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Evaluation of the Use of Shredded Tires Around Buried Pipes

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Evaluation of the Use of Shredded Tires Around Buried Pipes

Technical Assistance Report Number 19

by

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INTRODUCTION

The use of waste tires in highway construction presents an economically beneficial solution for the reuse of a large volume of tires that are discarded annually in waste sites. Several uses for scrap tires have been proposed in the past and put into practice in various highway applications. Waste tires were mainly used in asphalt pavement mix as crumb rubber additive, and as lightweight fills in embankment. Studies have also been done on the use of whole tires as reinforcing mats in slopes and walls [*1,2*]. Many states have experimentally incorporated or studied the use of rubber tires in these applications. A survey of the use of waste tires by several states [*1*] showed varied experience with regard to the economical advantages and performance of such systems.

The objective of this project was to assess the potential of placement and compaction of shredded tire chips and soil-tire mix in confined trenches around buried pipes and to evaluate the stability and deformation of metal pipes in such systems. The methodology used for this purpose was to construct a full-scale test section with tire chips as fill around buried steel pipe. Soil deformation around the pipe was monitored and compared with other test sections constructed with soil only and with soil-tire mix as fill material. A laboratory-testing program was conducted to evaluate the deformation of the metal pipe embedded in tire chips and soil-tire mix when subjected to various vertical loading levels. This report presents a summary of the experimental work and the conclusions based on the construction procedure of the test sections, field monitoring, and the laboratory-testing program.

The laboratory tests conducted to define the engineering properties of the tire chips and the soil-tire mix are presented in chapter 1. Details of the construction and instrumentation of the test sections are presented in chapter 2. The results of the field monitoring program are discussed in chapter 3. Chapter 4 presents the experimental tests on the pipe in the laboratory.

METHODOLOGY

The applicability of using tire chips around buried drainage metal pipes was investigated through a field monitoring program and laboratory tests. The field work consisted of the construction of three full-scale test sections. Each section had a corrugated metal pipe with a 1.35 m (54 in.) diameter and 12 m (40 feet) long. The pipes were buried inside various backfill materials. One section was constructed using tire chips only as a backfill around the buried pipe. The second section contained a mix of soil and tire chips with a ratio of one-to-one by volume. The third section was constructed using compacted silty-clay soil fill. An embankment of silty-clay soil was built on the top of each of the three sections in order to apply overburden pressure. The embankment had an initial height of two meters (7 ft) above the pipe and it was later increased to a height of four meters (14 ft). Field instrumentation consisted of installing settlement plates on the top and bottom of each backfill in order to evaluate the settlement of the fill material under the applied load. Strains in the metal pipe were measured using strain gages installed in each section. Soil deformation around the pipe was monitored using vertical and horizontal inclinometers placed in the fill. The monitoring of the strain gages and the inclinometers continued for the period of one year after the construction of the test embankment.

The experimental program in the laboratory consisted of applying vertical loads on the metal pipe with no backfill material, with tire chips backfill, and in the soil-tire mix. The objective of these tests was to investigate the changes of the strains in the pipe cross section at these conditions. The laboratory tests were conducted on a corrugated metal pipe of 1.35 m (54 in.) diameter and 0.6 m (2 ft) long. The pipe was placed inside a large box 2.6 m (8.5 ft) long, 1.6 m (5.5 ft) high, and 0.6 m (2 ft) wide. A hydraulic loading frame applied incremental vertical load on the top of the pipe. Vertical deformation of the pipe was monitored using an LVDT (Linear Variable Differential Transducer) placed on the loading frame. Strains in the pipe at various locations at the cross section were measured using strain gages.

CHAPTER 1

CHARACTERIZATION OF TIRE CHIPS AND SOIL-TIRE MIX

A. Tire Chips Properties

The shredded tire material was processed using scrap tires taken from within the State of Louisiana. The shredded tires were supplied in accordance with the construction specifications that limited the maximum size of the chips in any direction to be less than 150 mm (6 inches) with a minimum of 60 percent being less than 75 mm (3 inches). It was also required that a minimum of 90 percent of the tire chips had exposed wires less than 12 mm (½ inches). The size of the tire chips is usually dictated by the design of the shredding machine. Most of the currently used machines utilize shearing process that produces fairly uniform pieces of tires with minimum pull of the reinforcing wire [*3*].

The dry density of the tire chips typically averages from 0.3 to 0.6 t/m3 (20 to 38 pcf) [*3*]. A much narrower density range from 0.62 to 0.64 t/m3 (38.6 to 40 pcf) was reported in the literature [*4*]. The narrow range of density shows that it is not highly dependent on chip size and compaction effort. The specific gravity of the tire has a typical average value of 1.2. No experimental work was conducted to specify these parameters for the tire chips in this project.

Shear strength is the design parameter that characterizes the tire chips when used as fill in embankments and slopes. In order to determine the shear strength properties of the tire chips, direct shear tests were conducted in a large direct shear box. The direct shear test apparatus consisted of two boxes, each with a 300 mm (12 inches) by 300 mm interface shear area. The boxes were 75 mm (3 inches) high with the lower box connected to the shear loading system. Figure 1 shows a view of the large direct shear testing equipment. The vertical pressure and the shear load were applied on the specimen by means of controlled hydraulic system. Tests were performed on the specimen at a shearing rate of .25 mm/min (0.01 in./min).

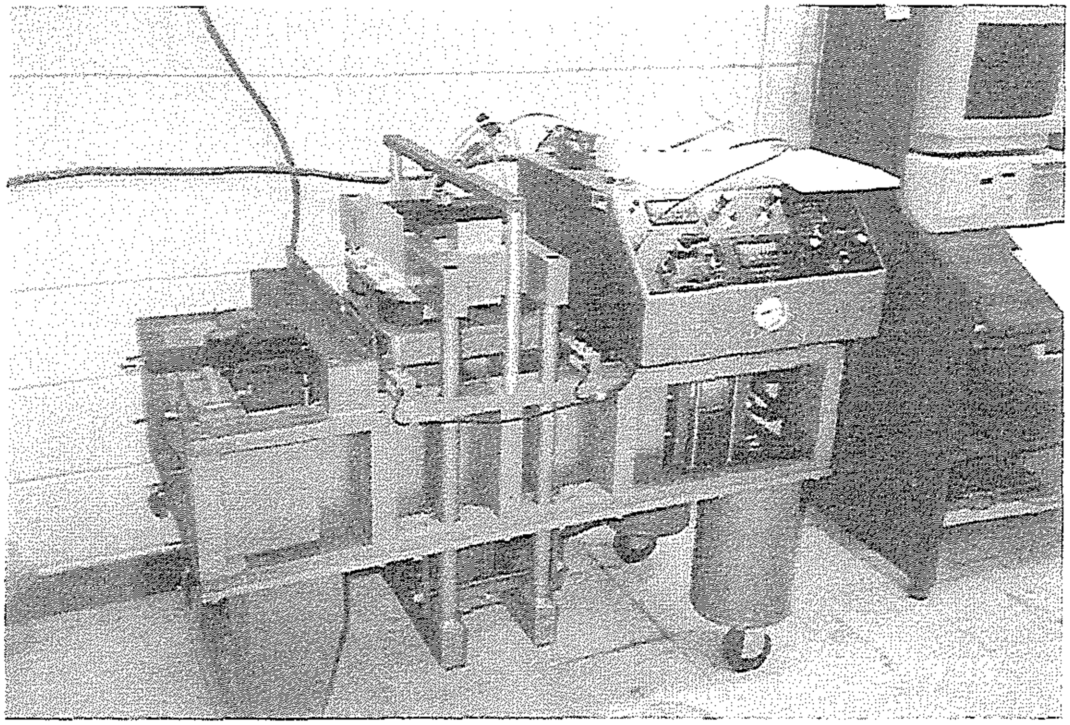


Figure 1. View of the large direct shear testing apparatus

The results of direct shear tests on the tire chips are shown in figure 2. Detailed figures of the direct shear test results are shown in appendix A. The results show a friction angle of about 28 degrees and a cohesion intercept of about 4.2 kPa (0.6 psi) for the tire chips alone. These results compare with results reported in the range of 19 to 25 degrees with cohesion intercepts between 8 and 11 kPa (1.1 to 1.6 psi) [5].

