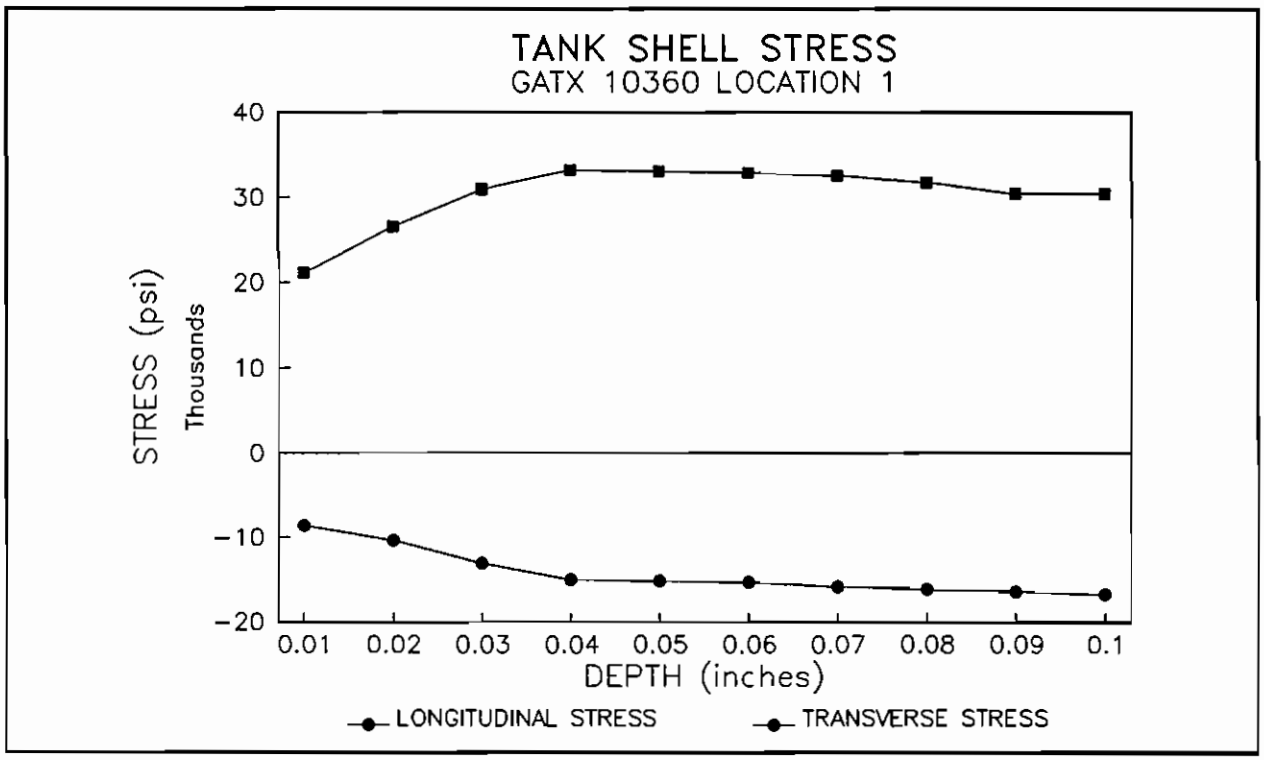


Figure B-23. Longitudinal and Transverse Stresses Measured at Location 1 on GATX 10360

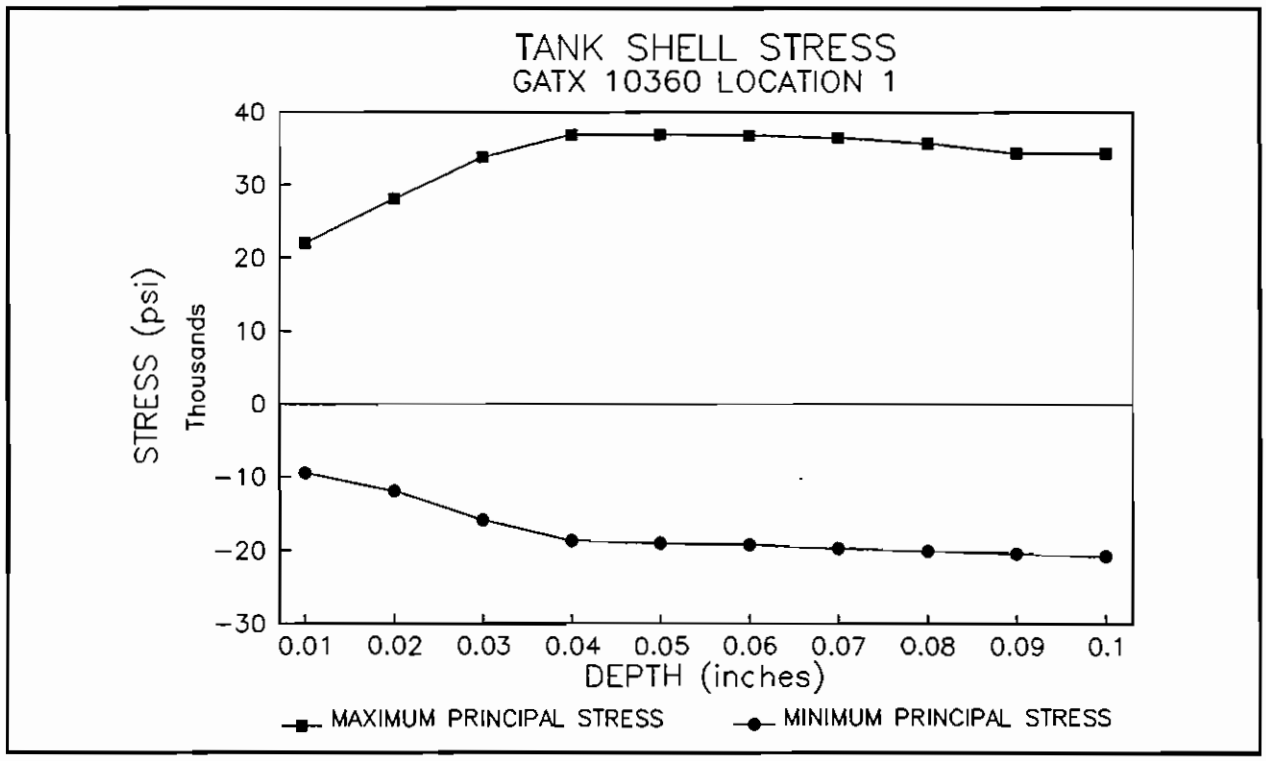


Figure B-24. Principal Stresses Measured at Location 1 on GATX 10360

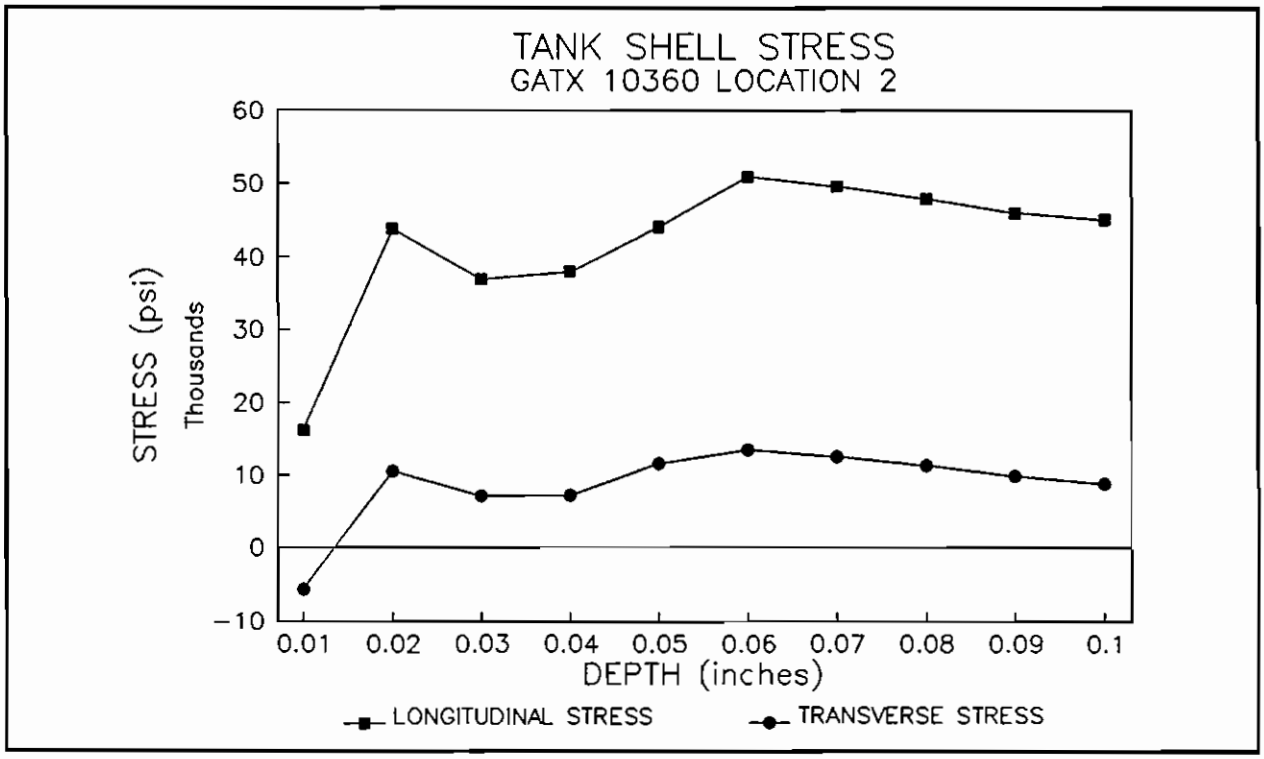


Figure B-25. Longitudinal and Transverse Stresses Measured at Location 2 on GATX 10360

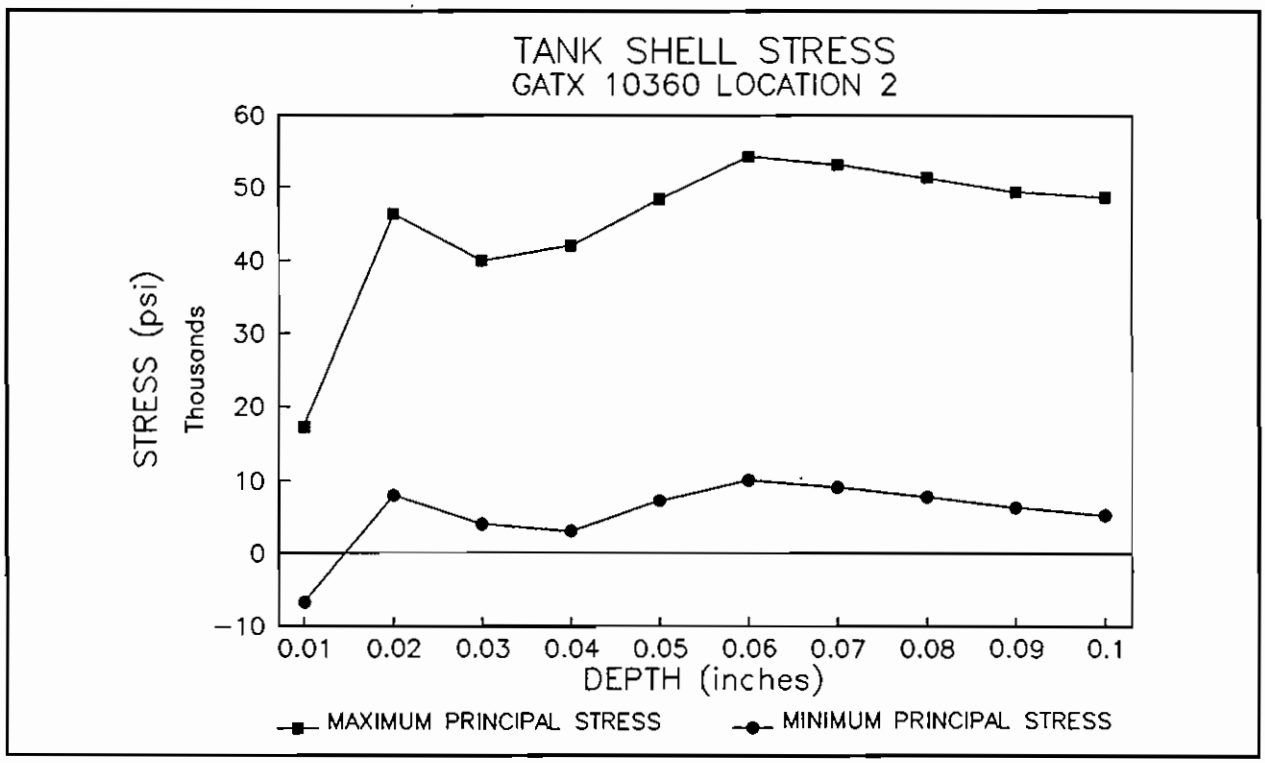


Figure B-26. Principal Stresses Measured at Location 2 on GATX 10360

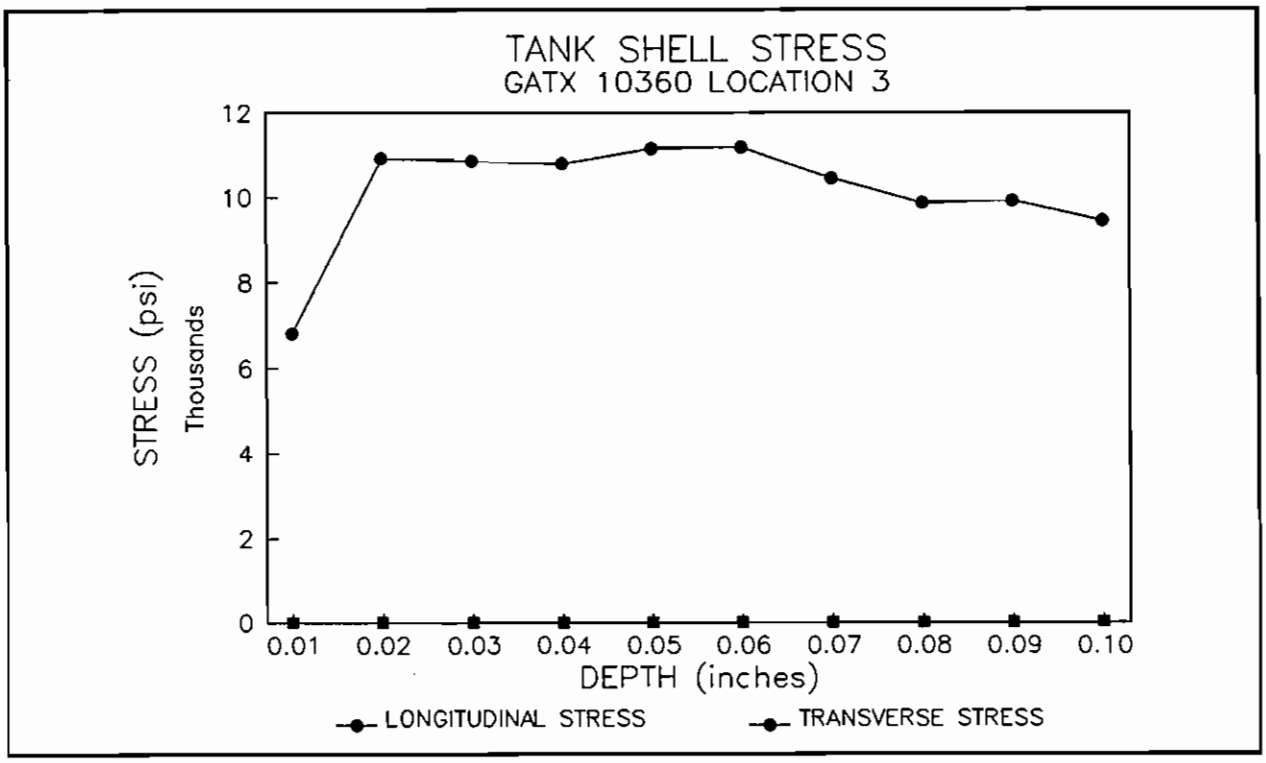


Figure B-27. Longitudinal and Transverse Stresses Measured at Location 3 on GATX 10360

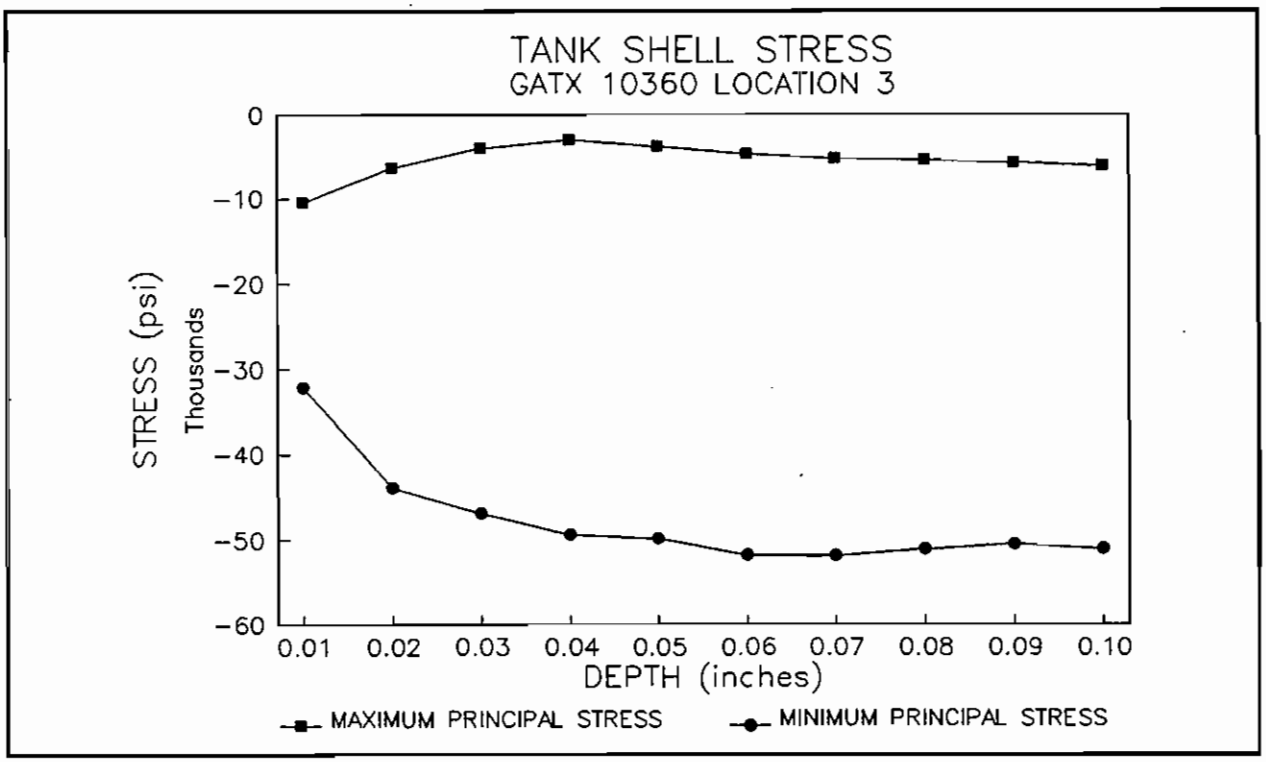


Figure B-28. Principal Stresses Measured at Location 3 on GATX 10360

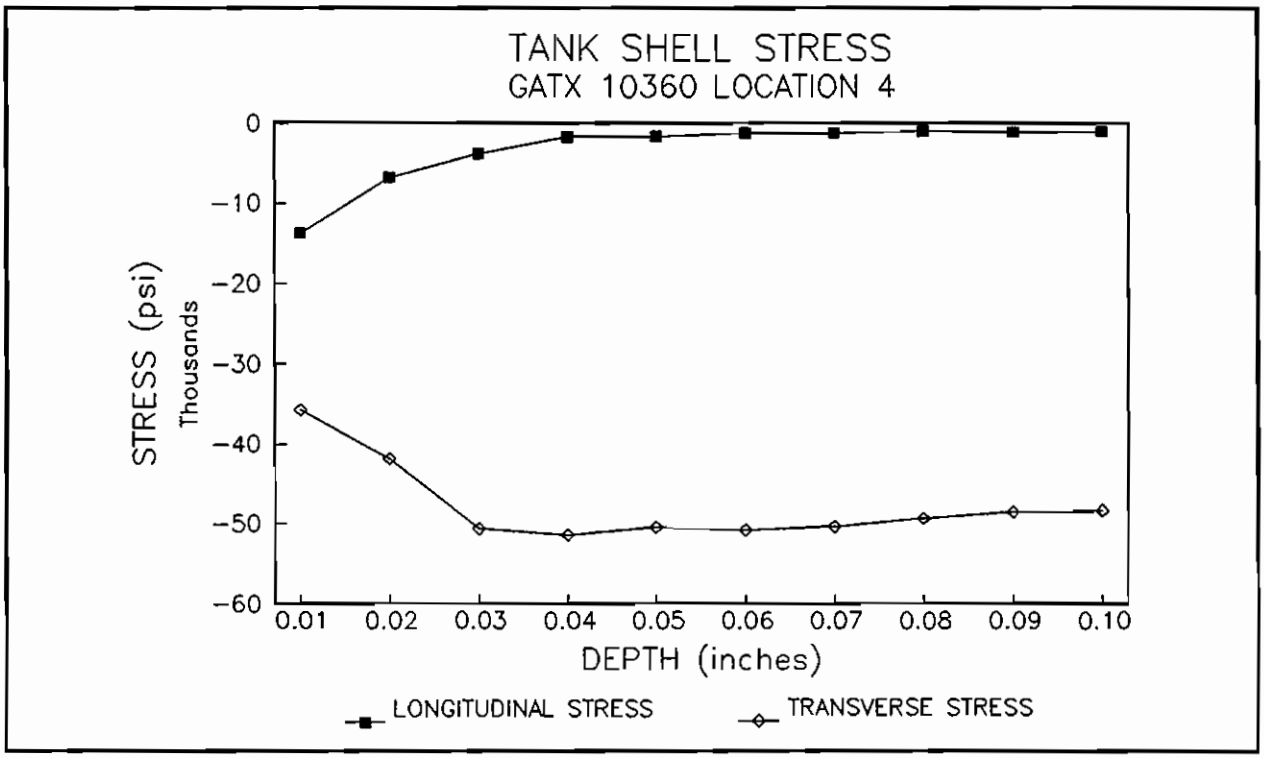


Figure B-29. Longitudinal and Transverse Stresses Measured at Location 4 on GATX 10360