Tire chips are highly compressible compared to soils. This compressibility is mainly due to the nature of the rubber material in the tire chips and the reorientation of chips inside the mass [3]. This compressibility governs the density of the tire chips, their shear strength properties and, consequently, the selection of the appropriate design parameters at the various confining pressures that the tire chips may be subjected to in the field.

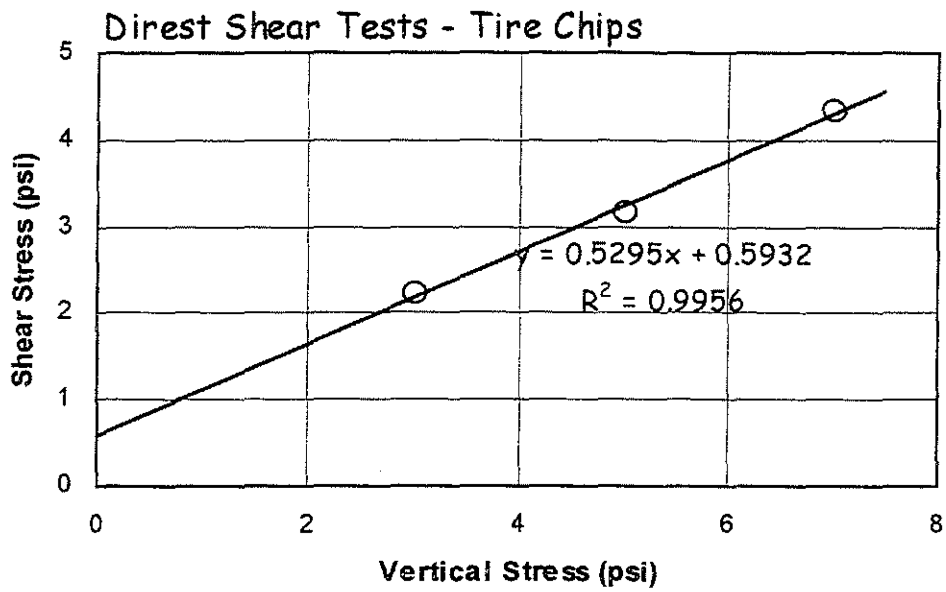


Figure 2. Direct shear test results on the tire chips

An evaluation of the compressibility of the tire chips was investigated while applying the confining pressure in the direct shear box. A quasi-static vertical loading was applied at several intervals during a relatively short period of time (about 15 minutes). The measurement of the vertical compression of the tire chips alone and the mix of soil-tire chips is shown in figure 3. The mix had a 50 percent soil to 50 percent tires by volume. The results show the relatively high compressibility of the tire chips alone.

Figure 3 shows that a vertical compression of about 20 percent was measured when the applied vertical pressure was 34 kPa (5 psi). Such decrease in the specimen thickness required re-adjusting the specimen height to attain similar densities in all the tests regardless to the amount of confining pressure.

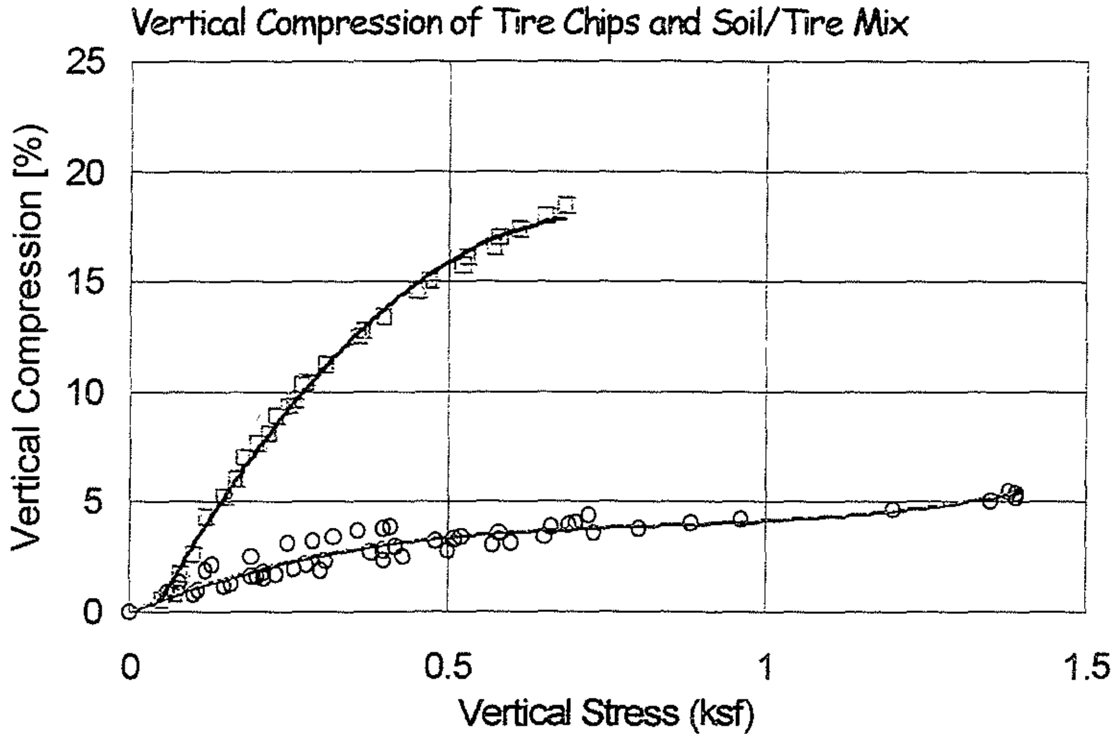


Figure 3. Compressibility of tire chips and soil-tire mix

B. Soil Properties

Silty-clay soil was used in the mixture with the tire-chips in the field. The soil was about 55 percent sand, 33 percent silt and 10 percent clay, with a medium plasticity index of 15. Direct shear tests on the soil were conducted in a small direct shear box of two-inch diameter interface area. The results are shown in figure 4. The results show a soil friction angle of about 27 degrees and a cohesion intercept of about 20 kPa (0.24 tsf).

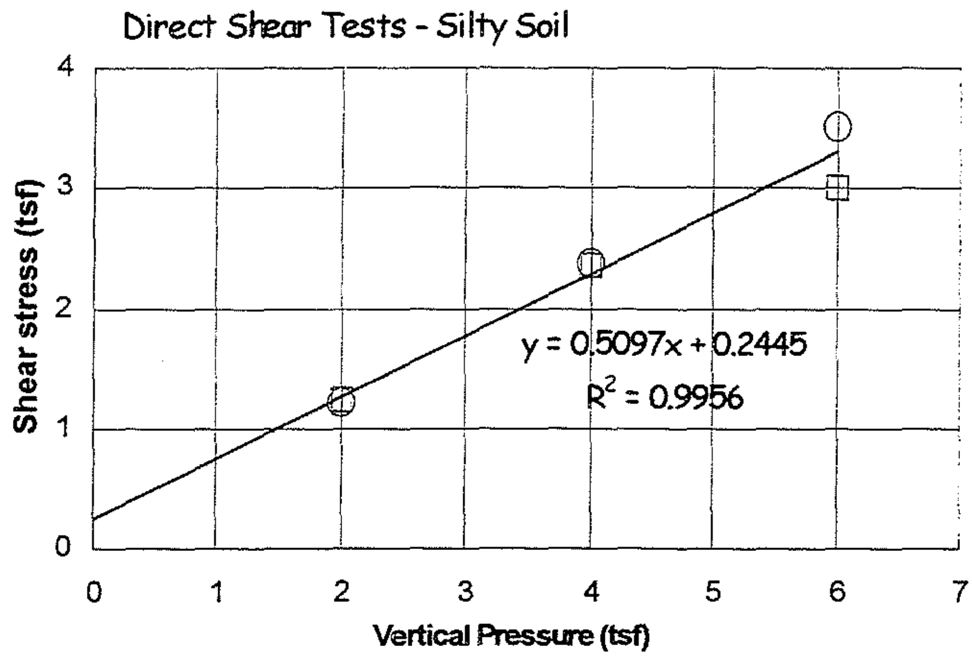


Figure 4. Direct shear test results on the silty-clay soil

C. Soil-Tire Mix Properties

The tire chips and silty clay soil were mixed with a ratio of one-to-one by volume. The mixing procedure in the field consisted of mixing one-bucket volume of tire chips with one-bucket of the silty-clay soil. The mixing procedure in the lab replicated this ratio by volume, which is approximately equivalent to one-unit weight of tire chips to three-unit weight of soil.