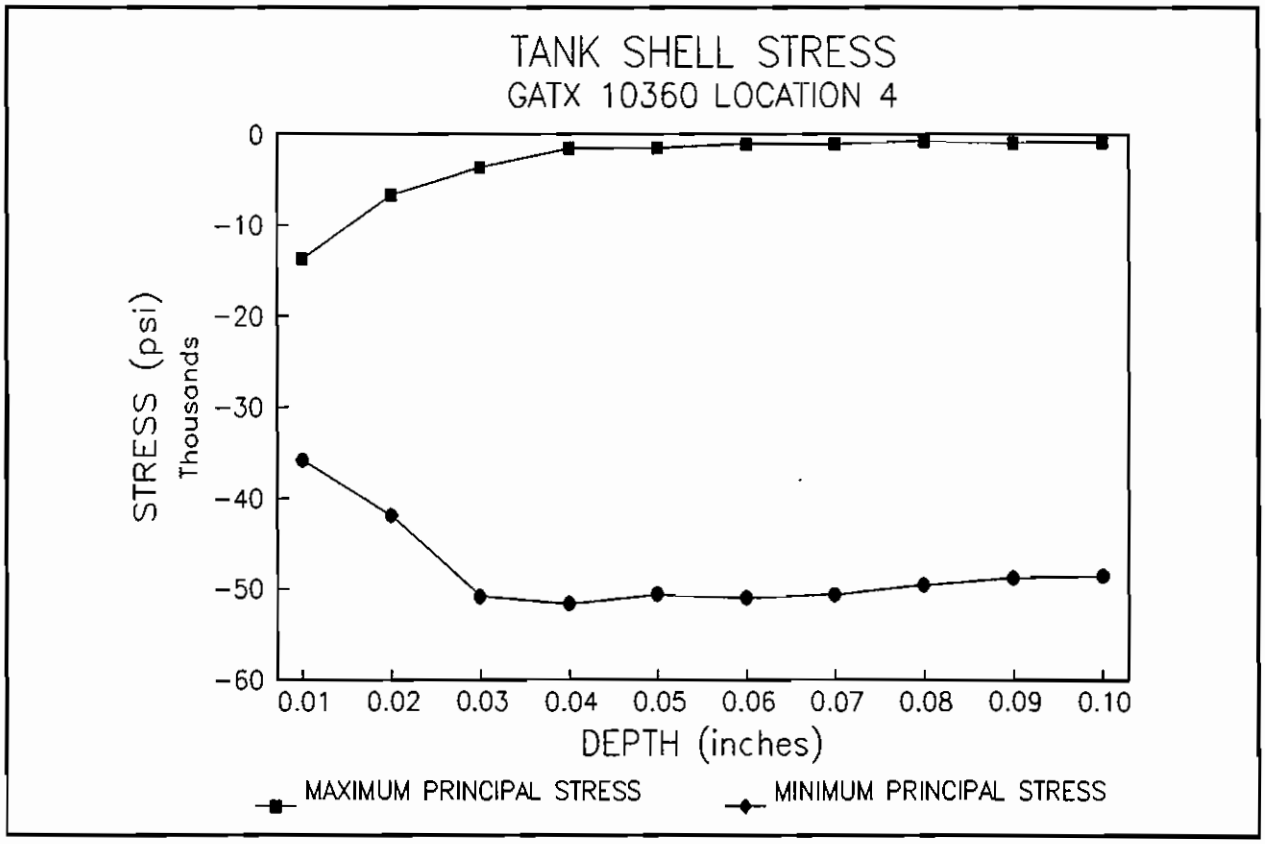


Figure B-30. Principal Stresses Measured at Location 4 on GATX 10360

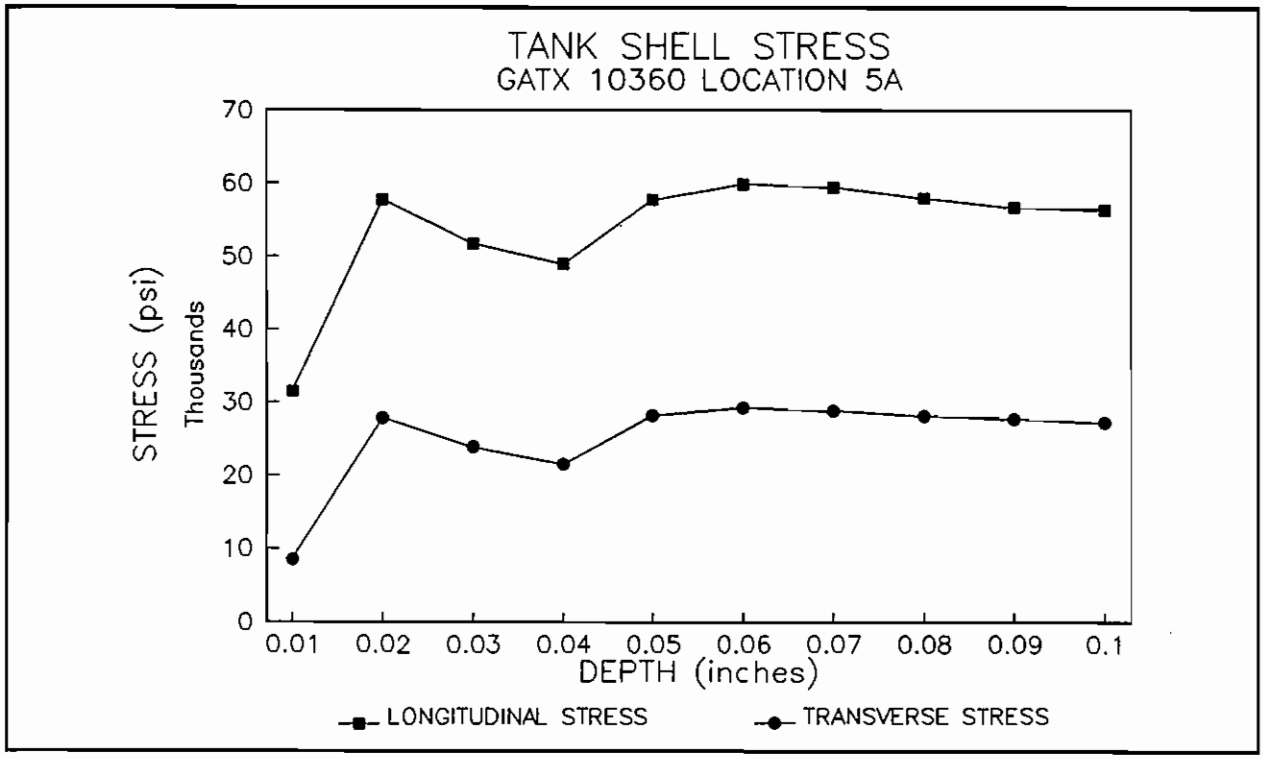


Figure B-31. Longitudinal and Transverse Stresses Measured at Location 5A on GATX 10360

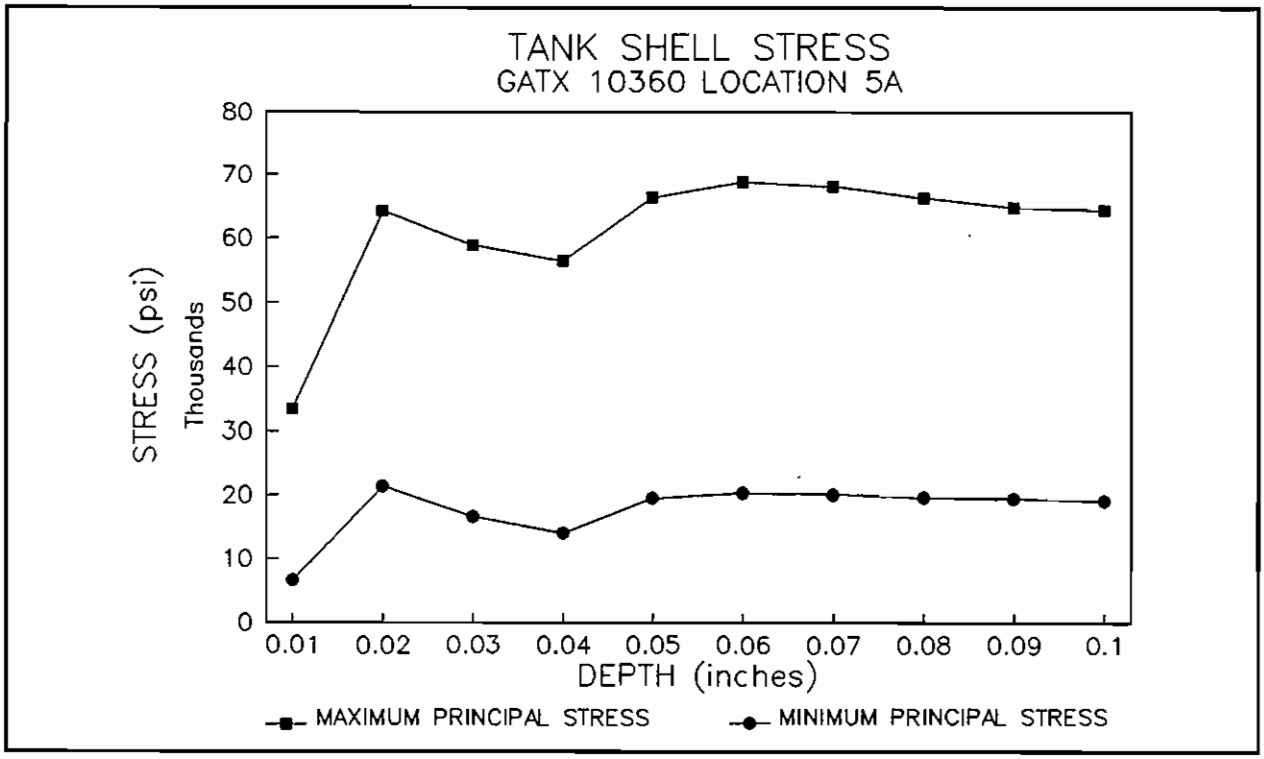


Figure B-32. Principal Stresses Measured at Location 5A on GATX 10360

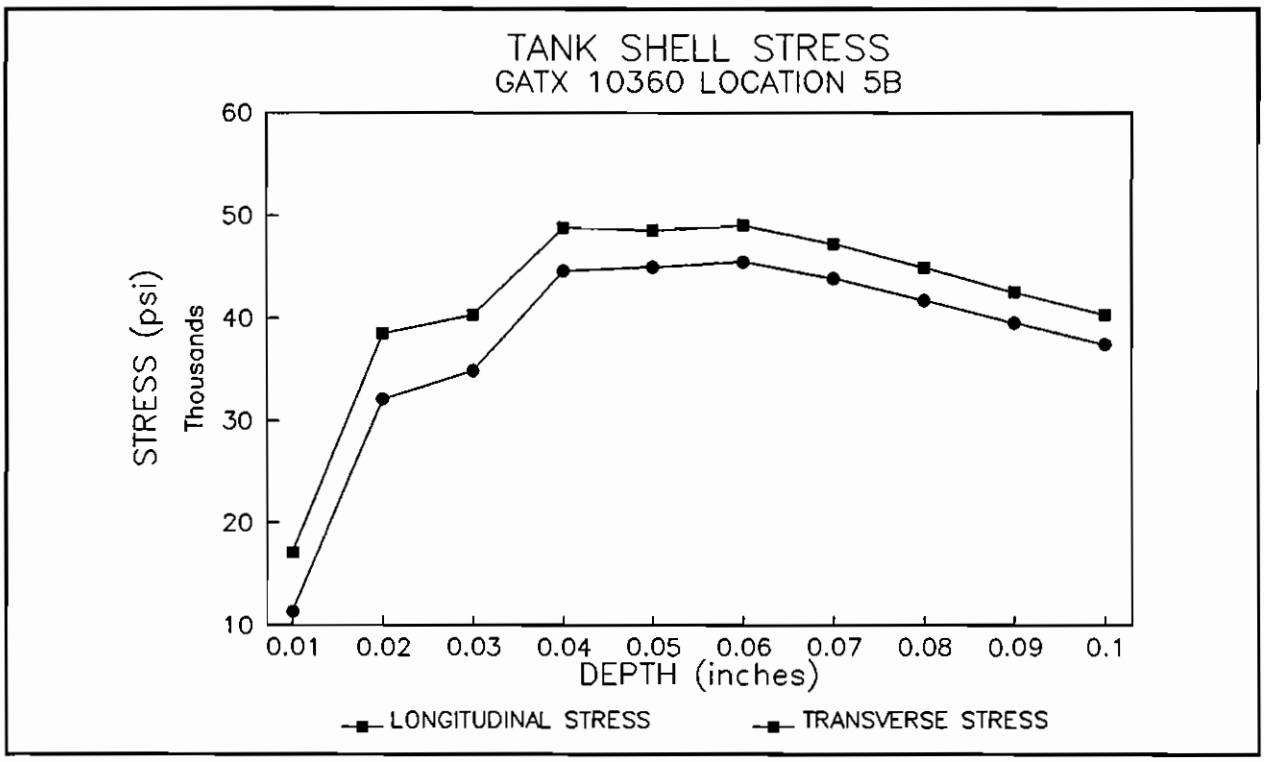


Figure B-33. Longitudinal and Transverse Stresses Measured at Location 5B on GATX 10360

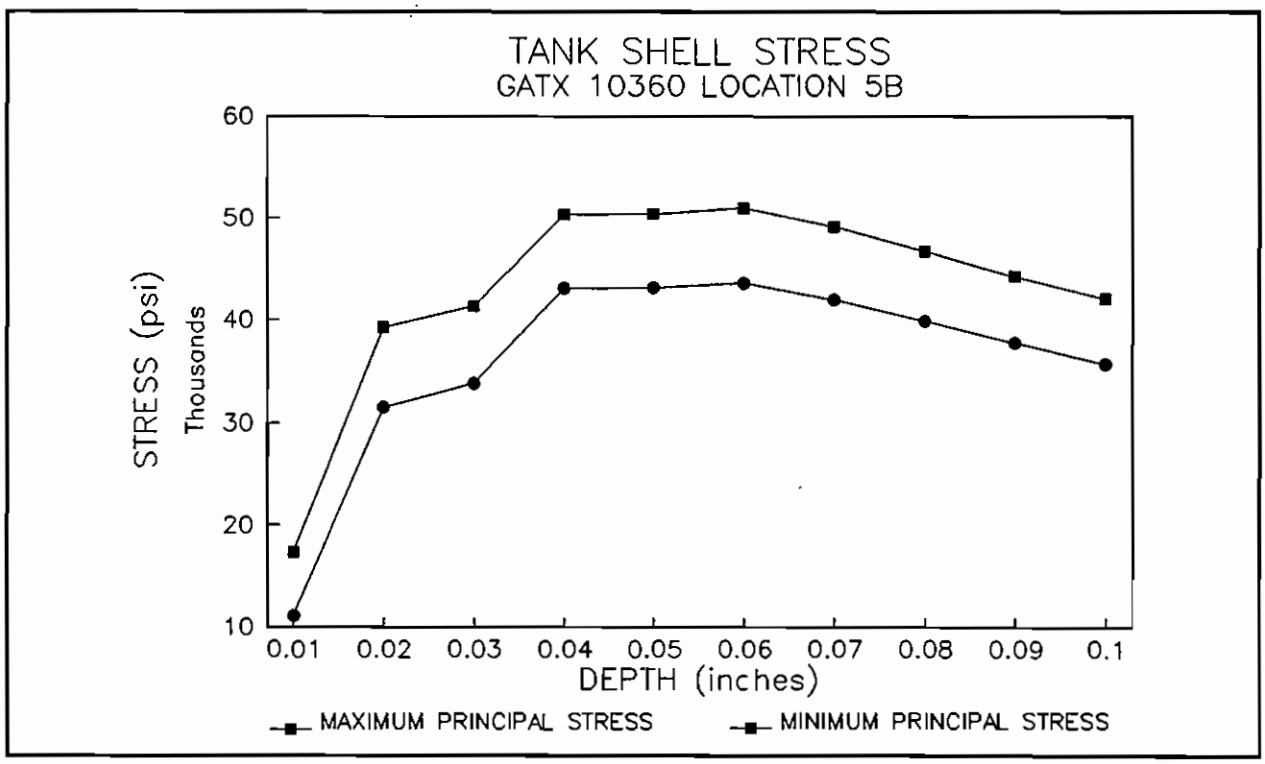


Figure B-34. Principal Stresses Measured at Location 5B on GATX 10360

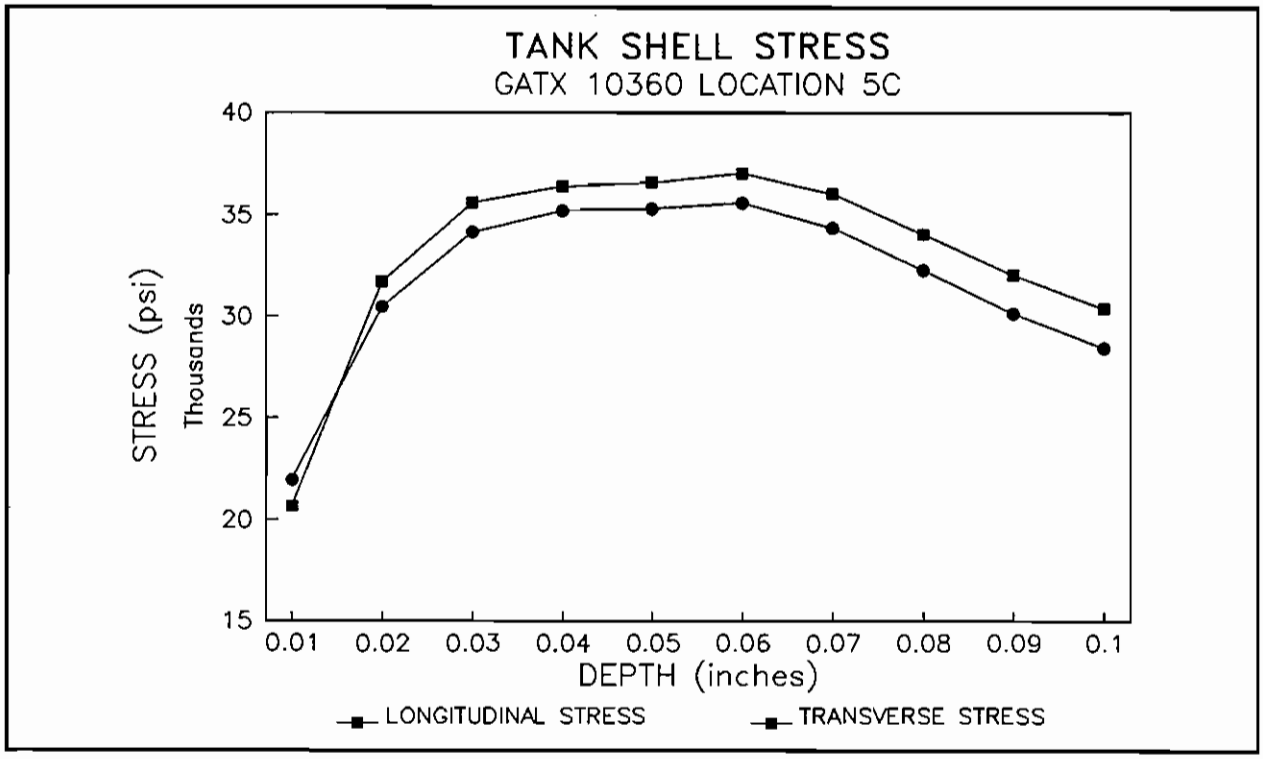


Figure B-35. Longitudinal and Transverse Stresses Measured at Location 5C on GATX 10360