The results of direct shear test on the soil-tire mix are shown in figure 5. The results show an increase in the frictional angle to 39 degrees with a cohesion intercept of 19.5 kN/m2 (2.85 psi). The results of the direct shear tests at various confining pressures are shown in Appendix A. It should be noted that there were no defined peak shear stress values at these tests. Maximum shear stress was defined at 10 percent shear strain level.

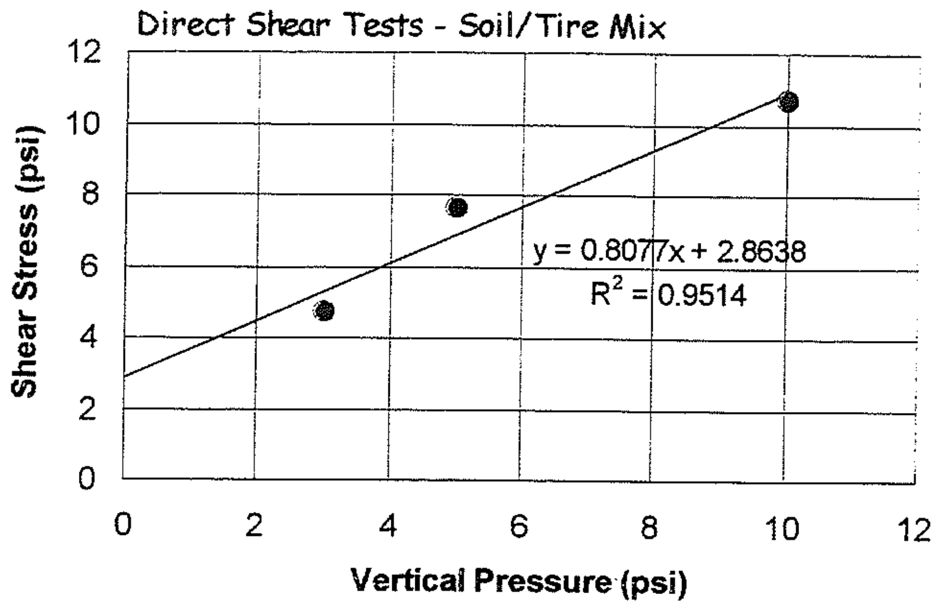


Figure 5. Direct shear test results on the soil-tire mix

The compaction characteristics of the tire chips and the soil-tire mix govern the in-place density and the shear strength properties of the material. Tire chips material is highly elastic and it absorbs the energy induced by the compaction effort. Moisture-density relationship of the soil-tire mix was investigated using 150-mm (6-inch) diameter compaction mold according to the ASTM -D 1557. Previous studies on compaction characteristics of tire and soil-tire mix has shown that moisture content and mold size have no significant effect on the compaction properties [*3*]. The procedure was modified to accommodate the large particle size of the tire chips. Tire chips of maximum size of 75 mm (3 inches) were used in the mix with soil specimen of maximum particle size of 4.75 mm (passing sieve No. 4). Equal volumes of the soil and the tire chips were dry mixed first. Water was added to the mix as percentage by weight. The mix was compacted in three layers in a mould. Each layer was compacted 56 times using the modified Proctor hammer. The top portion of the mold was removed and top of the sample was leveled. The density of the sample in the mold was noted and the water content measured. Figure 6 shows the moisture-density relationship of the soil-tire mix and the soil only.

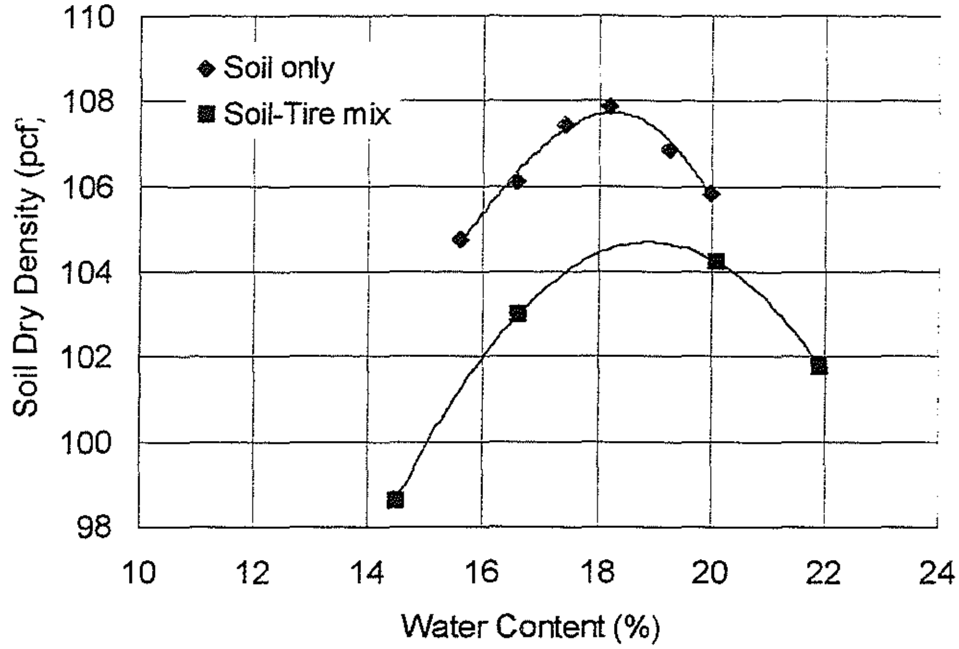


Figure 6. Moisture-Density relationship of the soil and the soil-tire mix

CHAPTER 2

CONSTRUCTION AND MONITORING OF TEST EMBANKMENT

A. Embankment Construction

Three test sections were constructed to investigate the performance of the tire chips and the soil-tire mix as pipe backfill and bedding. Each section had a metal pipe placed in a trench 12 m (40 ft) long and 2 m (7 ft) deep. The base of the trench was about 2.5 m (7.5 ft) with vertical cuts to the ground surface. A geotextile wrap for separation was installed and a corrugated metal pipe of length 12 m (40 ft) was placed in each section on top of one foot of bedding material. The pipes had a diameter of 1.35 m (54 in.), a 16-gage thickness, and a 76 mm (3 in.) x 25 mm (1 in.) corrugation. Figure 7 shows a typical cross section.

The first section was filled with tire chips, the second section was filled with a mix of one silty-clay soil to one tire chips by volume. The third section was filled using silty-clay soil as a control section. A surcharge of about two meters (7 ft) high was initially placed on the top of each section. The embankment height was raised to about four meters (14 ft) three months after construction. A longitudinal cross section of the test embankment is shown in figure 8.