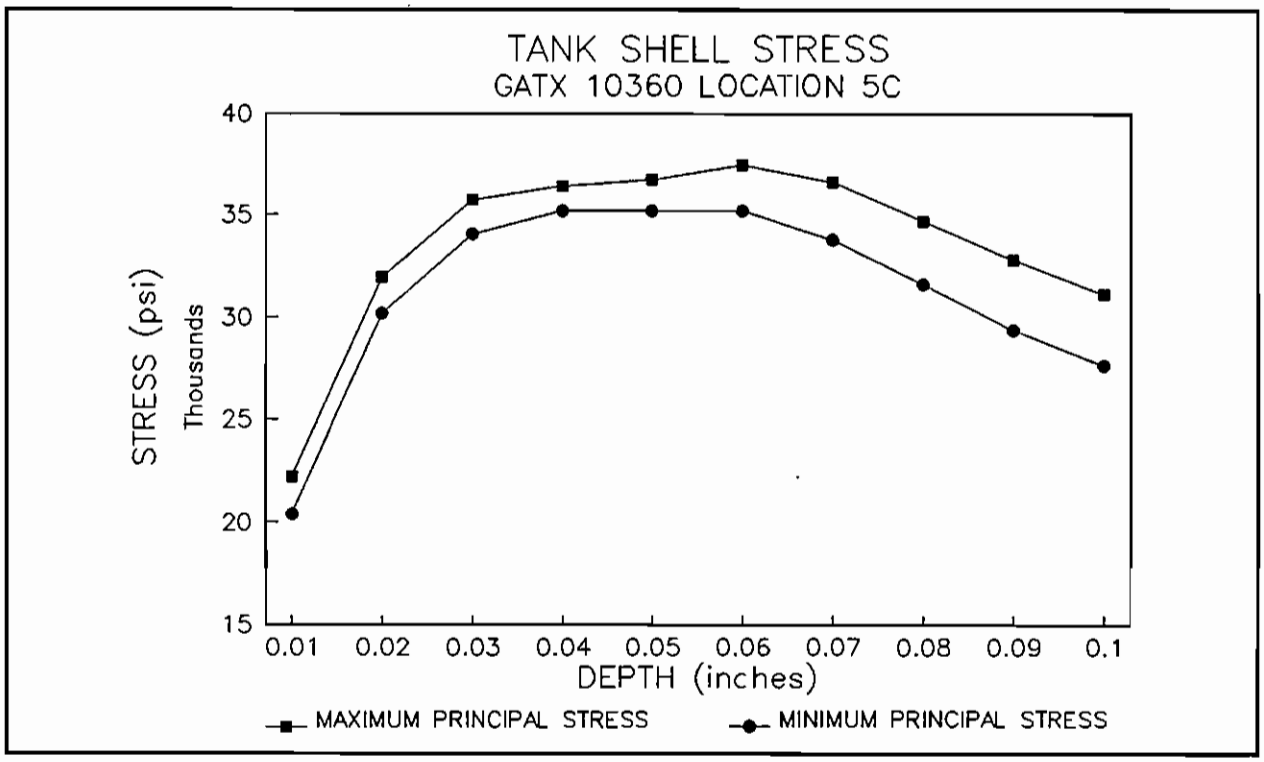


Figure B-36. Principal Stresses Measured at Location 5C on GATX 10360

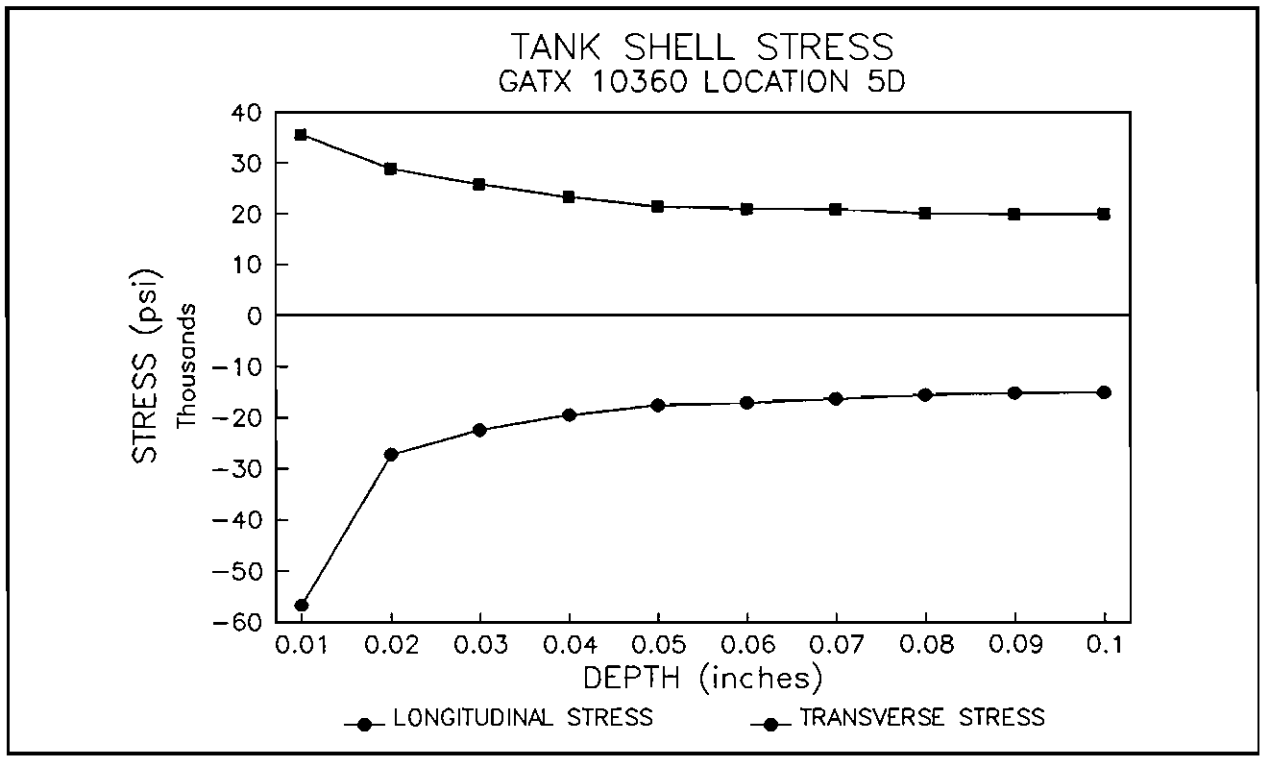


Figure B-37. Longitudinal and Transverse Stresses Measured at Location 5D on GATX 10360

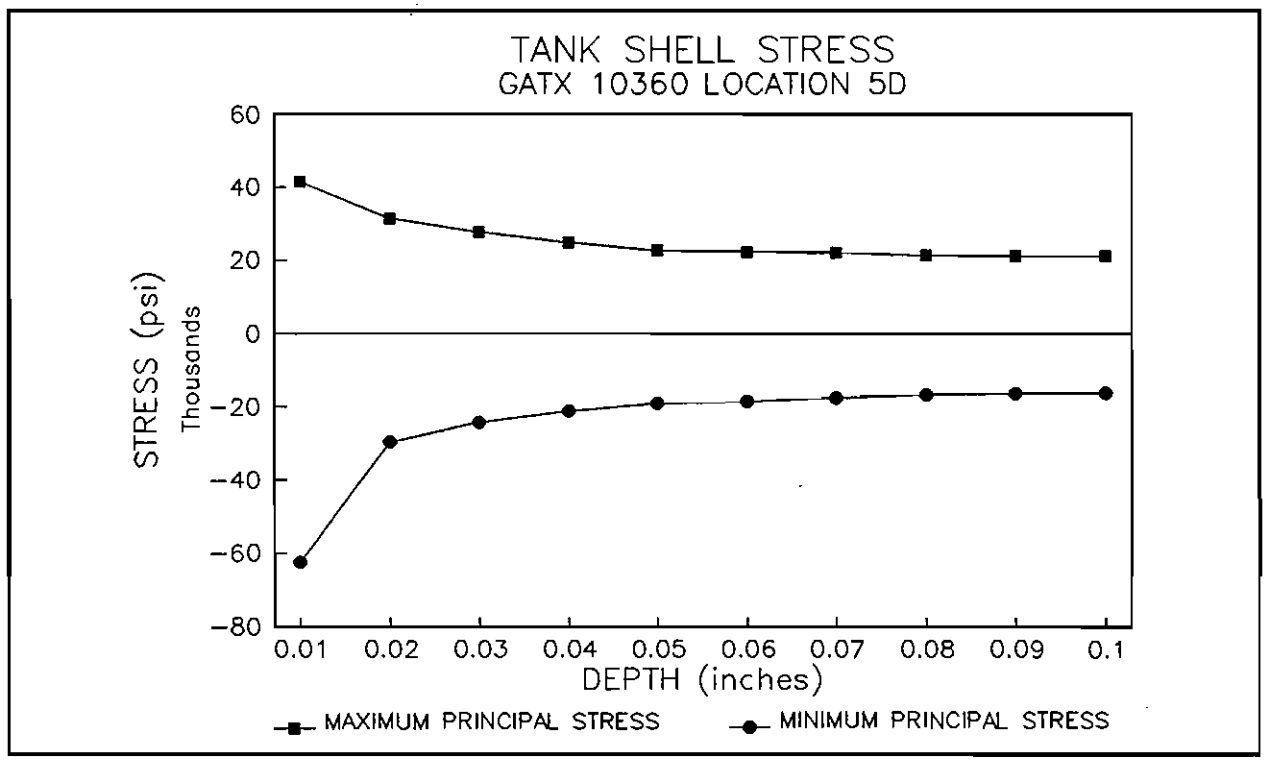


Figure B-38. Principal Stresses Measured at Location 5D on GATX 10360

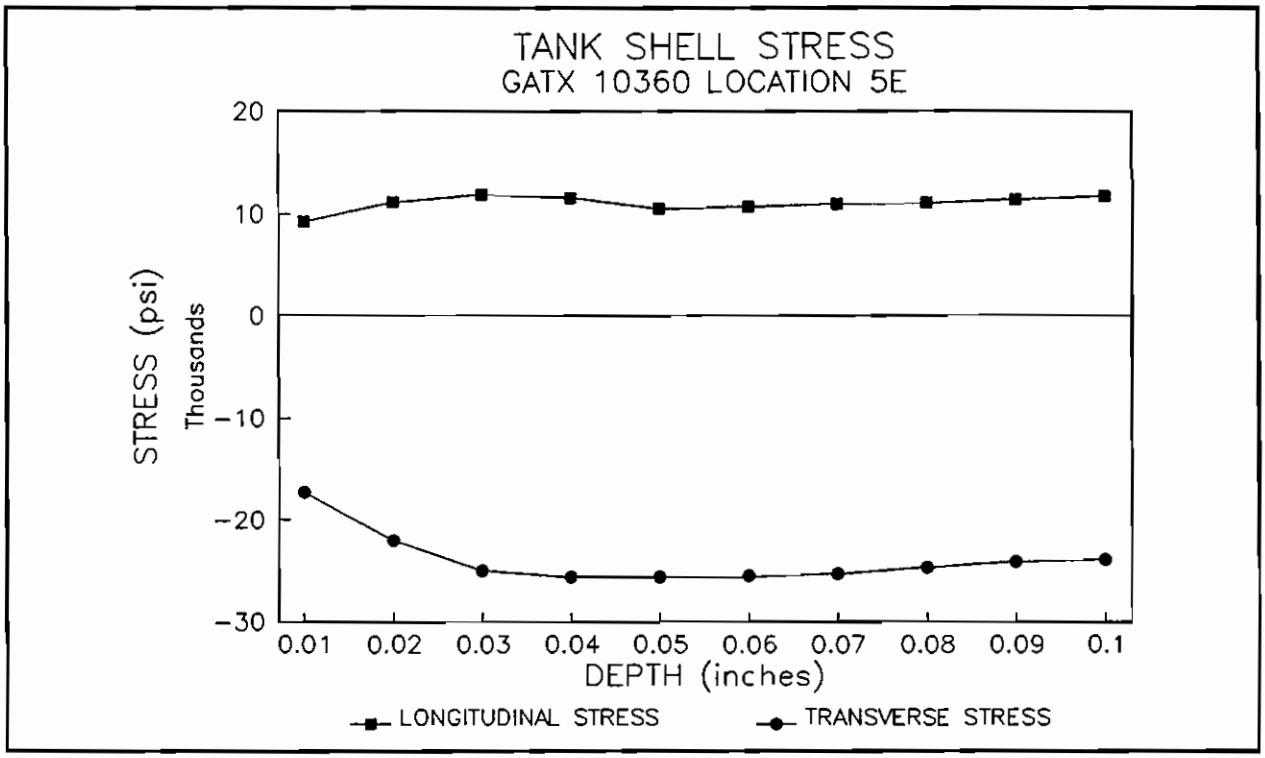


Figure B-39. Longitudinal and Transverse Stresses Measured at Location 5A on GATX 10360

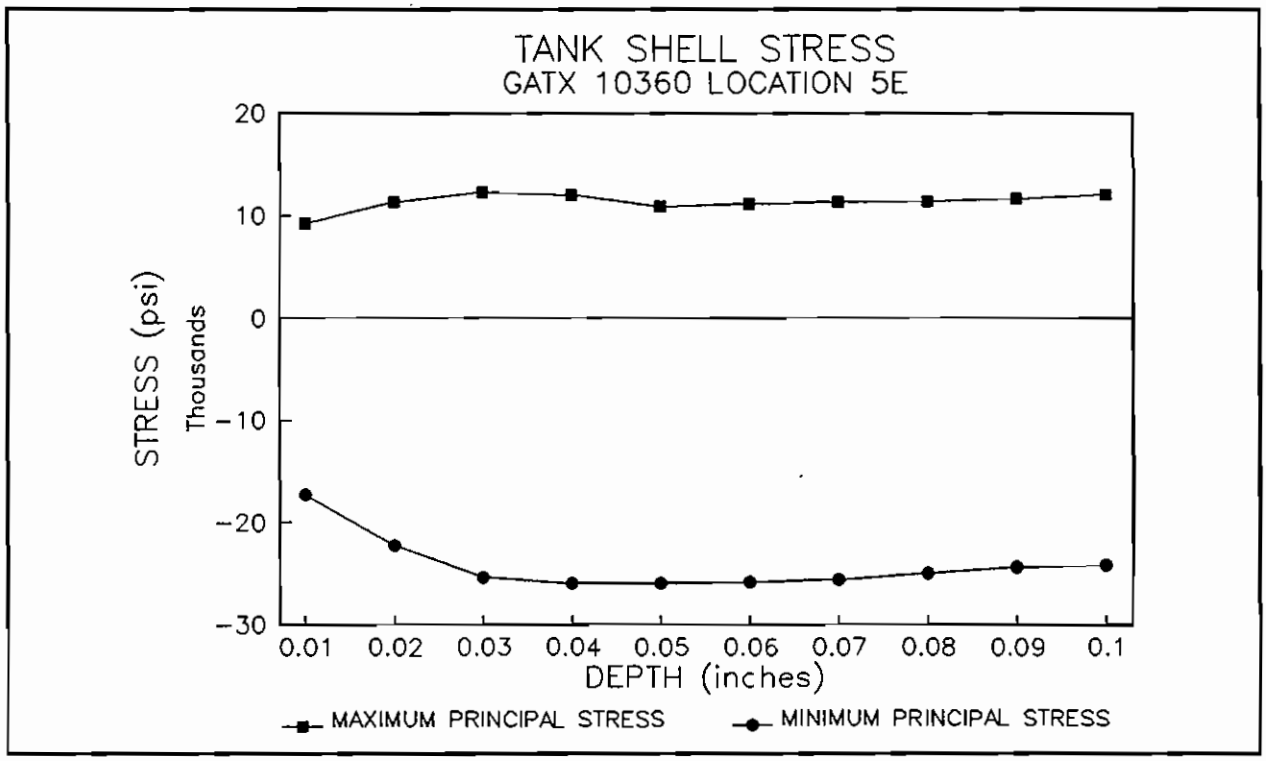


Figure B-40. Principal Stresses Measured at Location 5A on GATX 10360

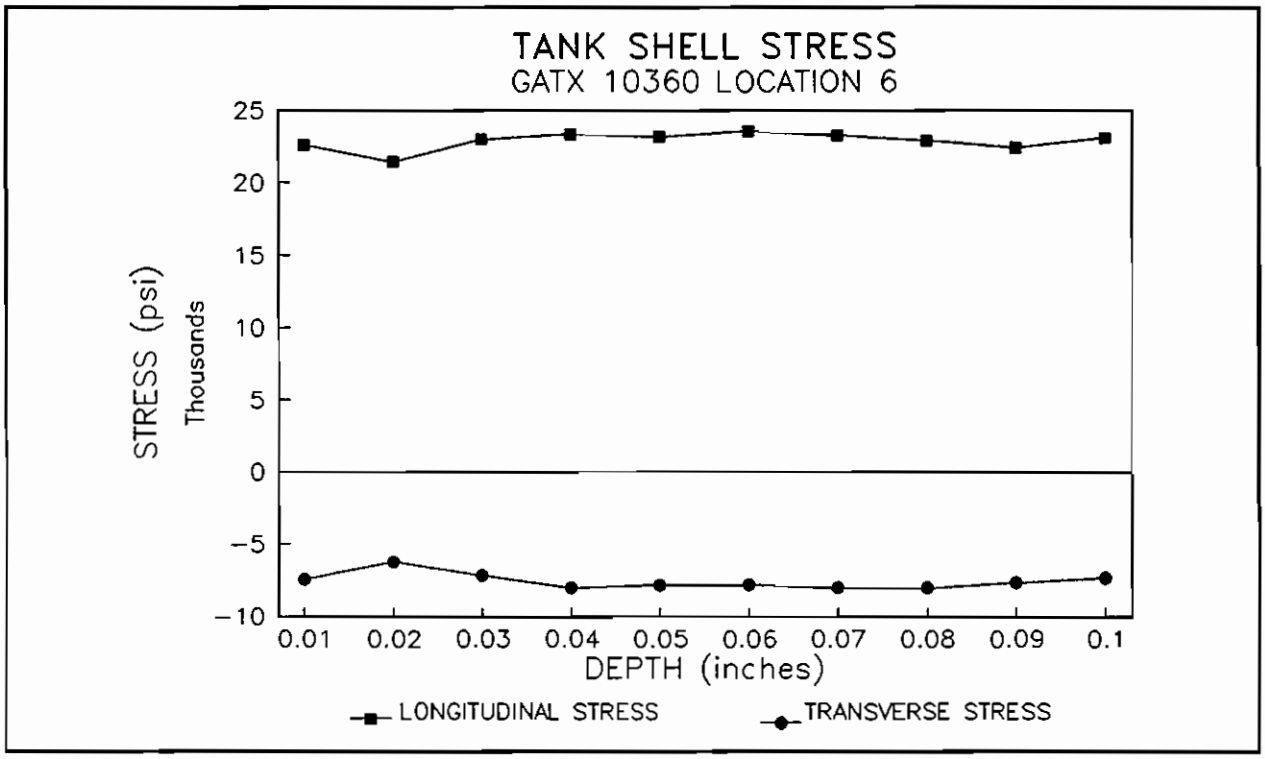


Figure B-41. Longitudinal and Transverse Stresses Measured at Location 5B on GATX 10360