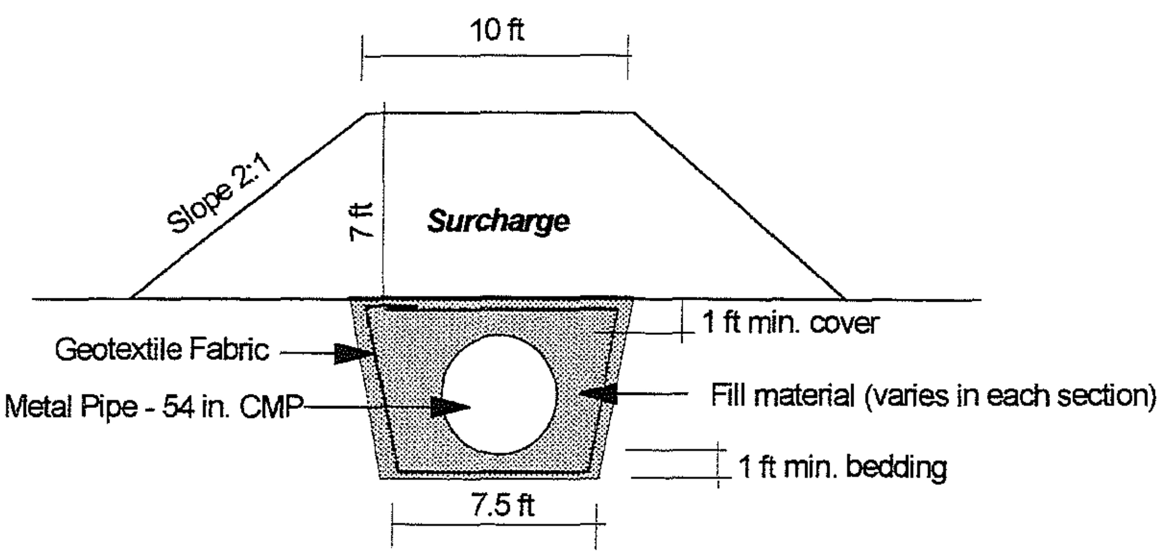


Figure 7. Typical cross section of the test embankment

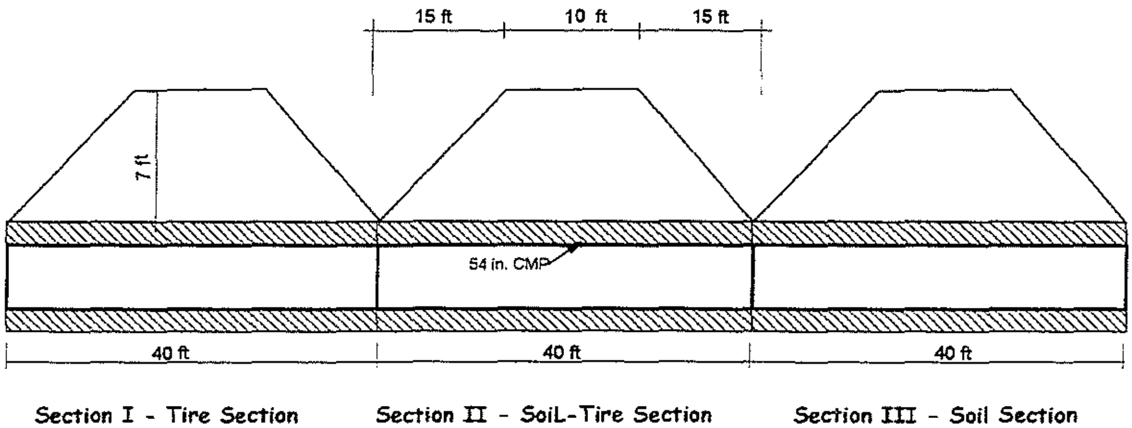


Figure 8. Longitudinal cross section of the test embankment

Tire chips were placed in about 30 cm (12 in.) lifts in the first section and they were manually spread around the pipe. Figure 9 shows the placement of the tire chips. Soil and tire chips were mixed in a large container in the field, using the bucket of a backhoe. The mixing ratio was one-to-one by volume. The mix was placed in its respective section using the bucket.

Compaction was performed using a hand-held vibrating compactor. Soil and soil-tire mix were compacted to about 90 percent of their maximum dry density using the vibrating compactor. Density was measured in the field using a nuclear density gage. Compaction of the tire chips was applied to reduce the voids between the dispersed plate-like tire chips. The attempt to compact the tires proved to be very difficult and labor intensive. The hand compactor would sink into the loose tire fill. A rope was attached to the compactor in an effort to pull it over the surface. As a conclusion, very little improvement in density was observed after compaction due to the elastic behavior of the tires. Figure 10 shows a view of the compaction of tire chips around the pipe.

Embankments were constructed on the top of each section to apply overburden pressure. The embankment had a slope of 1.5-to-1 on each side. The slopes were covered with fabric to reduce surface erosion. Figure 11 shows a view of the test embankments.

Figure 9. Placement of tire chips around the pipe

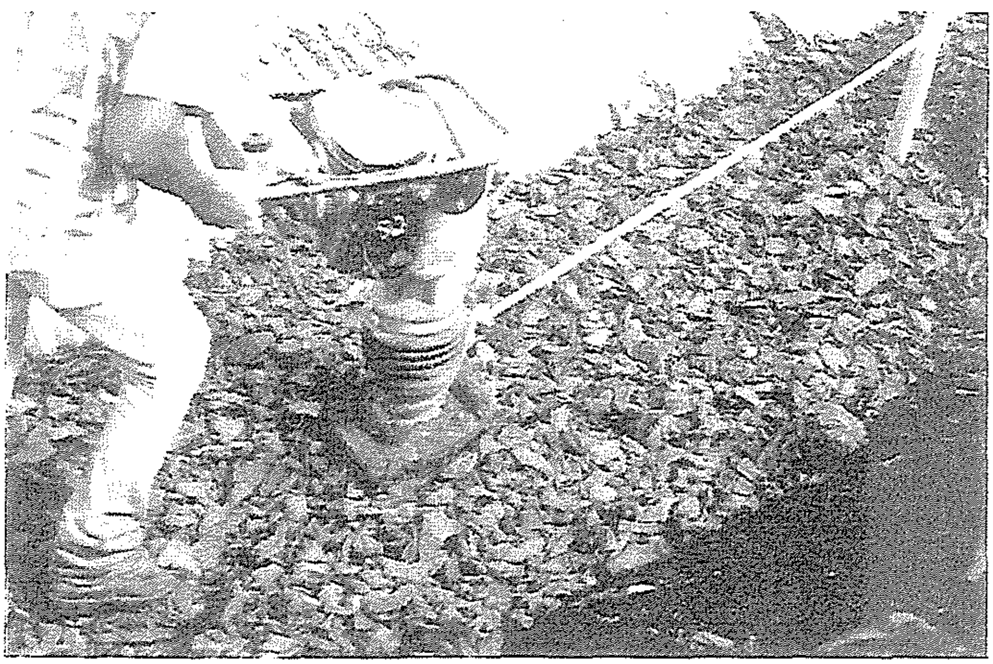


Figure 10. Compaction of the tire chips around the pipe

Figure 11. View of the test sections

B. Field Instrumentation

The three test embankments were instrumented to monitor the performance of the metal pipe in the three types of backfill materials. The instrumentation consisted of placing two settlement plates; one at the top and one at the bottom of the fill in order to determine the compression of each fill type under embankment weight. Settlements of the tire chips and soil-tire mix sections were monitored at the top of the metal pipe using a horizontal inclinometer that extended across both sections. Vertical inclinometers were installed in each section to measure the horizontal deformation of the fill near the metal pipe. Figure 12 shows a schematic of the instrumentation layout in a typical cross section of the pipe. A view of the inclinometer pipe in the field is shown in figure 13.