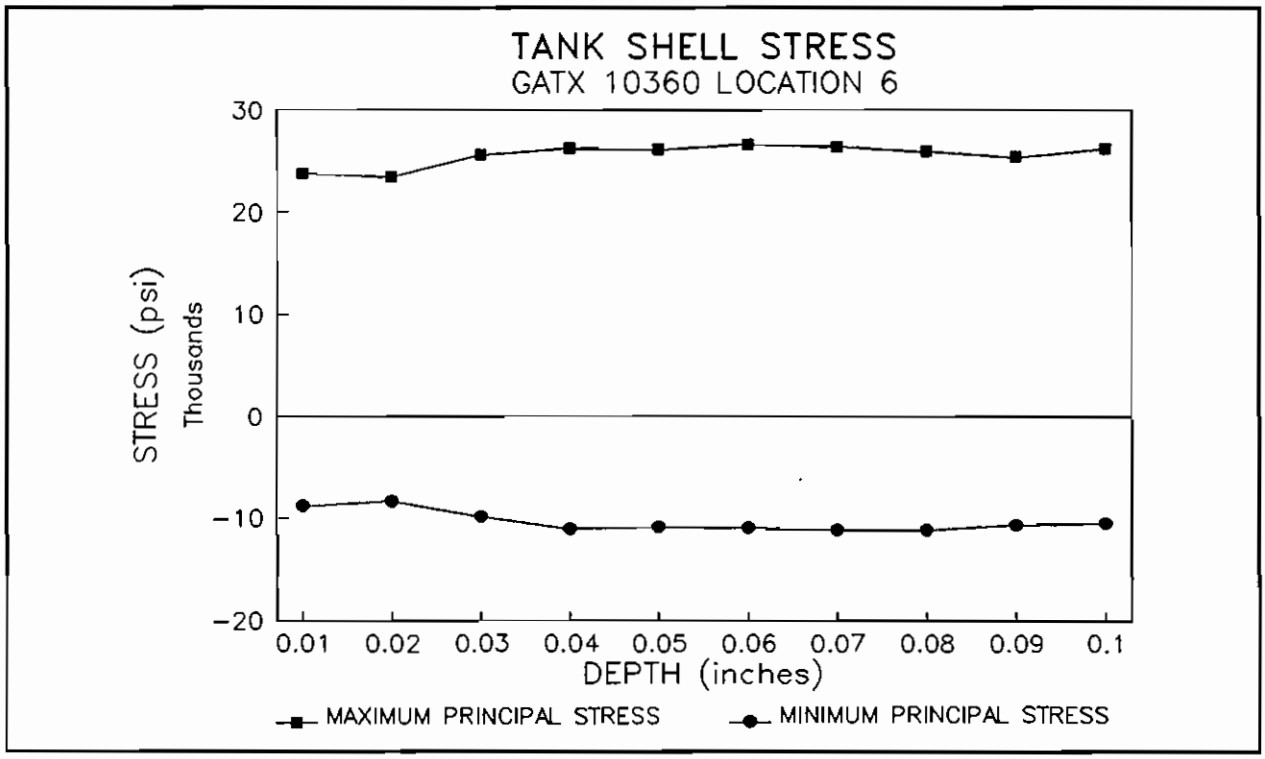


Figure B-42. Principal Stresses Measured at Location 5B on GATX 10360

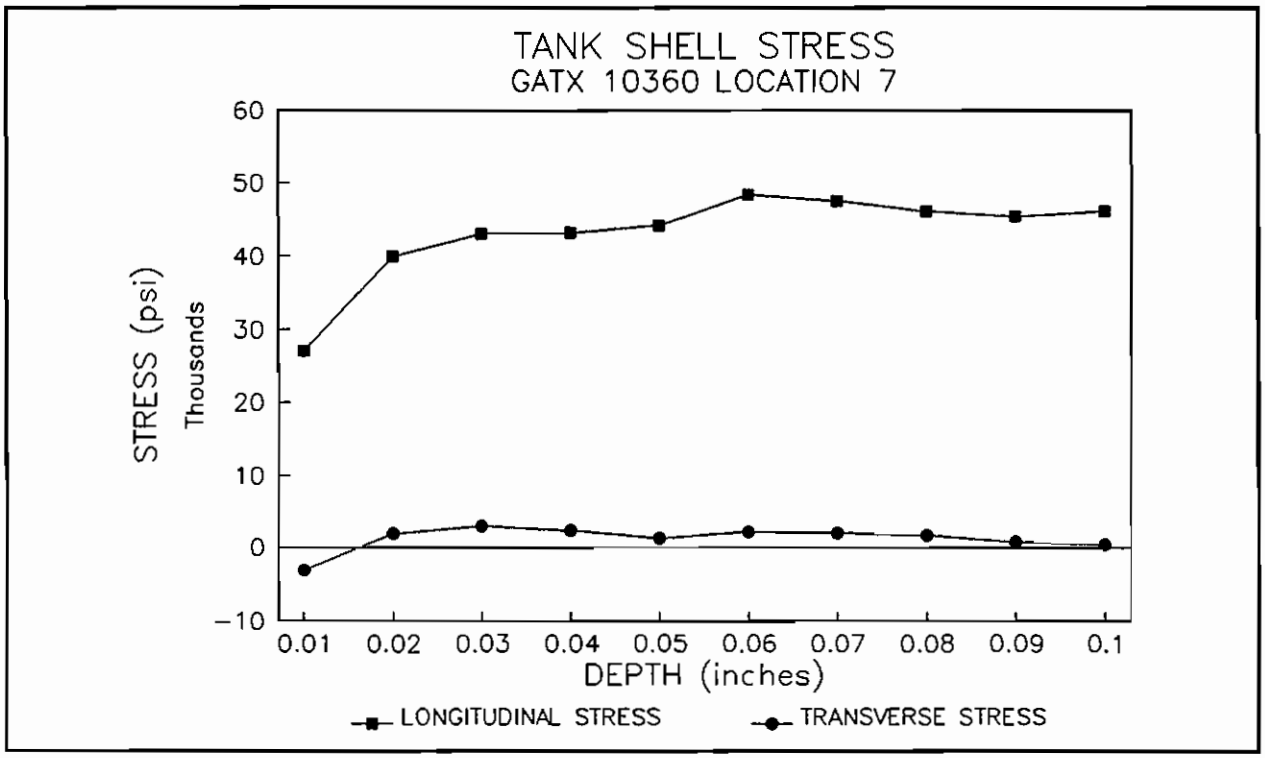


Figure B-43. Longitudinal and Transverse Stresses Measured at Location 5C on GATX 10360

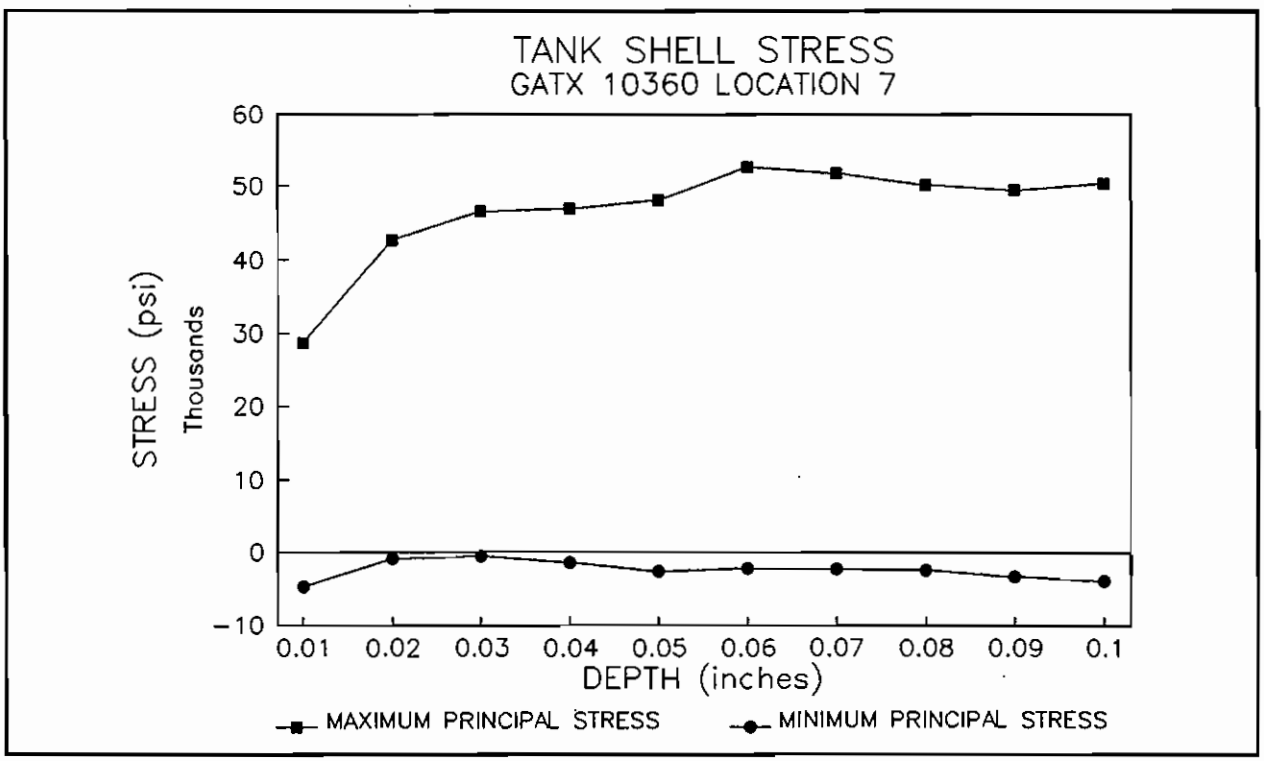


Figure B-44. Principal Stresses Measured at Location 5C on GATX 10360

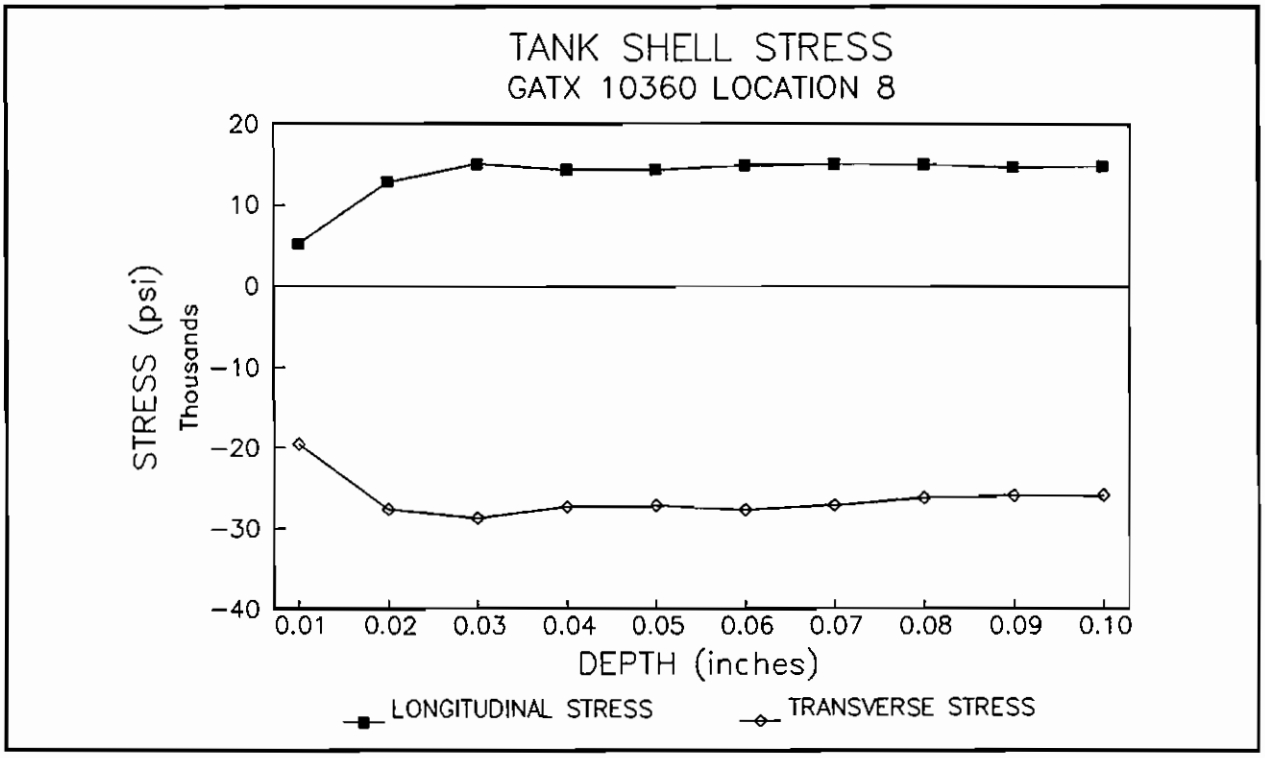


Figure B-45. Longitudinal and Transverse Stresses Measured at Location 5D on GATX 10360

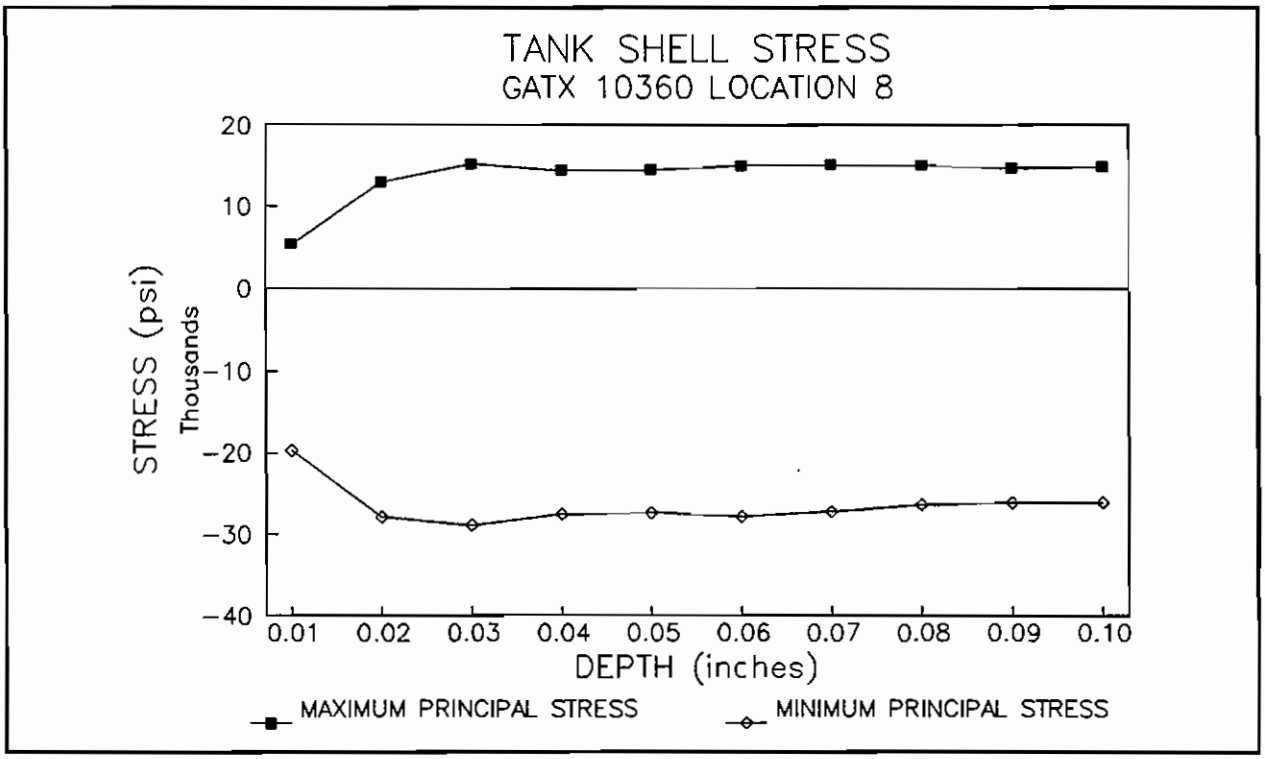
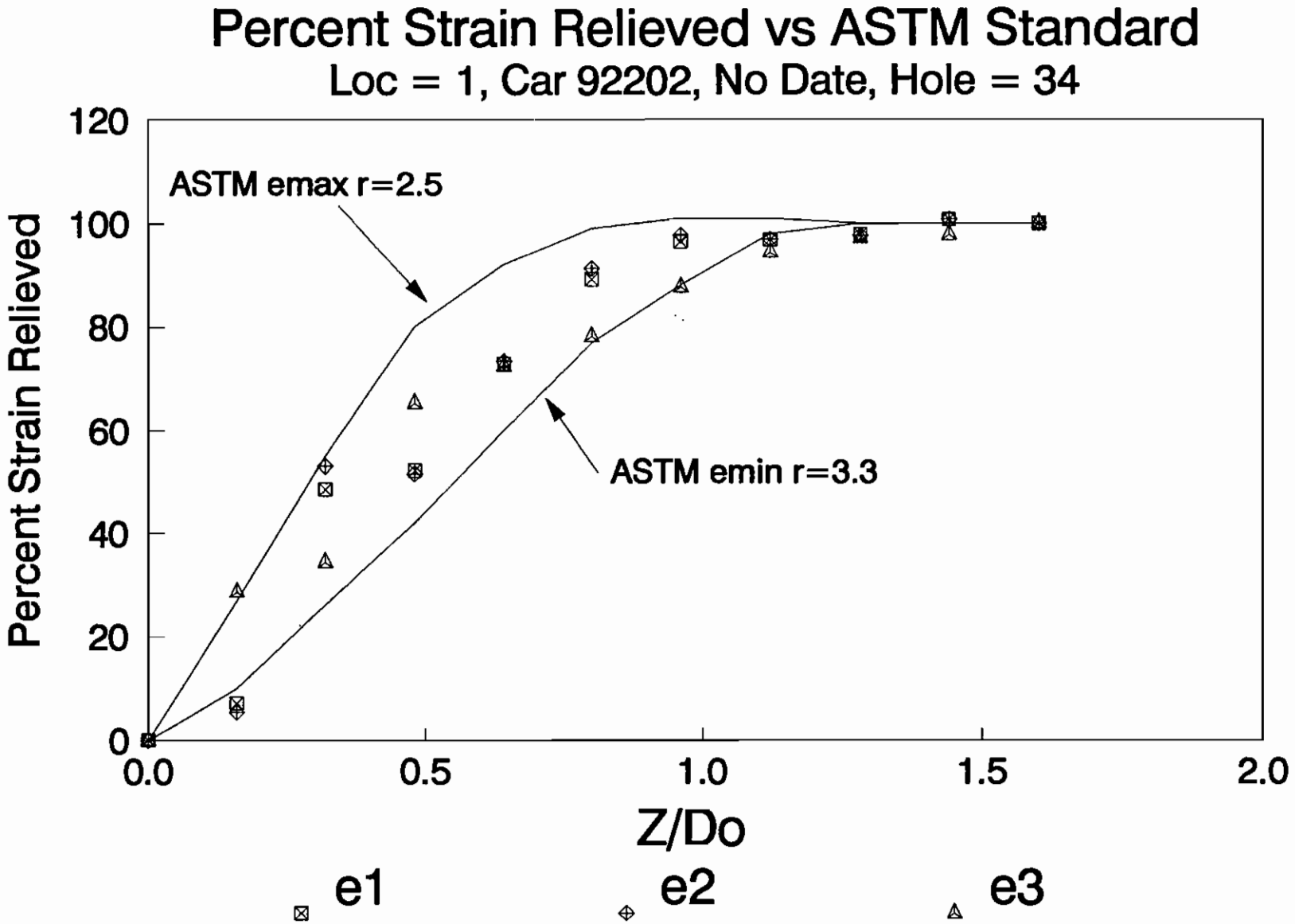
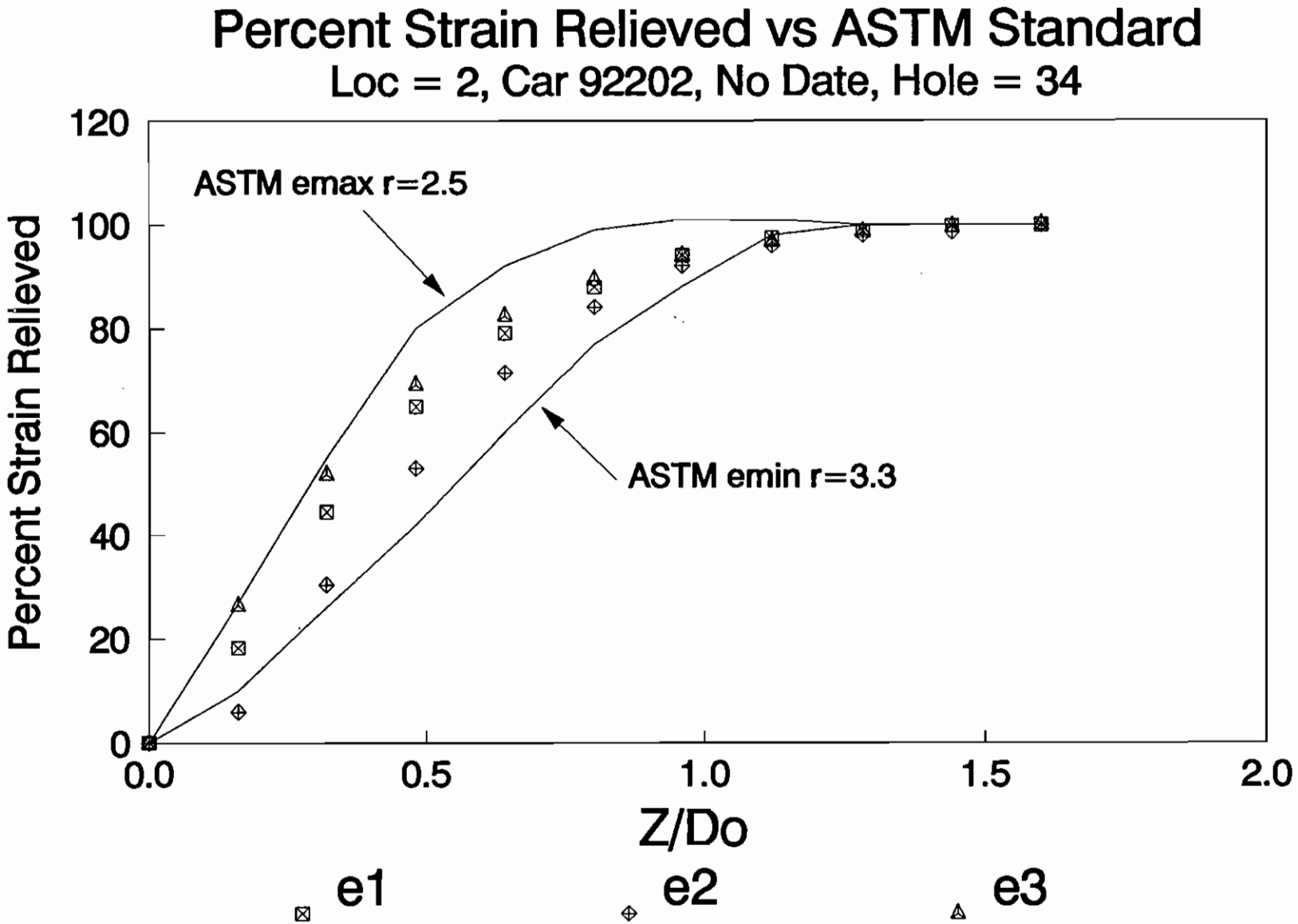