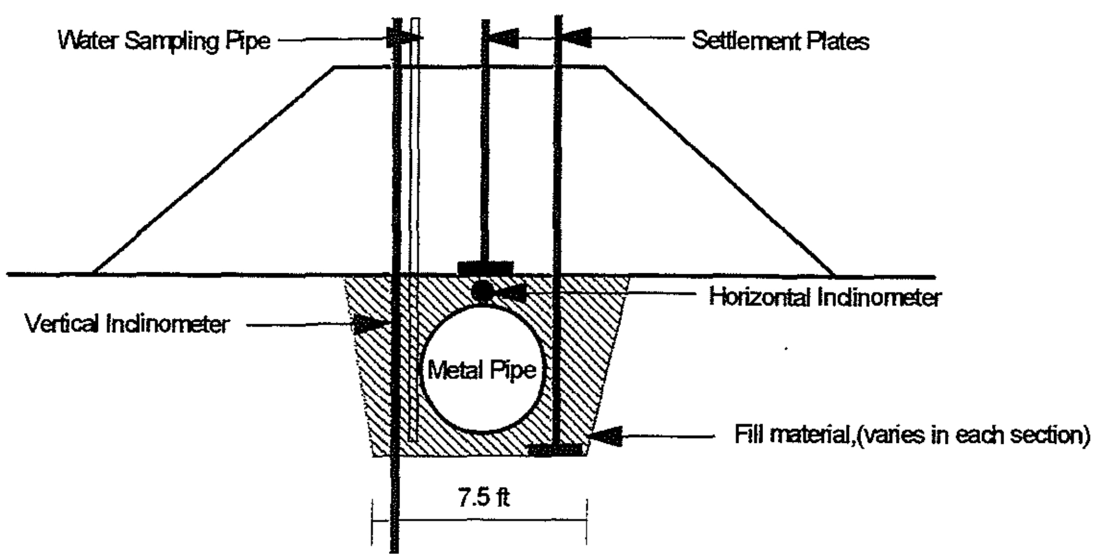


Figure 12. Layout of the field instrumentation

Figure 13. Installation of the vertical inclinometer in the field

The strains of the pipe in the three fill sections were compared using strain gages installed around the pipe cross section. A total of ten strain gages in each section were installed in the configuration shown in figure 14. Seven of the gages were installed in the hollow of the corrugation while the other three gages were installed on the hump. The strain gages were of Micro-Measurements type EP-40-250BF-350. Figures 15 and 16 show the installation of the strain gages on the metal pipe.

The compression and tension forces at the bottom and top of the corrugation can be estimated from the measured strains and the modulus of elasticity of the metal pipe. However, the estimation of the forces and stresses on the pipe surface were not in the scope of this study. Measurements of the strains were taken using a field read out box and they were compared in the three sections. Figure 17 shows the initial reading of the strain gages after pipe installation in the field.

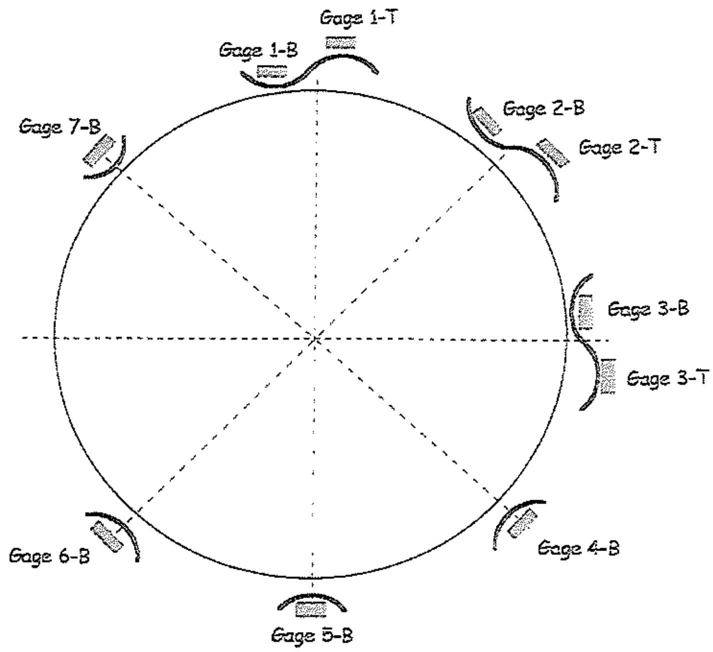


Figure 14. Schematic of the locations of strain gages in the Field

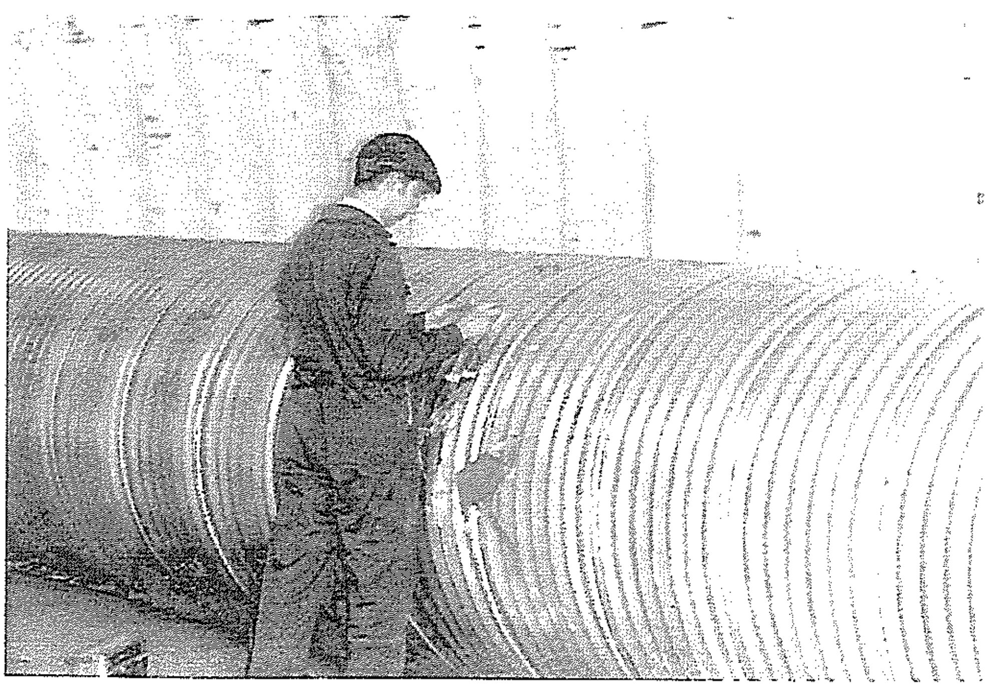


Figure 15. View of the inclinometer installation in the field

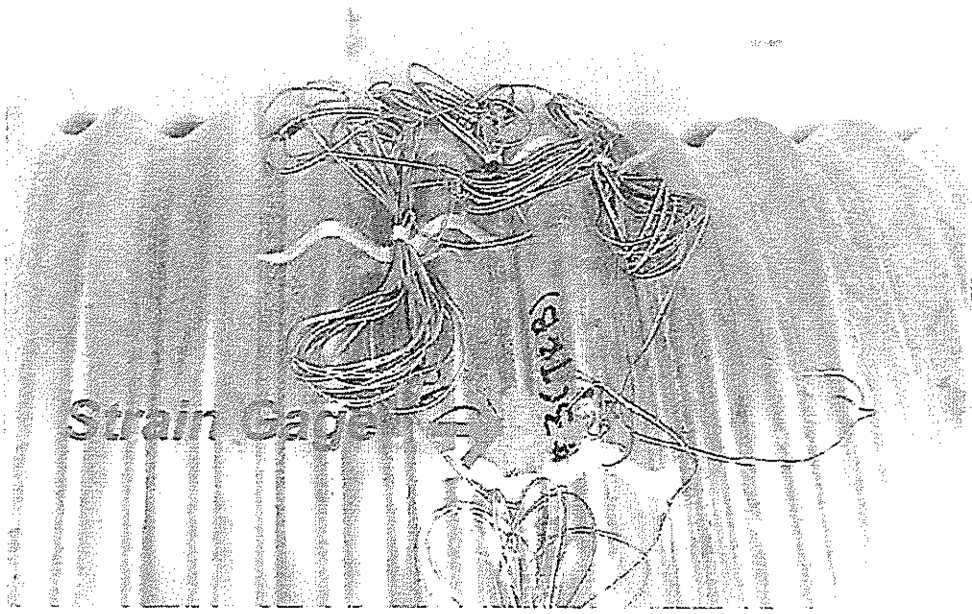


Figure 16. View of the strain gages on the pipe

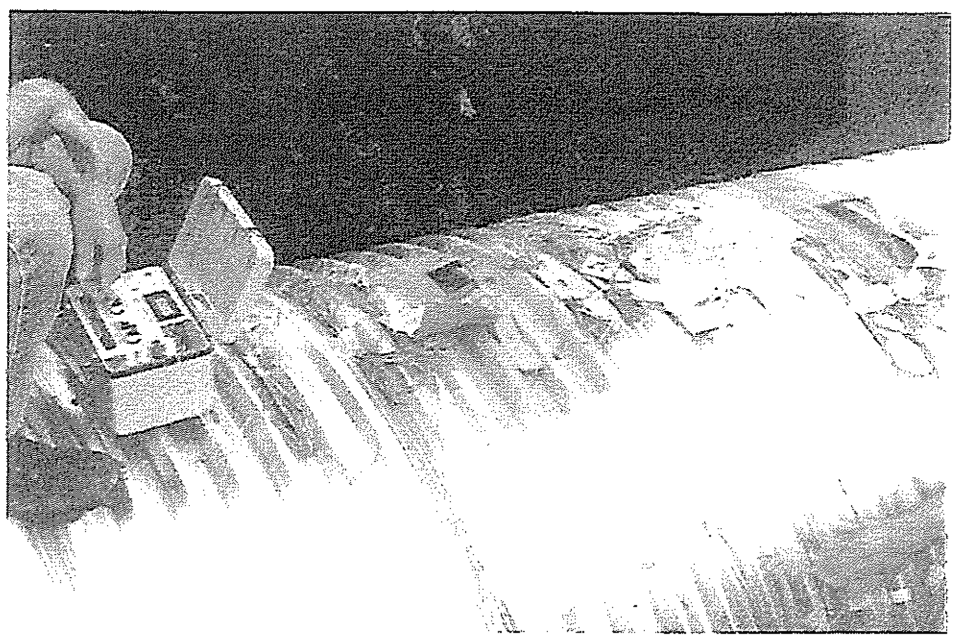


Figure 17. Initial reading of the strain gages in the field

C. Field Monitoring of Inclinometers

This section presents the results of the field measurements of the vertical and horizontal inclinometers and the strain gage readings around the pipe in the three test sections. With regard to the readings of the settlement plates, difficulties in the measurement of the initial levels during construction have resulted in unreliable readings and it was decided to discard these measurements.

The vertical inclinometer readings are plotted in figures 18, 19, and 20 for the tire section, the soil-tire mix section, and the soil section, respectively. The plots show the horizontal soil displacement near the metal pipe with the positive direction indicating soil movement away from the pipe. It should be noted that the plots show only the readings up to the top of the backfill material below the embankment. The readings of the vertical inclinometers in the embankment above the backfill are irrelevant to this evaluation study. However, for the sake of completeness, the total plots of the inclinometer readings are presented in appendix B.

The initial readings during construction were taken on May 31, 1997. The plots show the accumulated horizontal displacements at the dates shown in figures. The first three readings after construction, namely on 6/3/97, 6/10/97 and 6/24/97 where taken when embankment height was two meters (7 ft). Small horizontal displacements in the order of 1.5 mm (0.05 in.) were monitored in the three sections at this height. In order to investigate pipe deformation at higher loads, embankment height was increased to about four meters (14 ft). The readings beginning on 7/23/97 represent the horizontal displacement at this embankment height.

The maximum horizontal displacement (at the center height of the metal pipe) in the tire section was 16.5 mm (0.65 in.). Displacements of 7.5 mm (0.30 in.) and 3 mm (0.12 in.) were monitored in the soil section, and the soil-tire section, respectively. Figure 21 shows a comparison of the maximum displacements in the three sections near the metal pipe. The figure demonstrates the significant increase of soil deformation around the pipe in the tire section in comparison with the other two sections.