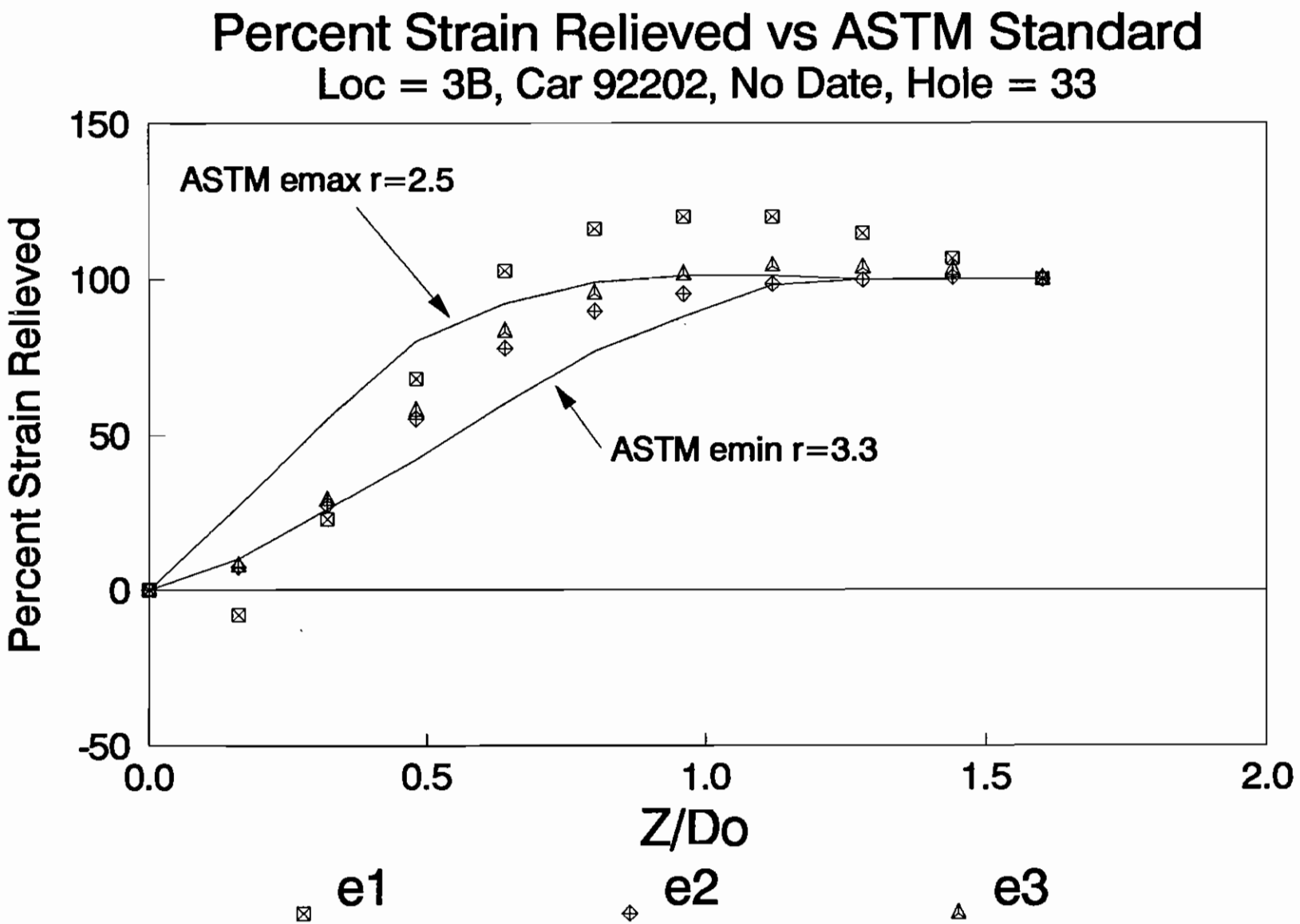
Figure B-46. Principal Stresses Measured at Location 5D on GATX 10360

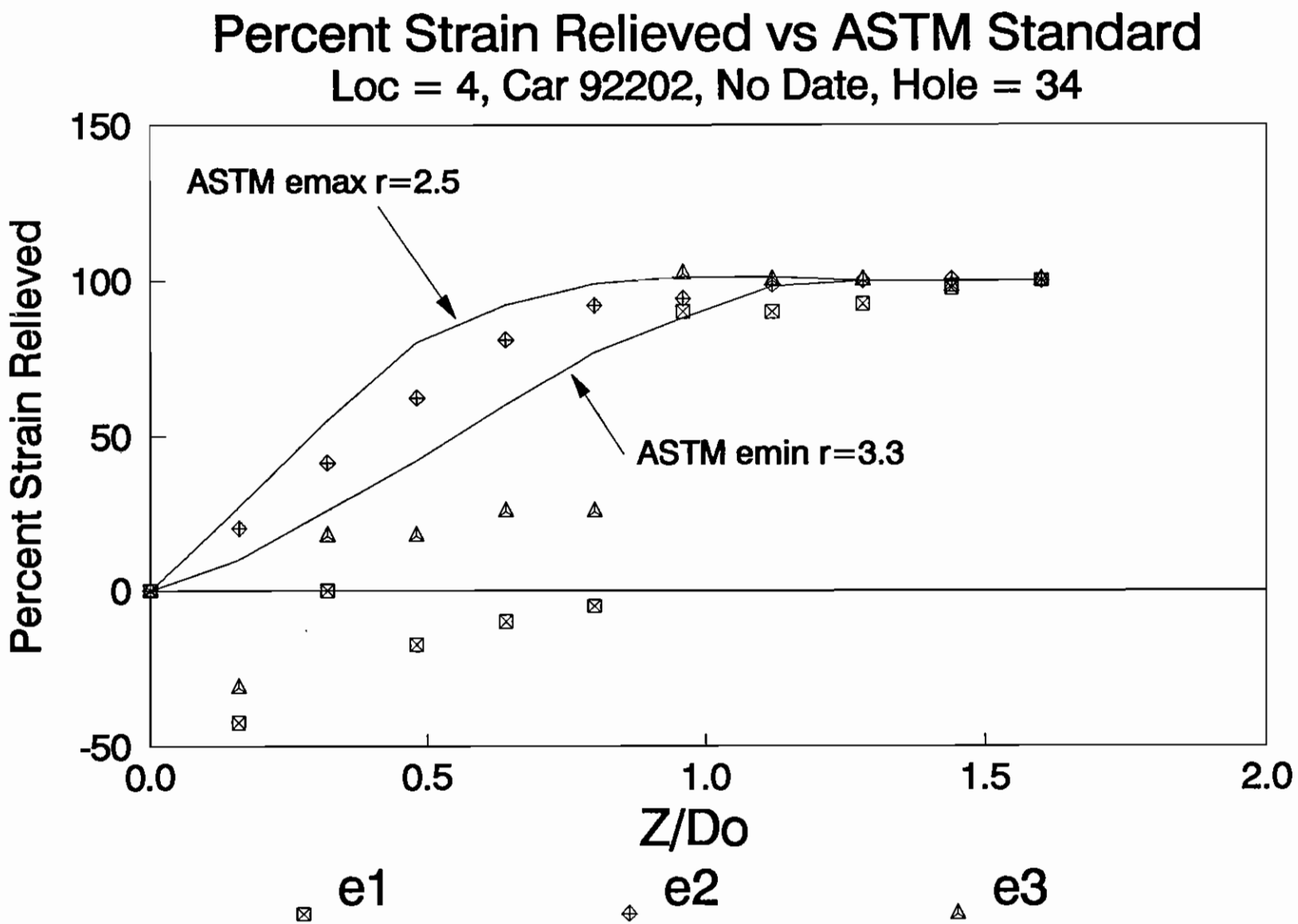
APPENDIX C

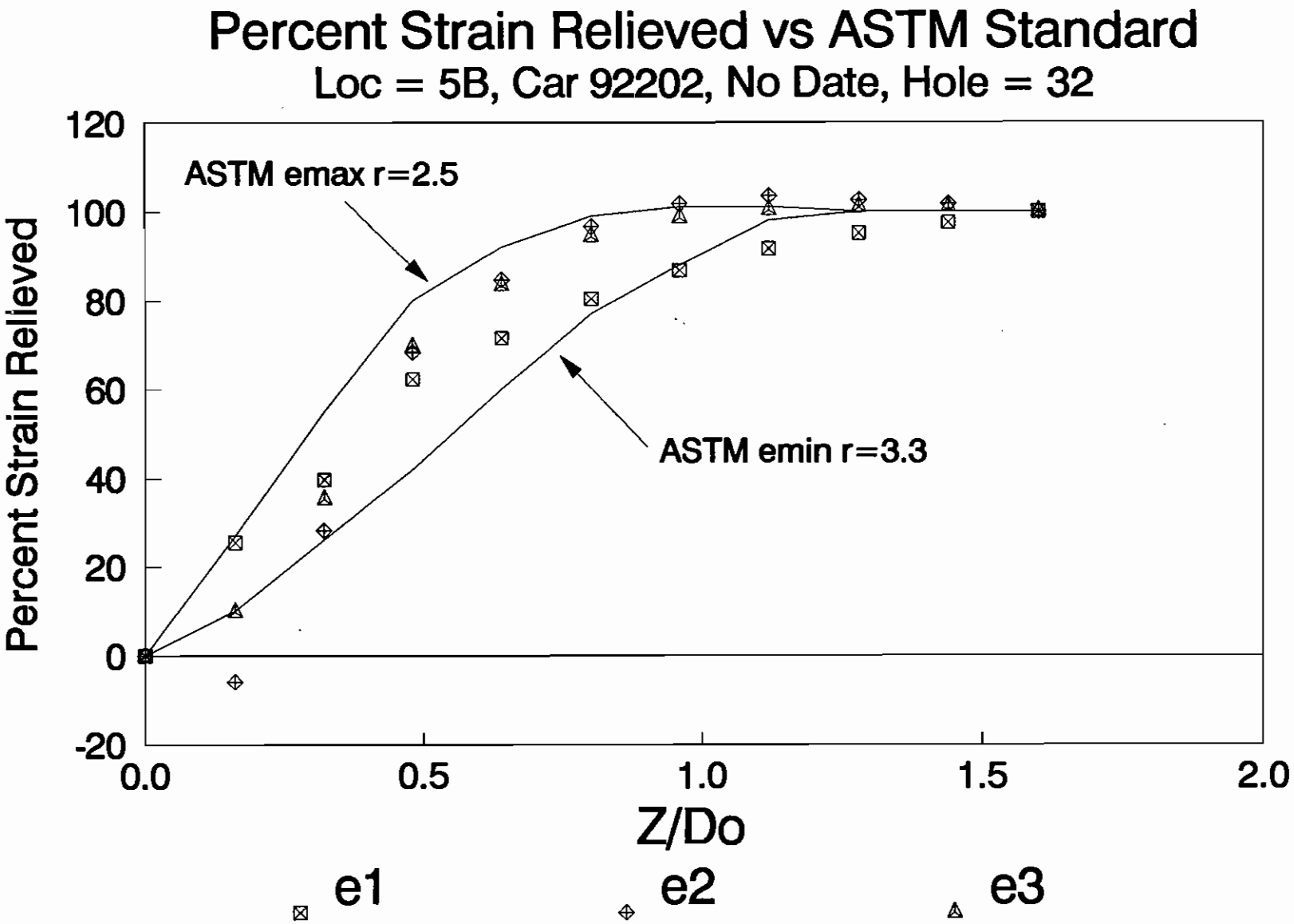
PERCENT STRAIN RELIEVED VS. ASTM STANDARD

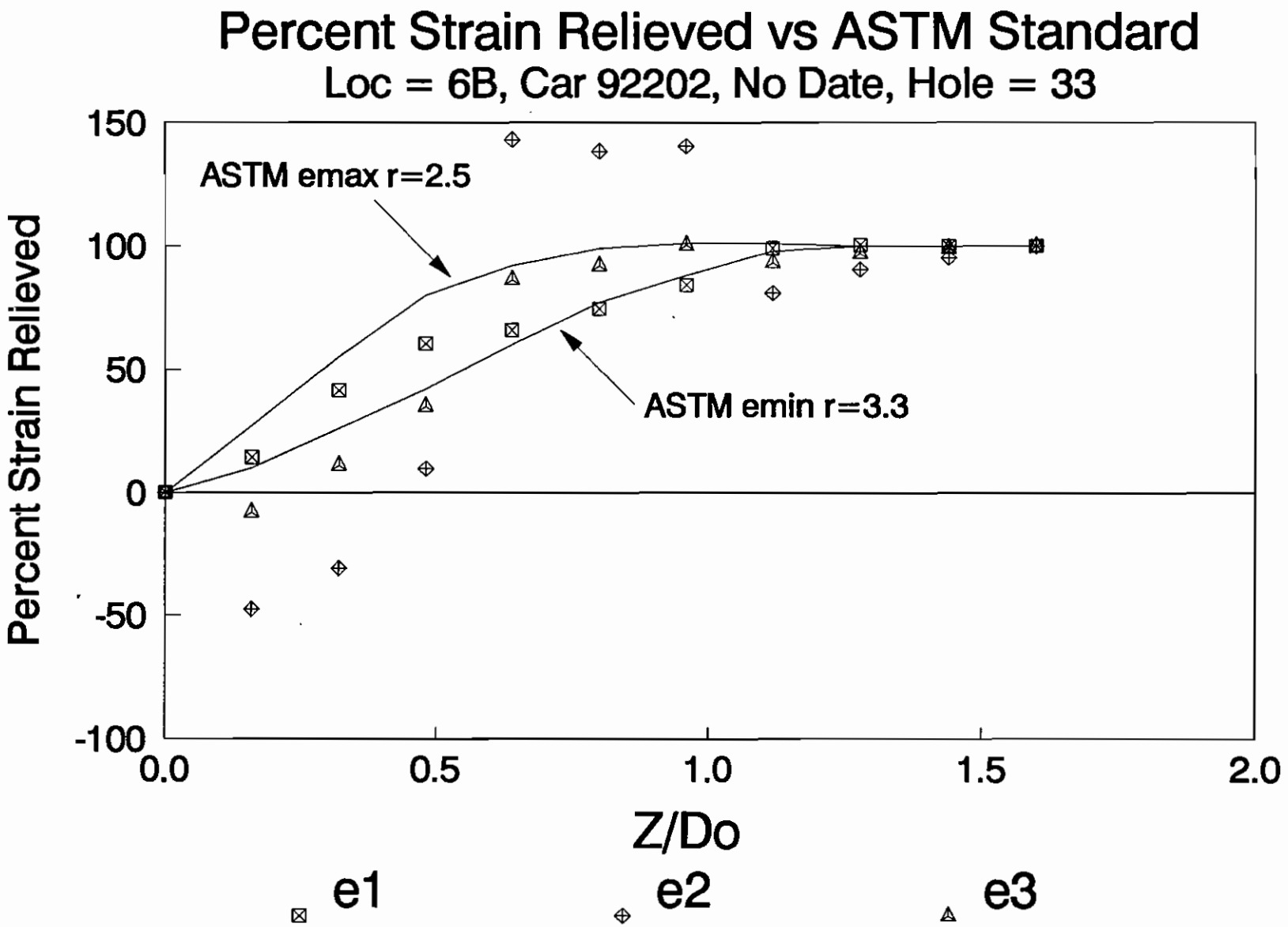

Percent Strain Relieved vs ASTM Standard
Loc = 1, Car 92202, No Date, Hole = 34
Percent Strain Relieved
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

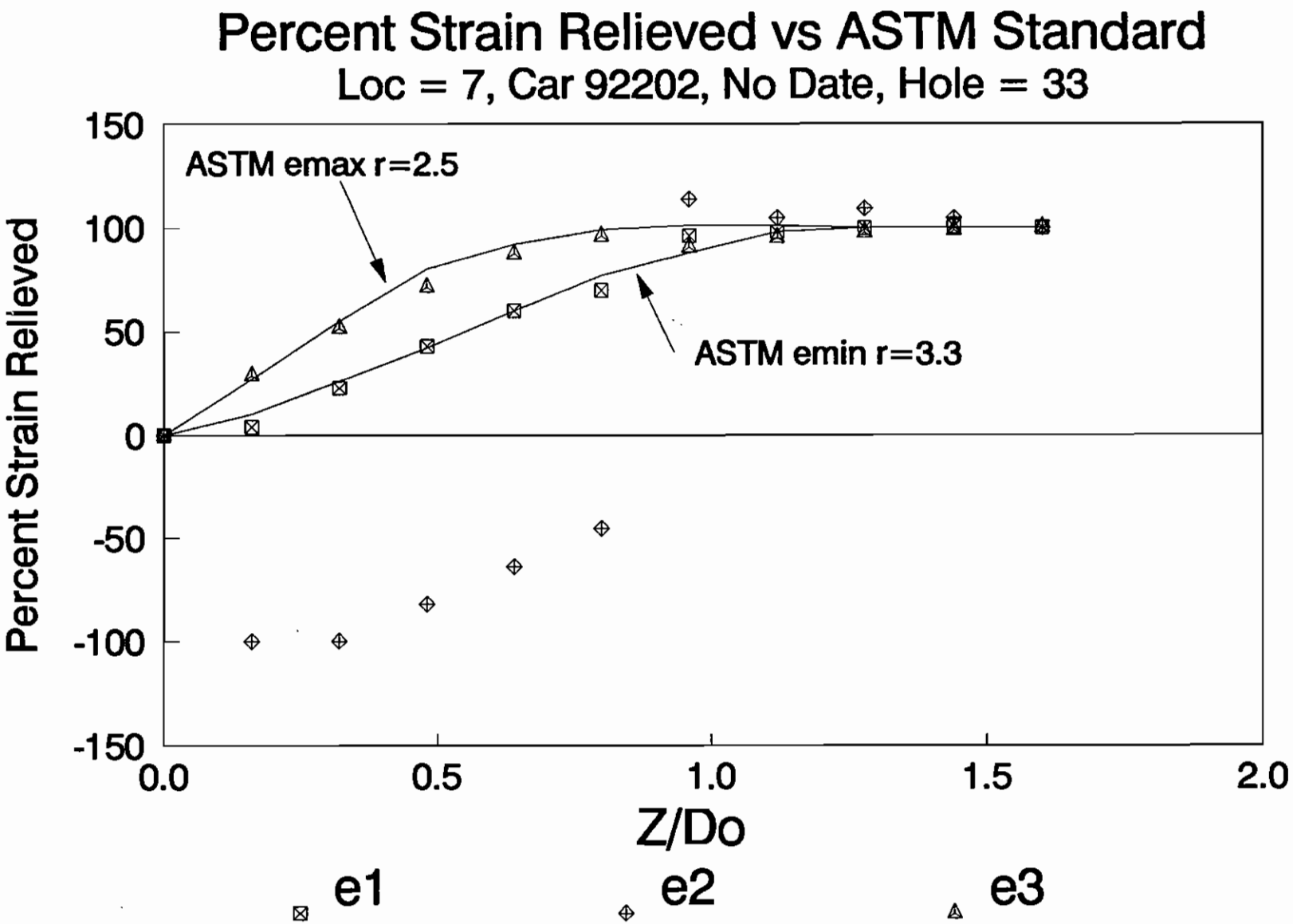

Percent Strain Relieved vs ASTM Standard
Loc = 2, Car 92202, No Date, Hole = 34
Percent Strain Relieved
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

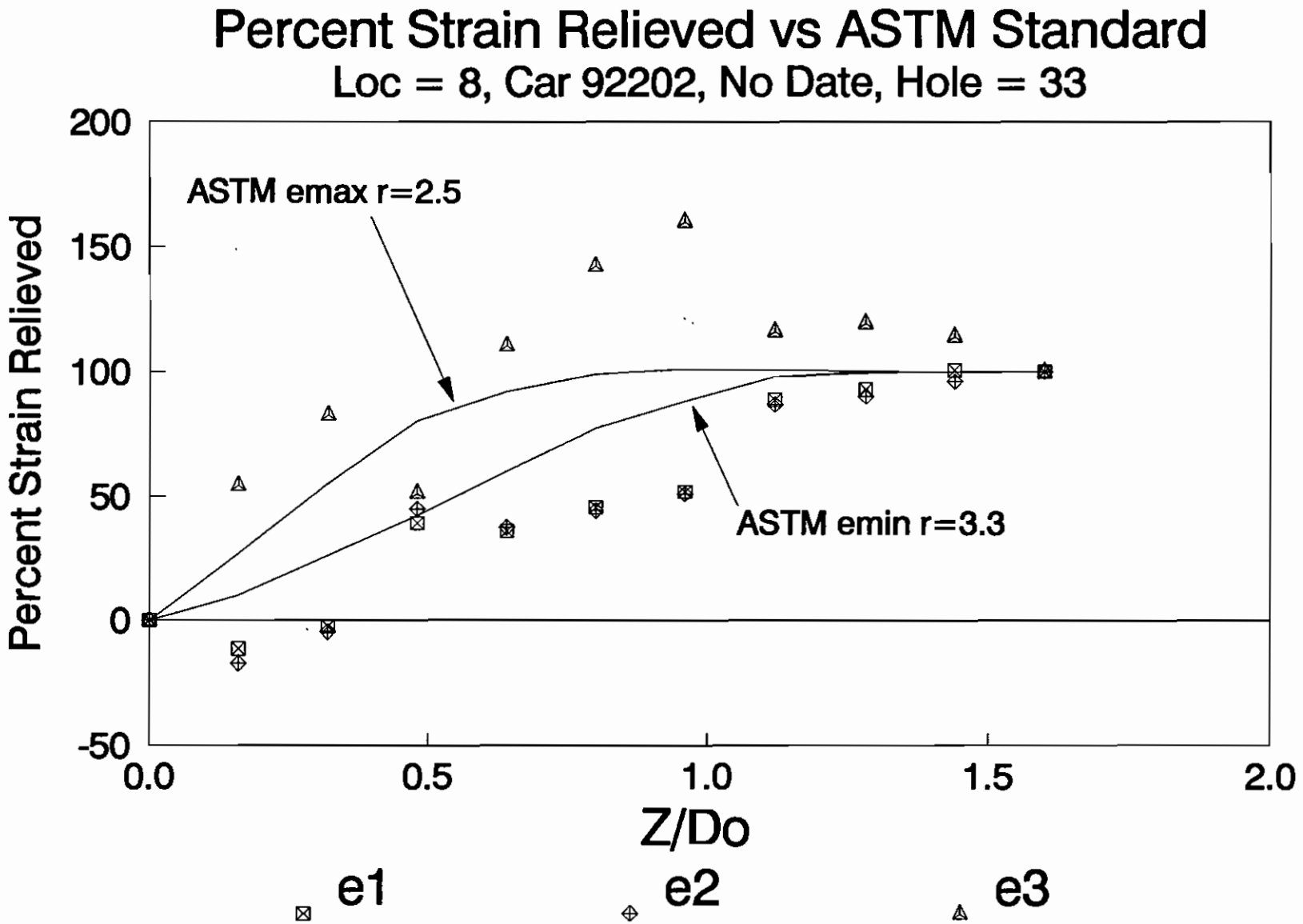

Percent Strain Relieved vs ASTM Standard
Loc = 3B, Car 92202, No Date, Hole = 33
Percent Strain Relieved
150
100
50
0
-50
0.0
0.5
1.0
1.5
2.0
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

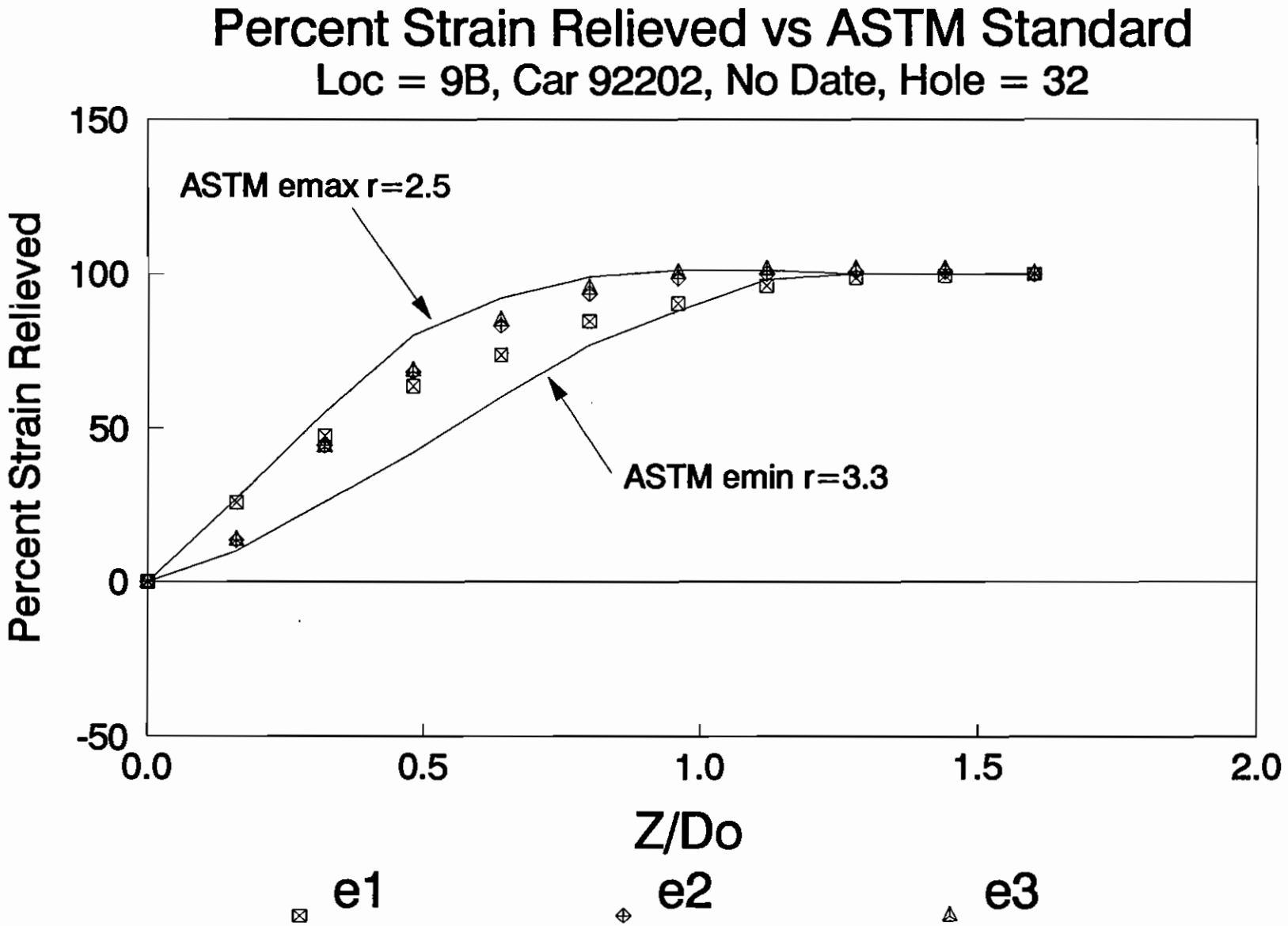

Percent Strain Relieved vs ASTM Standard
Loc = 4, Car 92202, No Date, Hole = 34
Percent Strain Relieved
150
100
50
0
-50
0.0
0.5
1.0
1.5
2.0
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

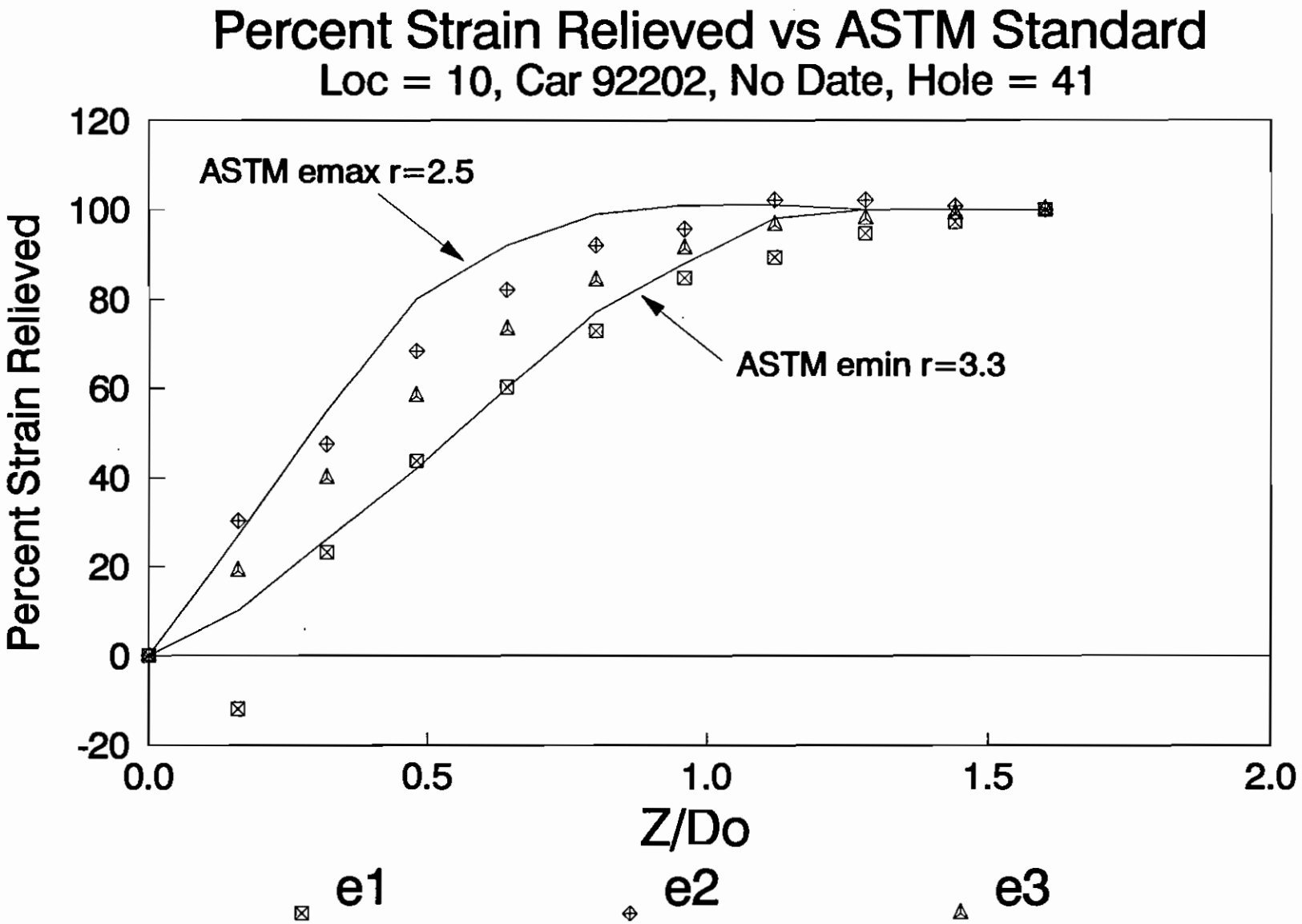

Percent Strain Relieved vs ASTM Standard
Loc = 5B, Car 92202, No Date, Hole = 32
ASTM emax r=2.5
ASTM emin r=3.3
Percent Strain Relieved
120
100
80
60
40
20
0
-20
0.0
0.5
1.0
1.5
2.0
Z/Do
e1
e2
e3

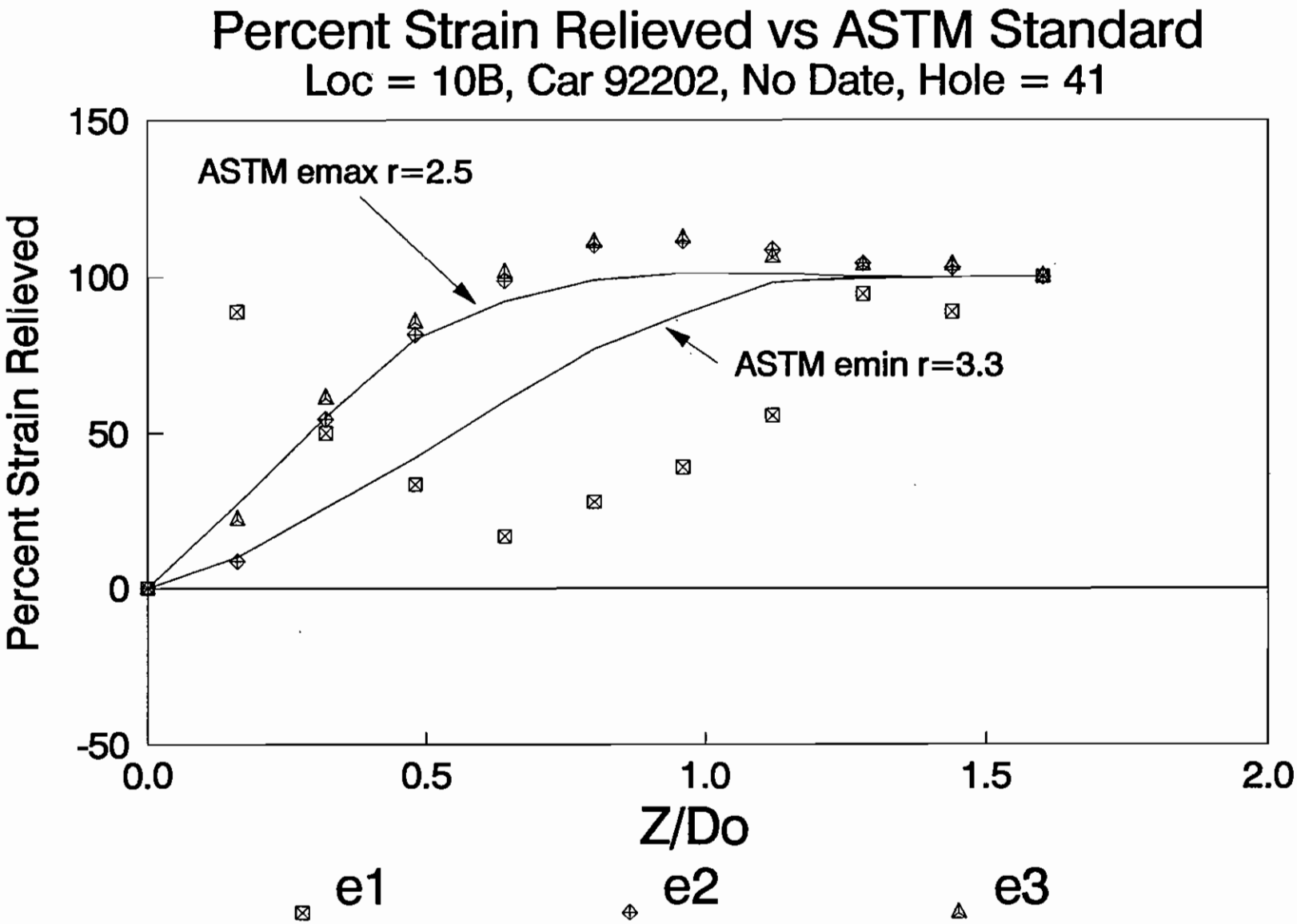

Percent Strain Relieved vs ASTM Standard
Loc = 6B, Car 92202, No Date, Hole = 33
Percent Strain Relieved
150
100
50
0
-50
-100
0.0
0.5
1.0
1.5
2.0
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

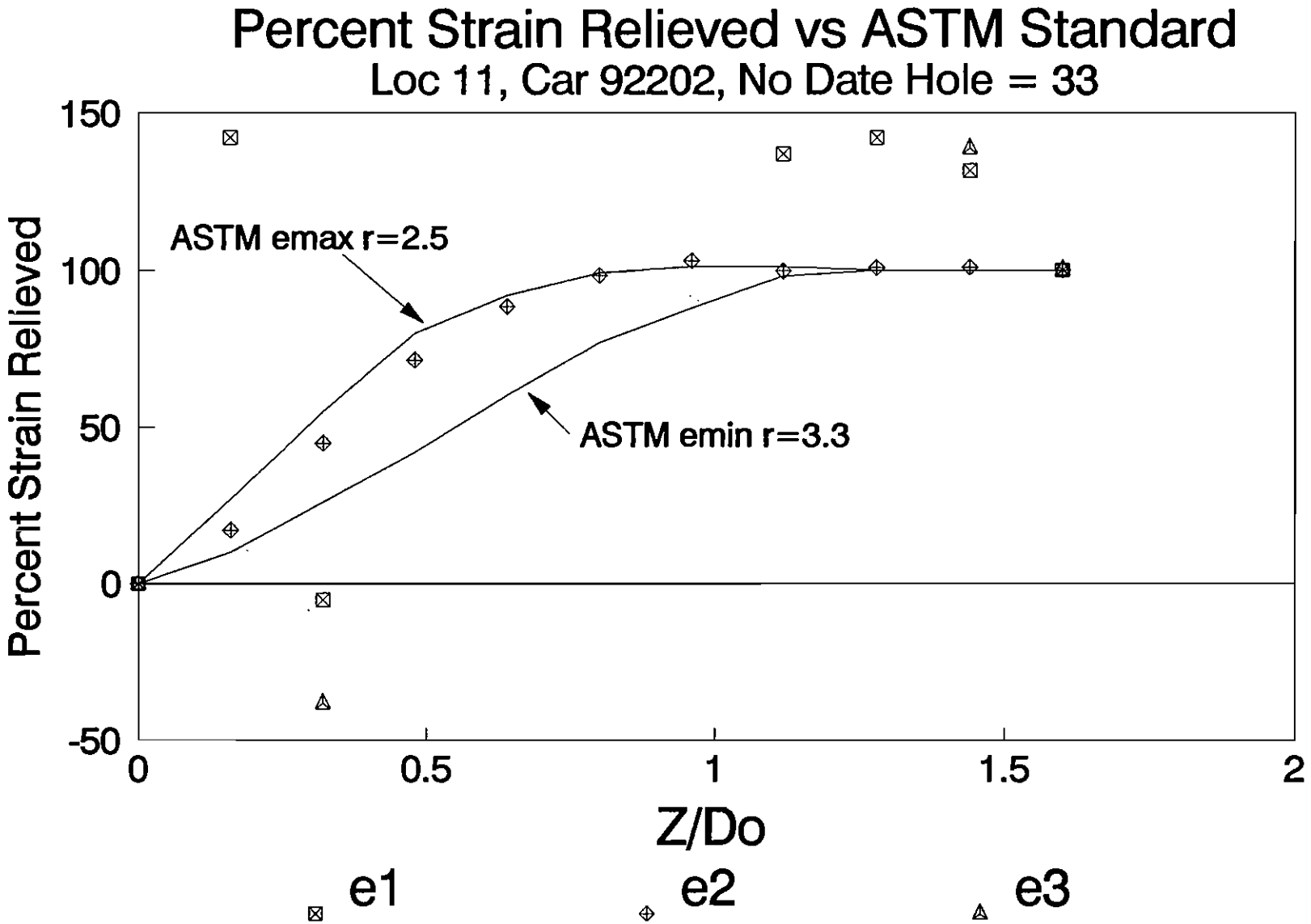

Percent Strain Relieved vs ASTM Standard
Loc = 7, Car 92202, No Date, Hole = 33
ASTM emax r=2.5
ASTM emin r=3.3
Percent Strain Relieved
150
100
50
0
-50
-100
-150
0.0
0.5
1.0
1.5
2.0
Z/Do
e1
e2
e3

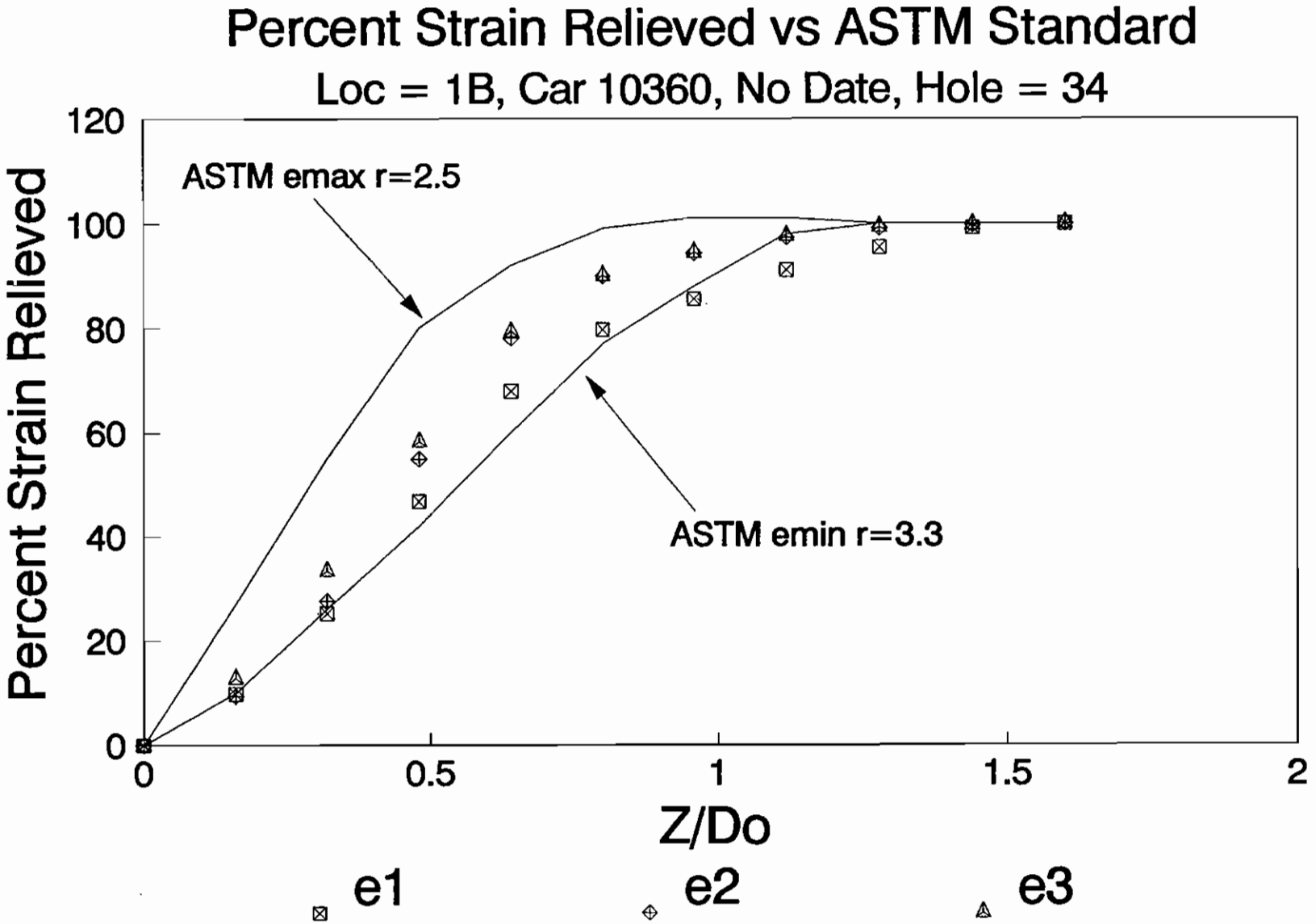

Percent Strain Relieved vs ASTM Standard
Loc = 8, Car 92202, No Date, Hole = 33
Percent Strain Relieved
200
150
100
50
0
-50
0.0
0.5
1.0
1.5
2.0
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