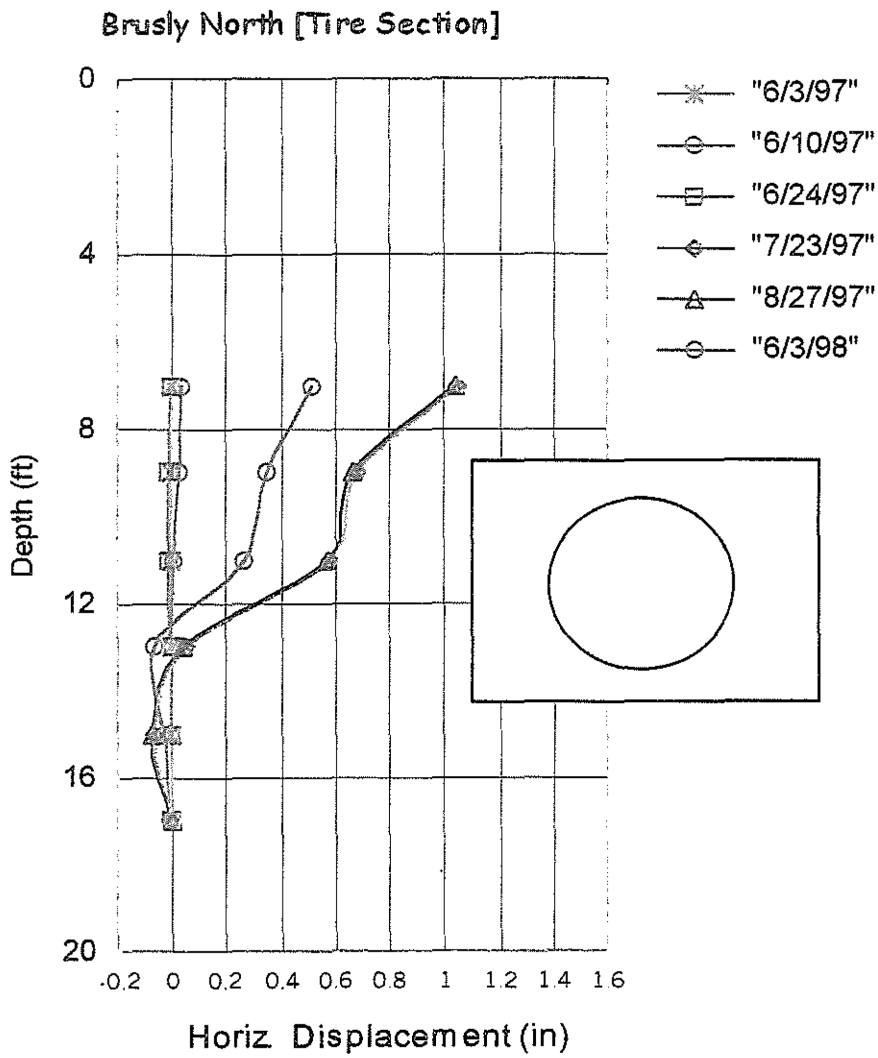


Figure 18. Horizontal soil displacement near the pipe in the tire section

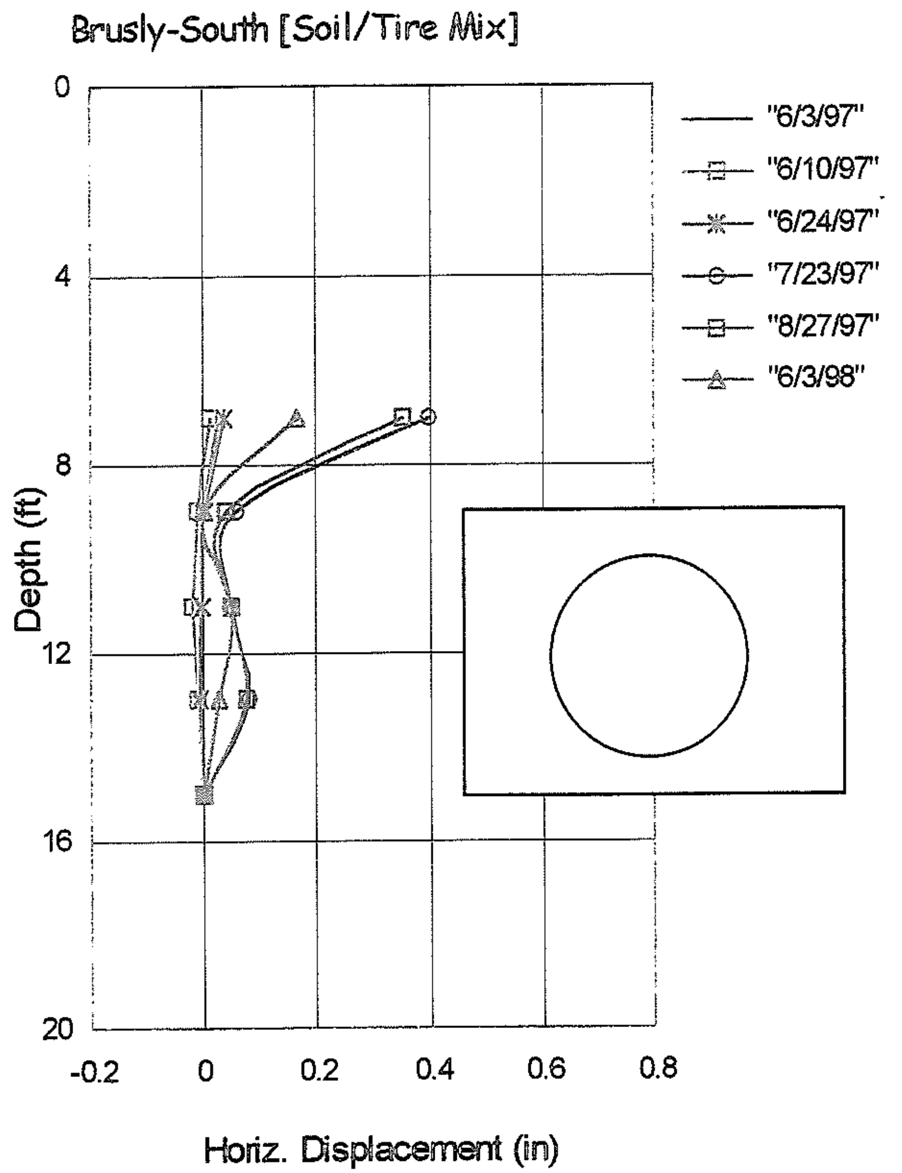


Figure 19. Horizontal soil displacement near the pipe in the soil-tire section

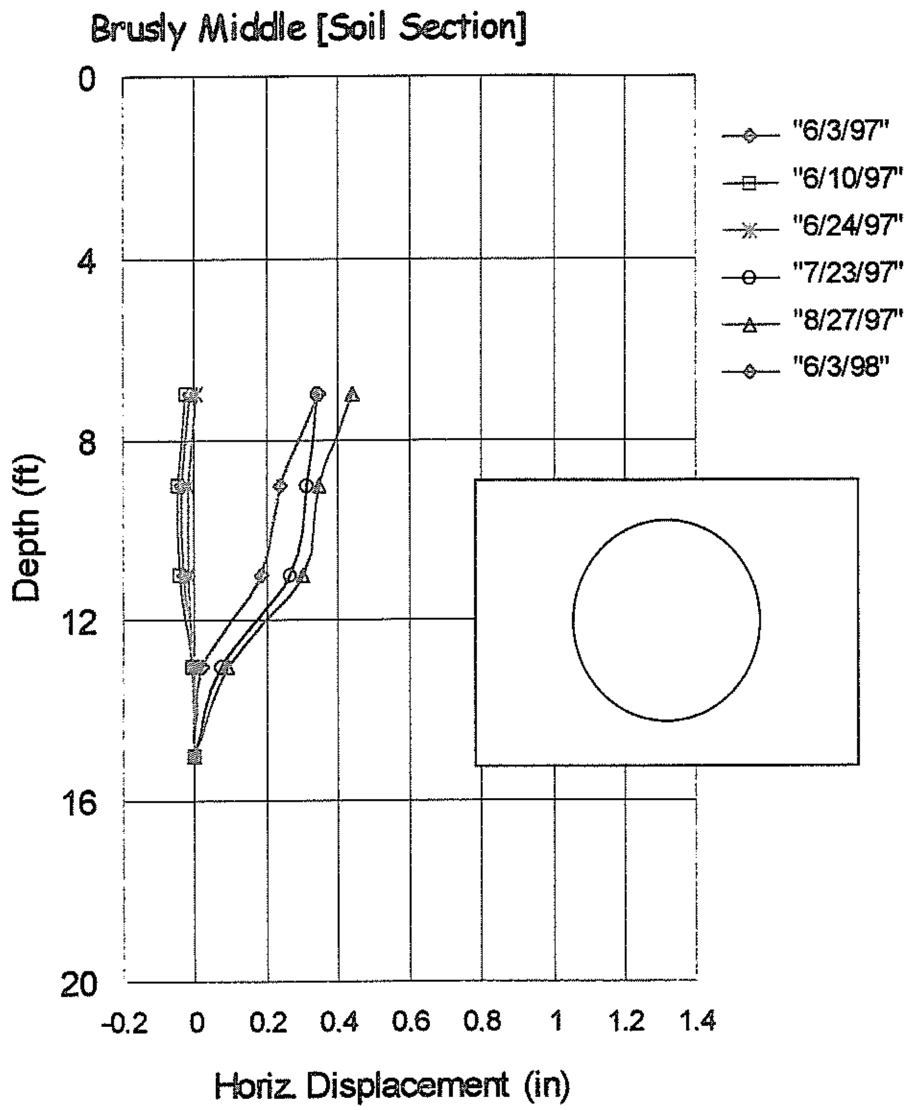


Figure 20. Horizontal soil displacement near the pipe in the soil section

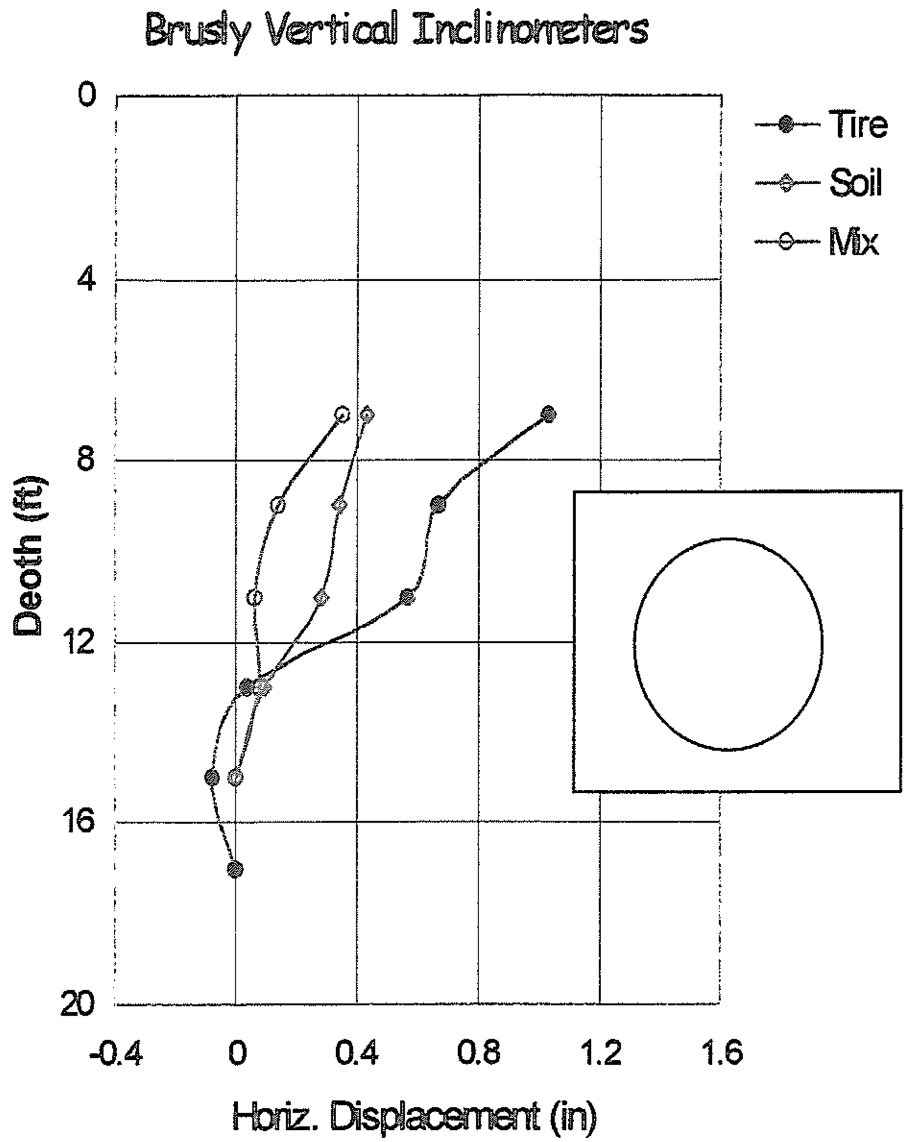


Figure 21. Comparison of horizontal soil movement in the three sections

The horizontal inclinometer was placed in both the tire section and the soil section. The inclinometer was placed directly on the top of the metal pipe as shown in figure 12. The measurements of the horizontal inclinometer are shown in figure 22. The results show that the vertical deformation of the metal pipe in the tire section was higher than that in the soil section. The higher vertical displacement in the tire section can be attributed to the compressibility of the part of the tire section underneath the metal pipe and to the higher deformation of the pipe in the tire section.

The results of the vertical and horizontal inclinometers show that the tire fill did not provide comparable horizontal stresses around the metal pipe to restrain pipe deformation. It can also be concluded that the horizontal deformation in the soil-tire mix fill was comparable to the one in the soil section. Further investigation of the deformation of the pipe was carried out through monitoring the strains in the pipe in the three sections.

The results of the pipe strains in the soil section are shown in figures 23 and 24 for the gages at the bottom and the top of corrugation, respectively. The strains in these figures are plotted in polar coordinates to represent the state of deformation around the circular pipe. The plots illustrate the development of strains after construction, when