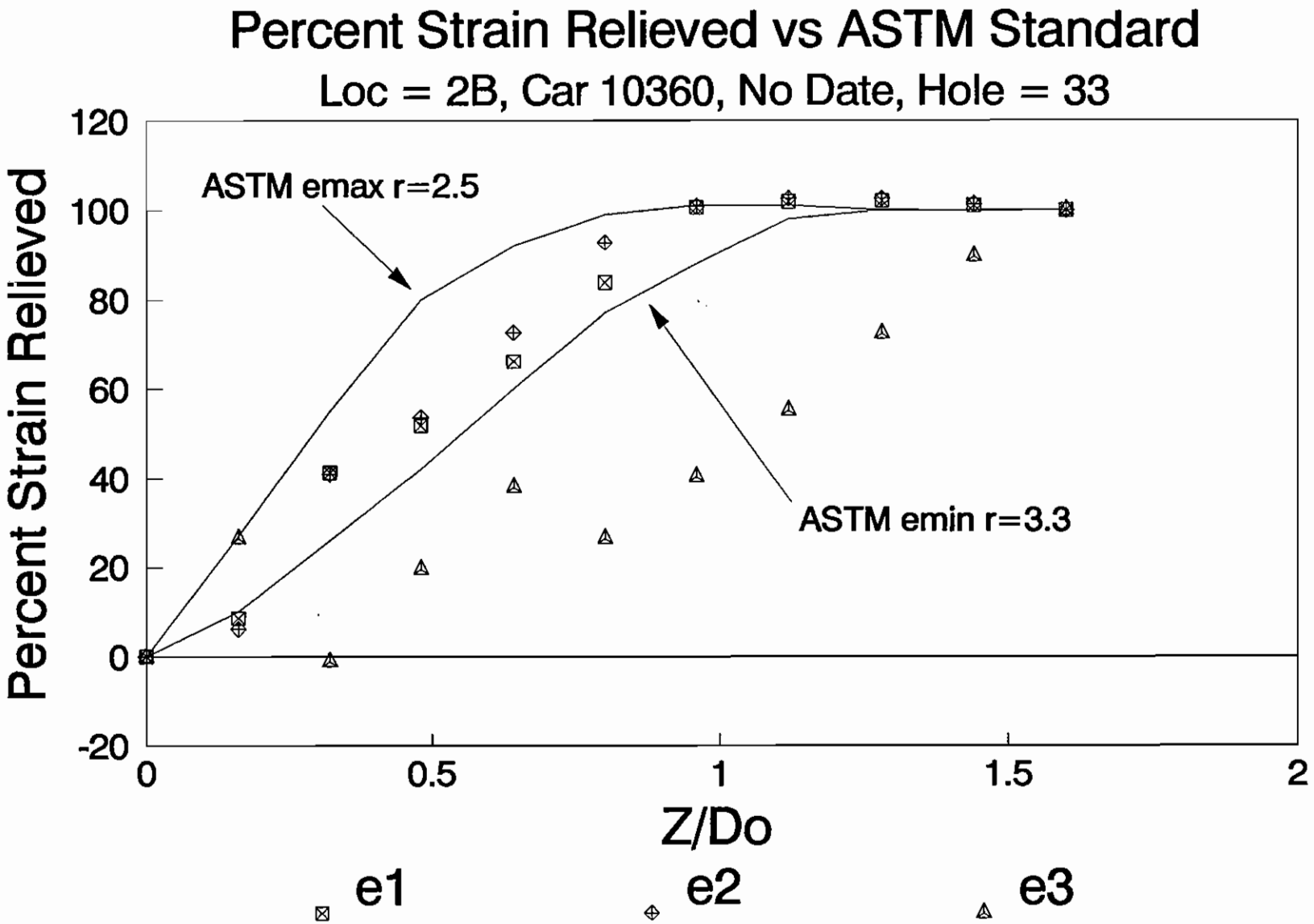

Percent Strain Relieved vs ASTM Standard
Loc = 9B, Car 92202, No Date, Hole = 32
Percent Strain Relieved
150
100
50
0
-50
0.0
0.5
1.0
1.5
2.0
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

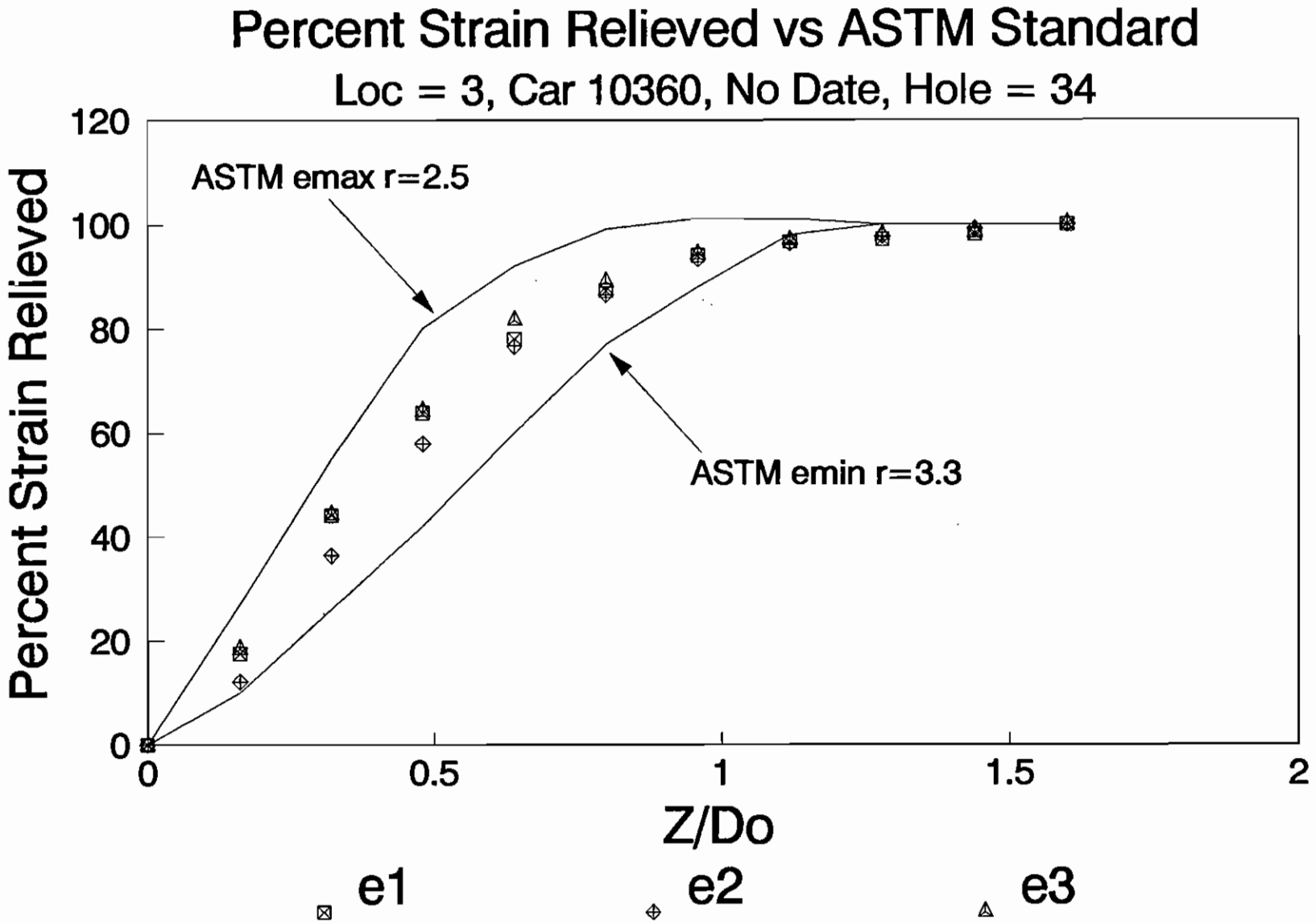

Percent Strain Relieved vs ASTM Standard
Loc = 10, Car 92202, No Date, Hole = 41
Percent Strain Relieved
120
100
80
60
40
20
0
-20
0.0
0.5
1.0
1.5
2.0
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

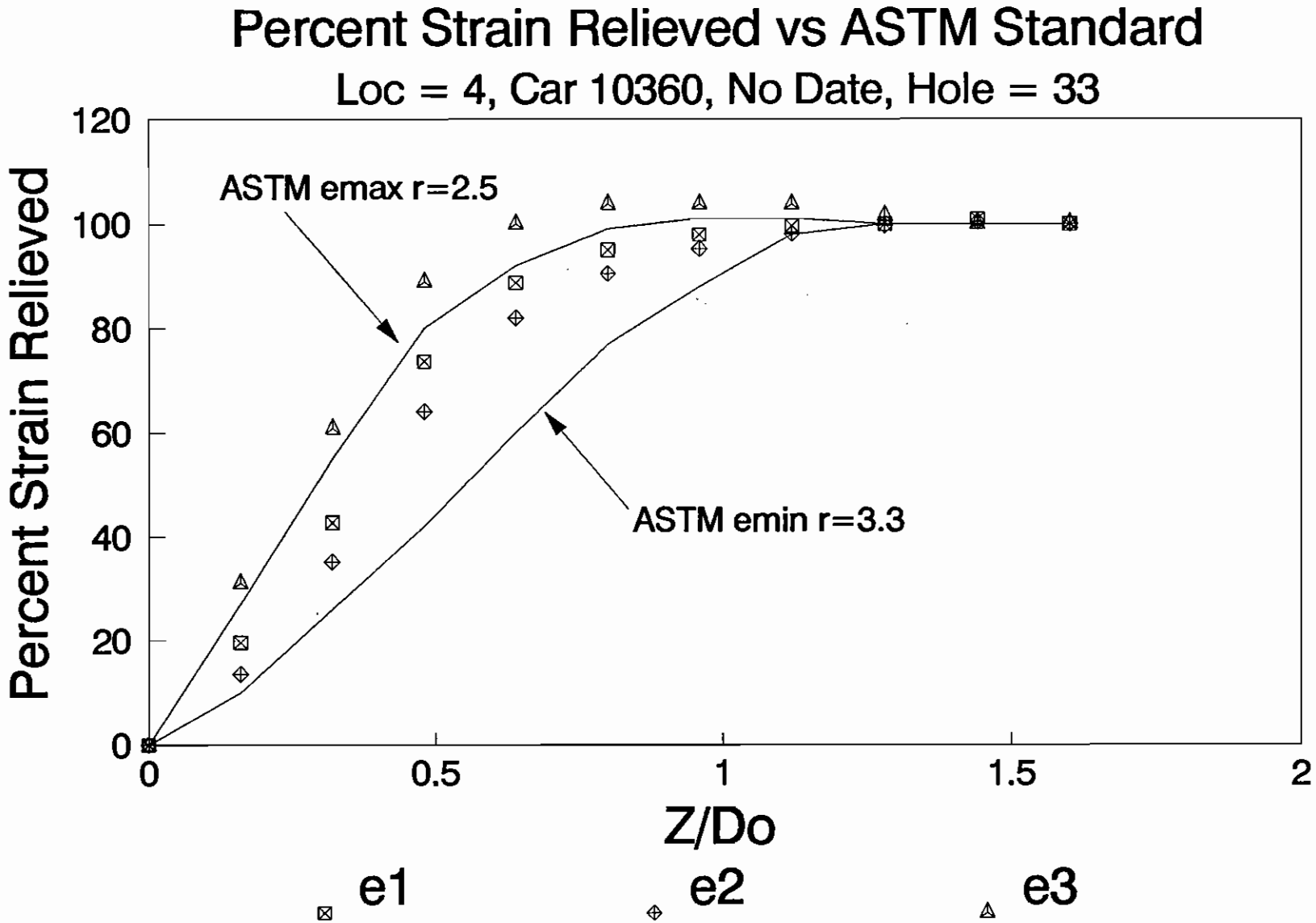

Percent Strain Relieved vs ASTM Standard
Loc = 10B, Car 92202, No Date, Hole = 41
Percent Strain Relieved
150
100
50
0
-50
0.0
0.5
1.0
1.5
2.0
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

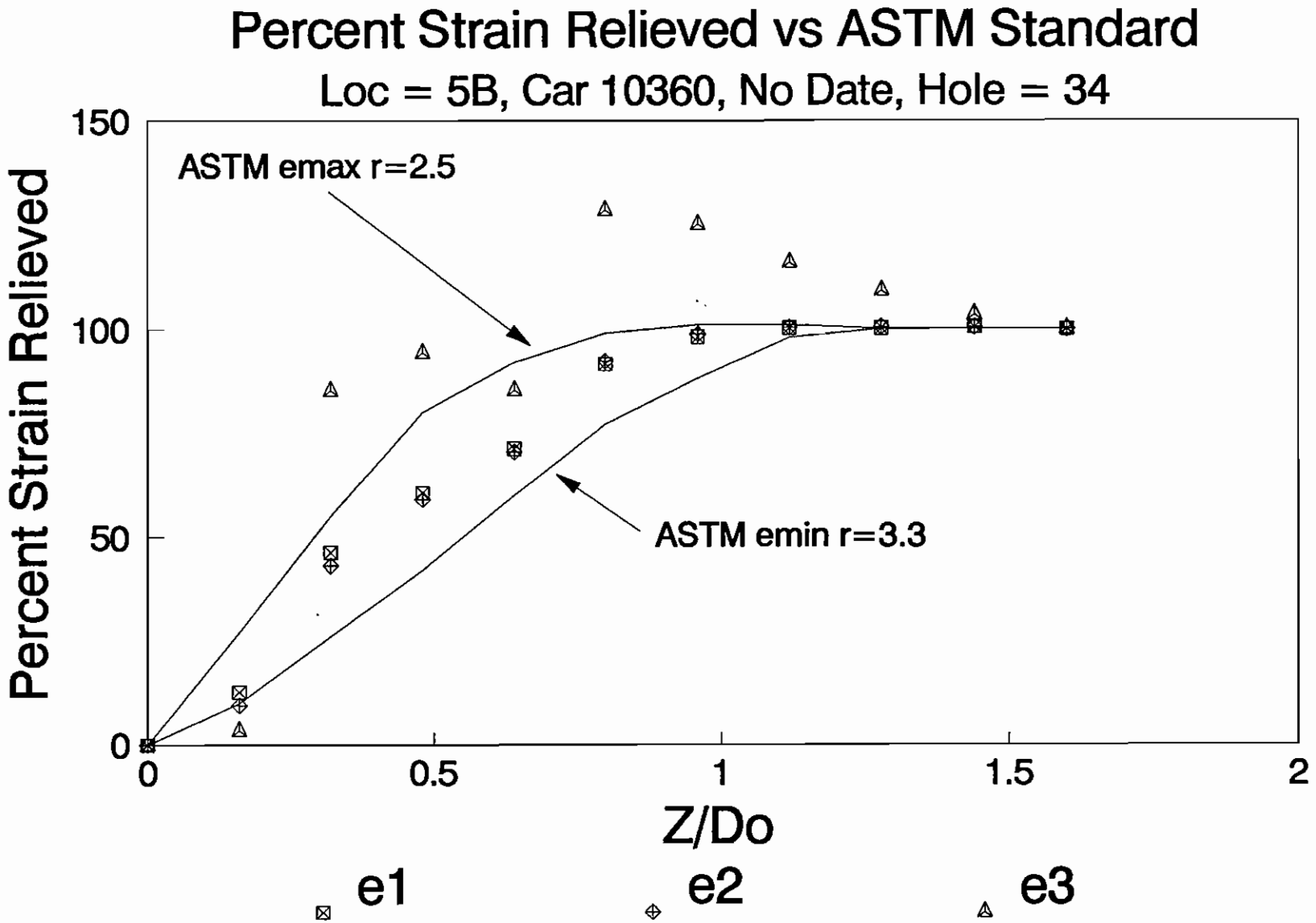

Percent Strain Relieved vs ASTM Standard
Loc 11, Car 92202, No Date Hole = 33
Percent Strain Relieved
150
100
50
0
-50
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3

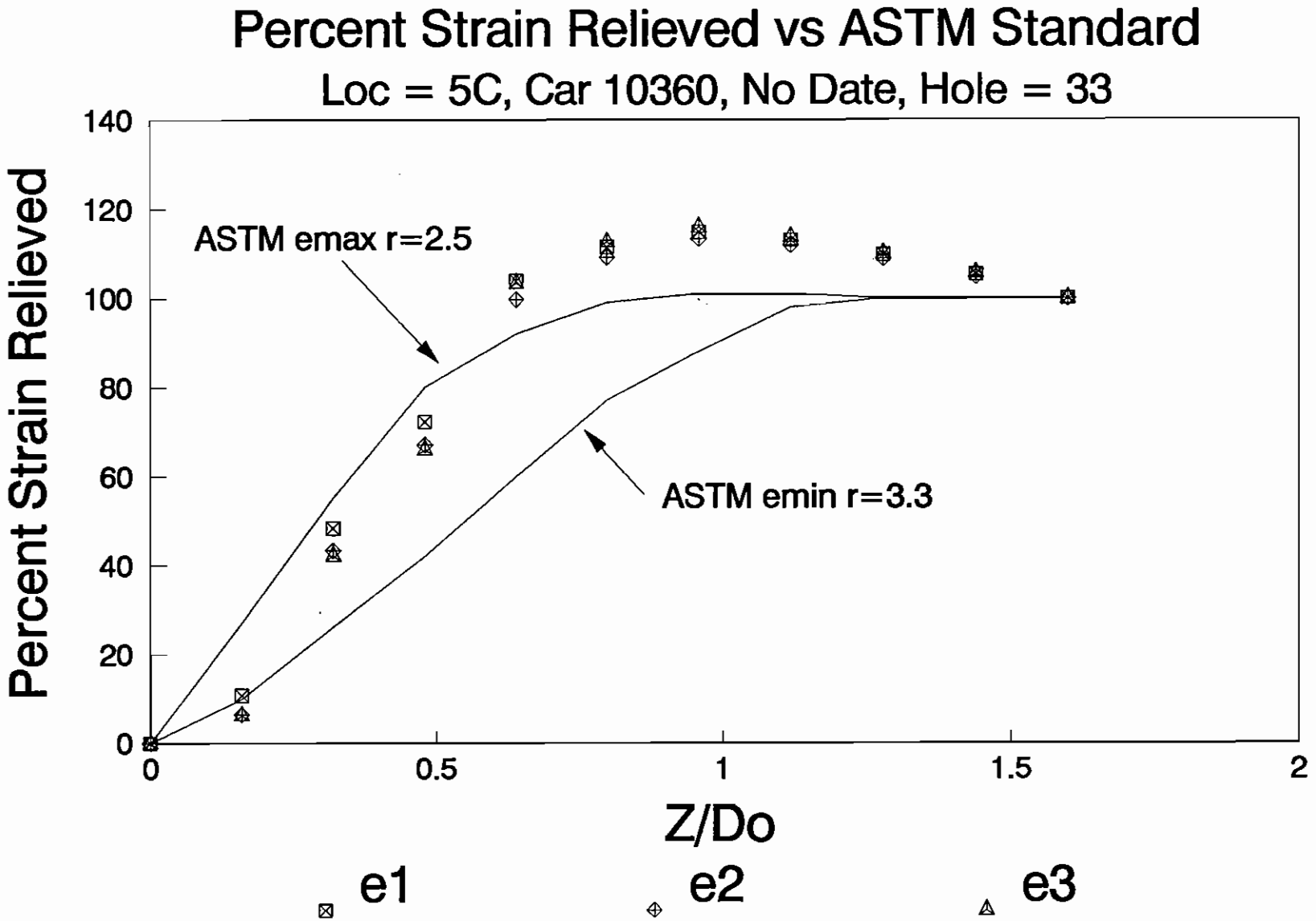

Percent Strain Relieved vs ASTM Standard
Loc = 1B, Car 10360, No Date, Hole = 34
Percent Strain Relieved
120
100
80
60
40
20
0
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3

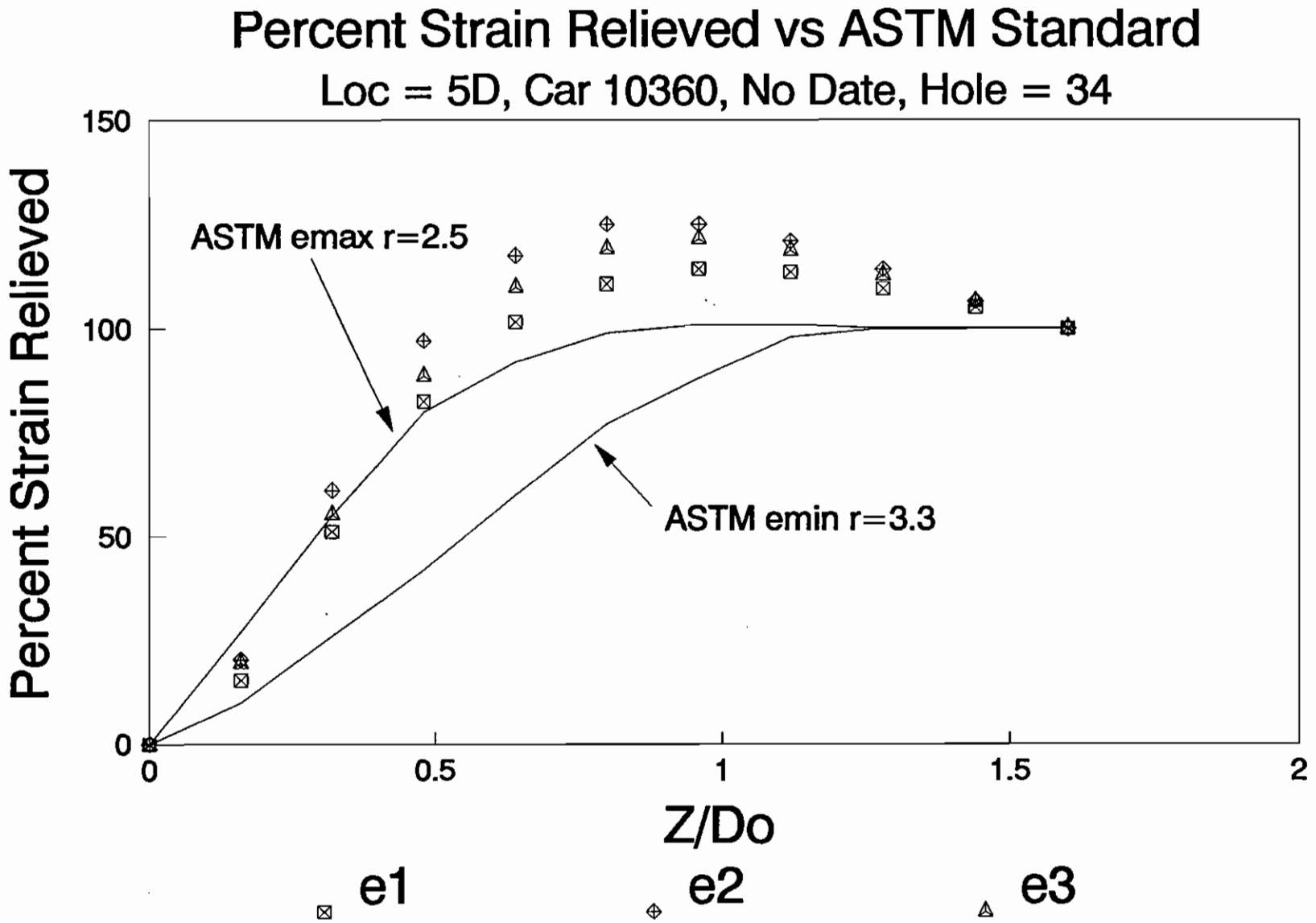

Percent Strain Relieved vs ASTM Standard
Loc = 2B, Car 10360, No Date, Hole = 33
Percent Strain Relieved
120
100
80
60
40
20
0
-20
0
0.5
1
1.5
2
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

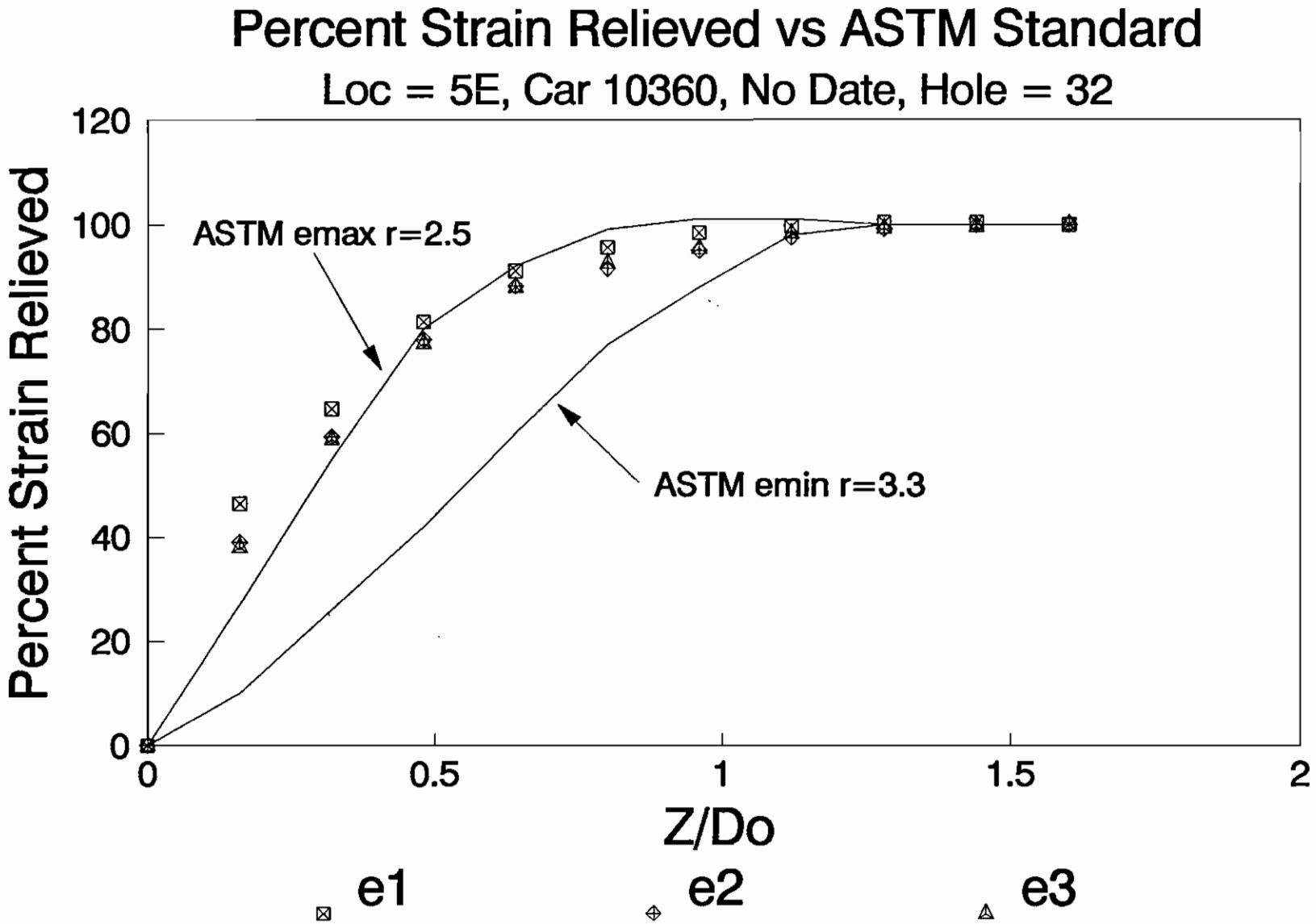

Percent Strain Relieved vs ASTM Standard
Loc = 3, Car 10360, No Date, Hole = 34
Percent Strain Relieved
120
100
80
60
40
20
0
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3

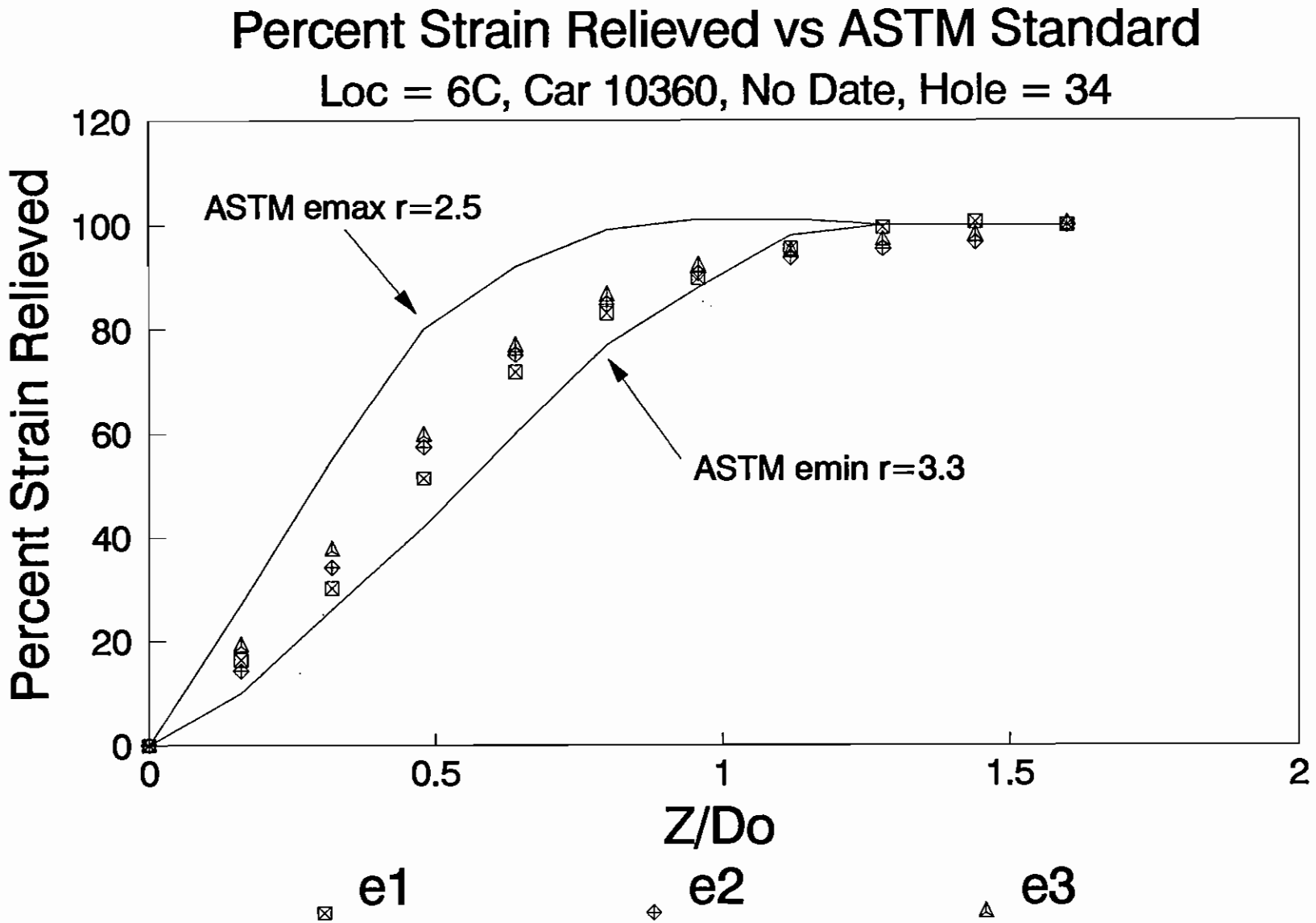

Percent Strain Relieved vs ASTM Standard
Loc = 4, Car 10360, No Date, Hole = 33
Percent Strain Relieved
120
100
80
60
40
20
0
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3

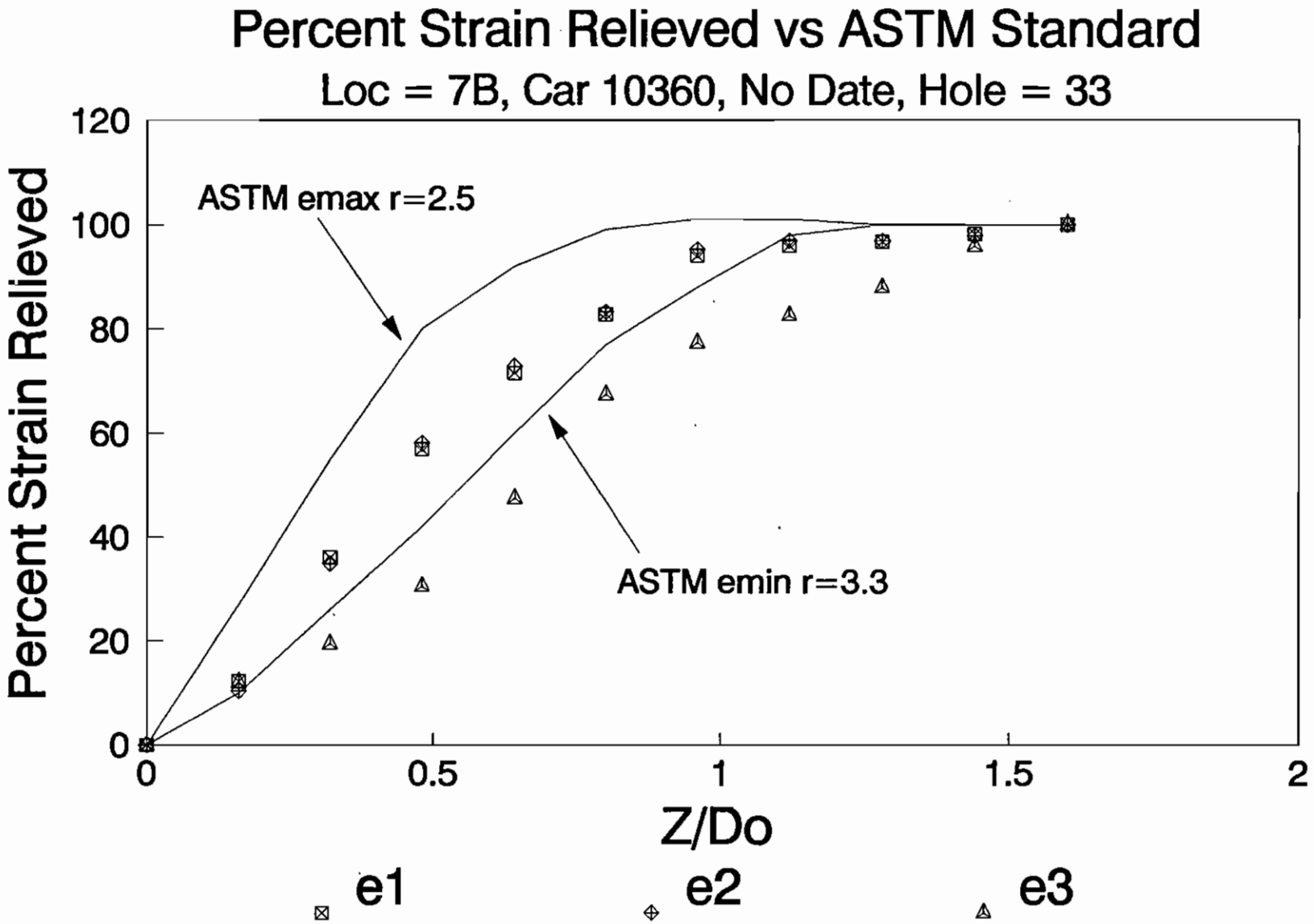

Percent Strain Relieved vs ASTM Standard
Loc = 5B, Car 10360, No Date, Hole = 34
Percent Strain Relieved
150
100
50
0
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3

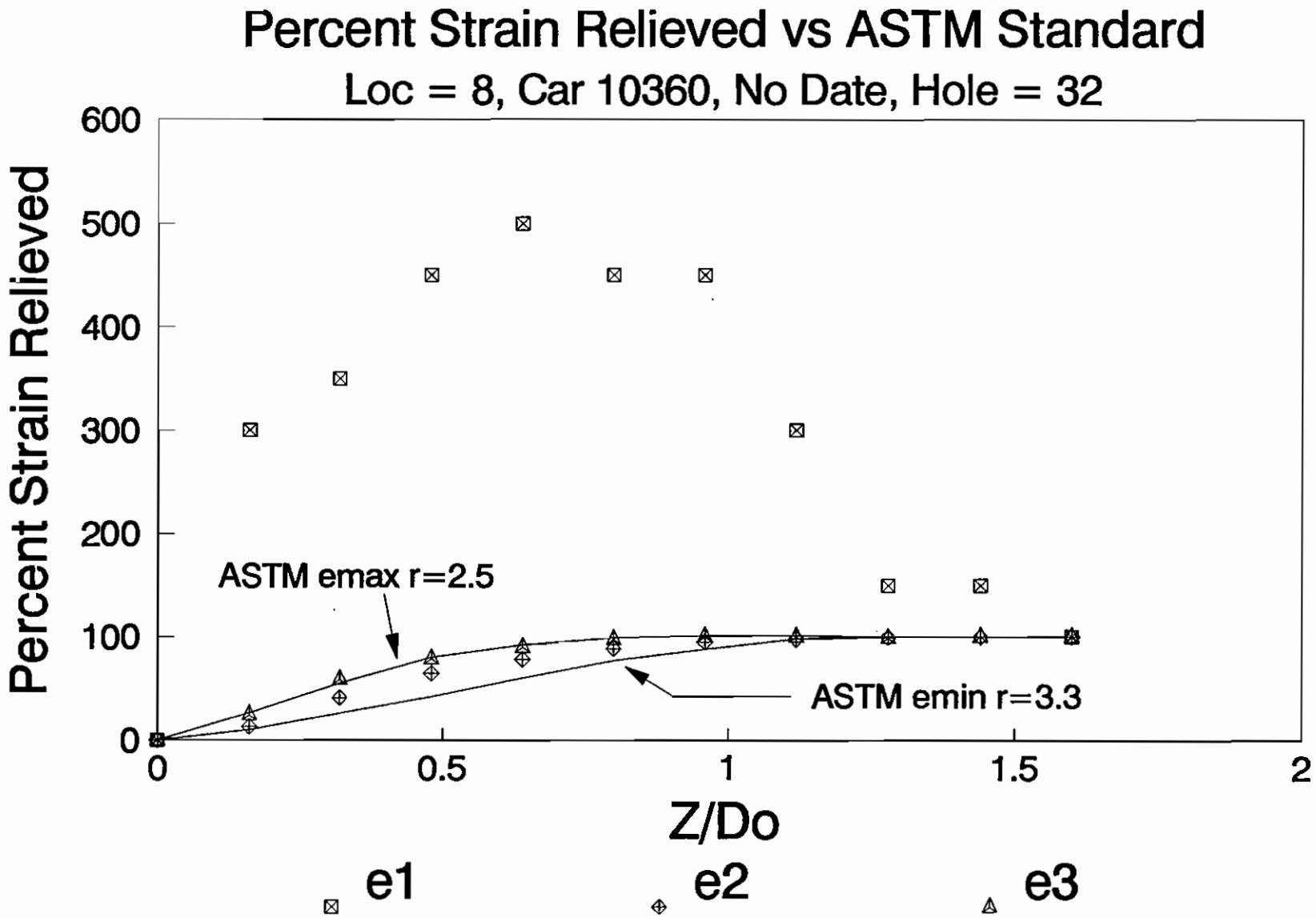

Percent Strain Relieved vs ASTM Standard
Loc = 5C, Car 10360, No Date, Hole = 33
Percent Strain Relieved
140
120
100
80
60
40
20
0
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3


Percent Strain Relieved vs ASTM Standard
Loc = 5D, Car 10360, No Date, Hole = 34
Percent Strain Relieved
150
100
50
0
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3


Percent Strain Relieved vs ASTM Standard
Loc = 5E, Car 10360, No Date, Hole = 32
Percent Strain Relieved
120
100
80
60
40
20
0
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3


Percent Strain Relieved vs ASTM Standard
Loc = 6C, Car 10360, No Date, Hole = 34
Percent Strain Relieved
120
100
80
60
40
20
0
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3


Percent Strain Relieved vs ASTM Standard
Loc = 7B, Car 10360, No Date, Hole = 33
Percent Strain Relieved
120
100
80
60
40
20
0
ASTM emax r=2.5
ASTM emin r=3.3
0
0.5
1
1.5
2
Z/Do
e1
e2
e3


Percent Strain Relieved vs ASTM Standard
Loc = 8, Car 10360, No Date, Hole = 32
Percent Strain Relieved
600
500
400
300
200
100
0
0
0.5
1
1.5
2
Z/Do
ASTM emax r=2.5
ASTM emin r=3.3
e1
e2
e3

Mr. Edward R. Walsh
Manager, Contracts & Procurement
AAR, Research and Test Department
Pueblo, Colorado 81001

Dear Mr. Walsh:

Reference: Contract DTFR53-82-C-00282, Task Order No. 31, Modification No. 2

Please find our comments to your draft report on subject Task Order titled, "Residual Stress Measurements of Retrofitted Tank Car Weldments".

A "METRIC CONVERSION FACTORS" chart similar to that contained in AAR/TTC Report No. 87-112,113, titled "ALUMINUM/COLD TEMPERATURE TANK CAR PUNCTURE RESISTANCE TESTS - DATA REPORT" dated January 1991 is needed.

Generally, the report should be expanded to contain at least all of the following. Some suggested wording is in the enclosed copy of the draft report.

* The "OBJECTIVE", "PROCEDURES", "DISCUSSION" and "CONCLUSIONS" should be expanded. Report in its present form is sketchy, at most, as it does not explain the purpose of the test.

* Appendix C is titled "Percent Strain relieved vs. ASTM Standard, but the charts do not show ASTM Standard curves against which to compare test results.

Other improvements to the Report to make the report more readable and useful are needed. Please make the necessary changes and submit another draft report for our review.

Sincerely,

WILLIAM R. PAXTON

enclosure:

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Manager, Contracts & Procurement
AAR, Research and Test Department
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