the readings on 07/22 and 8/22 were at embankment height of four meters (14 ft). The results of the strain gages readings in the soil-tire mix section and the tire section are shown in a similar fashion in figures 25 to 28. The plots of strains against the gage numbers are also shown in appendix B.

The results in these figures show that the profile of strains in the soil section and the soil-tire section were comparable. In both sections, maximum positive strains were in the range of 0.8 percent at the 45-degree angle, and minimum strains accrued at the bottom of the pipe. On the other hand, the profile of strains in the tire section was significantly different. In this section, maximum positive strains occurred at the top and bottom of the pipe while negative strains were measured at the middle height of the pipe at the 90-degree angle.

Maximum strains in the pipe in the three test sections are plotted in figures 29 and 30 for the strain gages at the bottom and the top of the corrugation, respectively. The figures show the state of strain in the metal pipe for the three types of fill.

It can be concluded from the previous figures that the deformation behavior of the metal pipe in the tire section is fundamentally different than that of the other two sections and that the strains in the soil-tire section had values closer to the ones in the soil section. In order to further investigate pipe deformation in the tire backfill, a laboratory testing program was developed to compare pipe strains in tire backfill with the strains when the pipe is tested unconfined in the air.

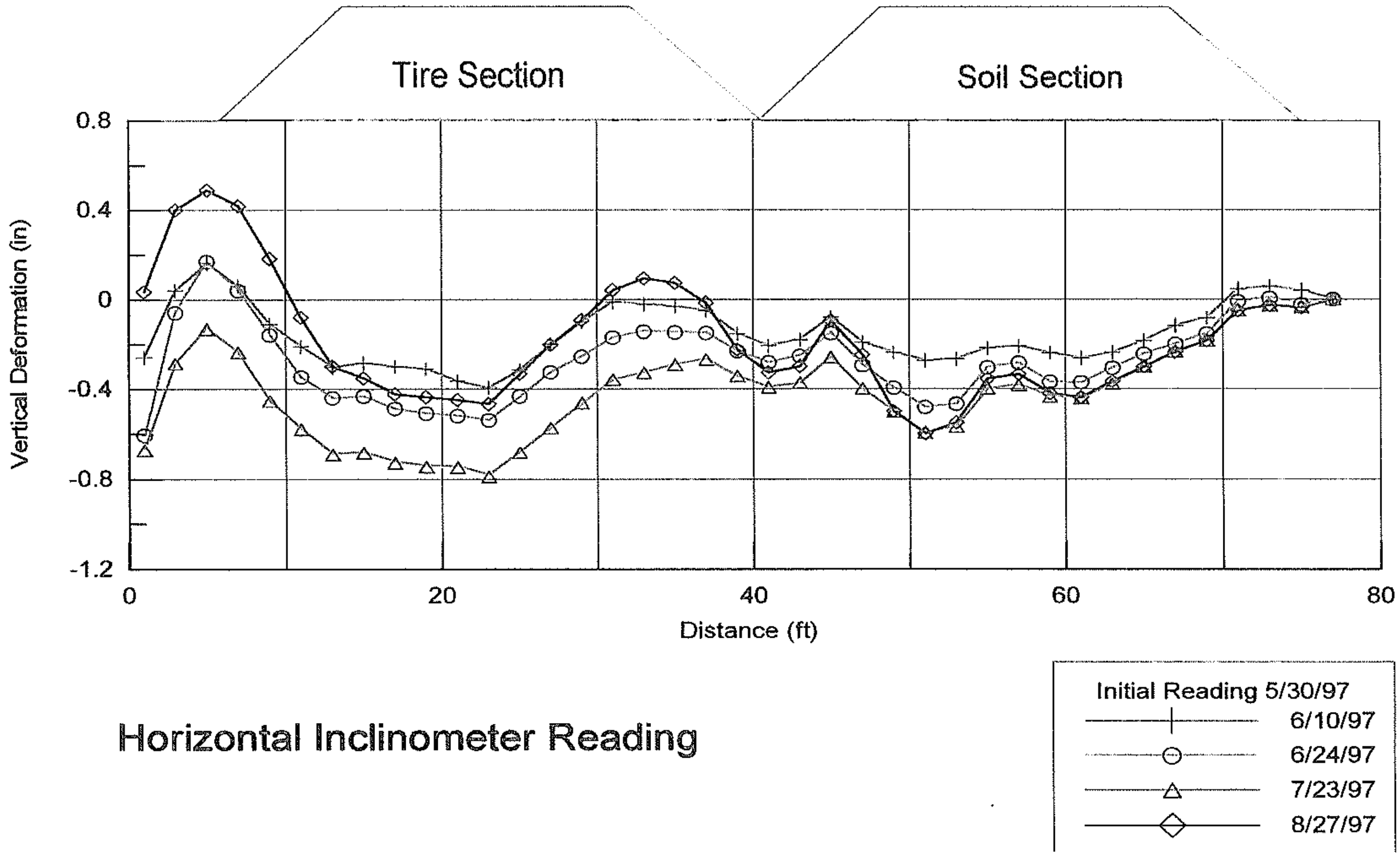

Tire Section
Soil Section
Vertical Deformation (in)
0.8
0.4
0
-0.4
-0.8
-1.2
0
20
40
60
80
Distance (ft)
Horizontal Inclinometer Reading
Initial Reading 5/30/97
6/10/97
6/24/97
7/23/97
8/27/97

Figure 22.

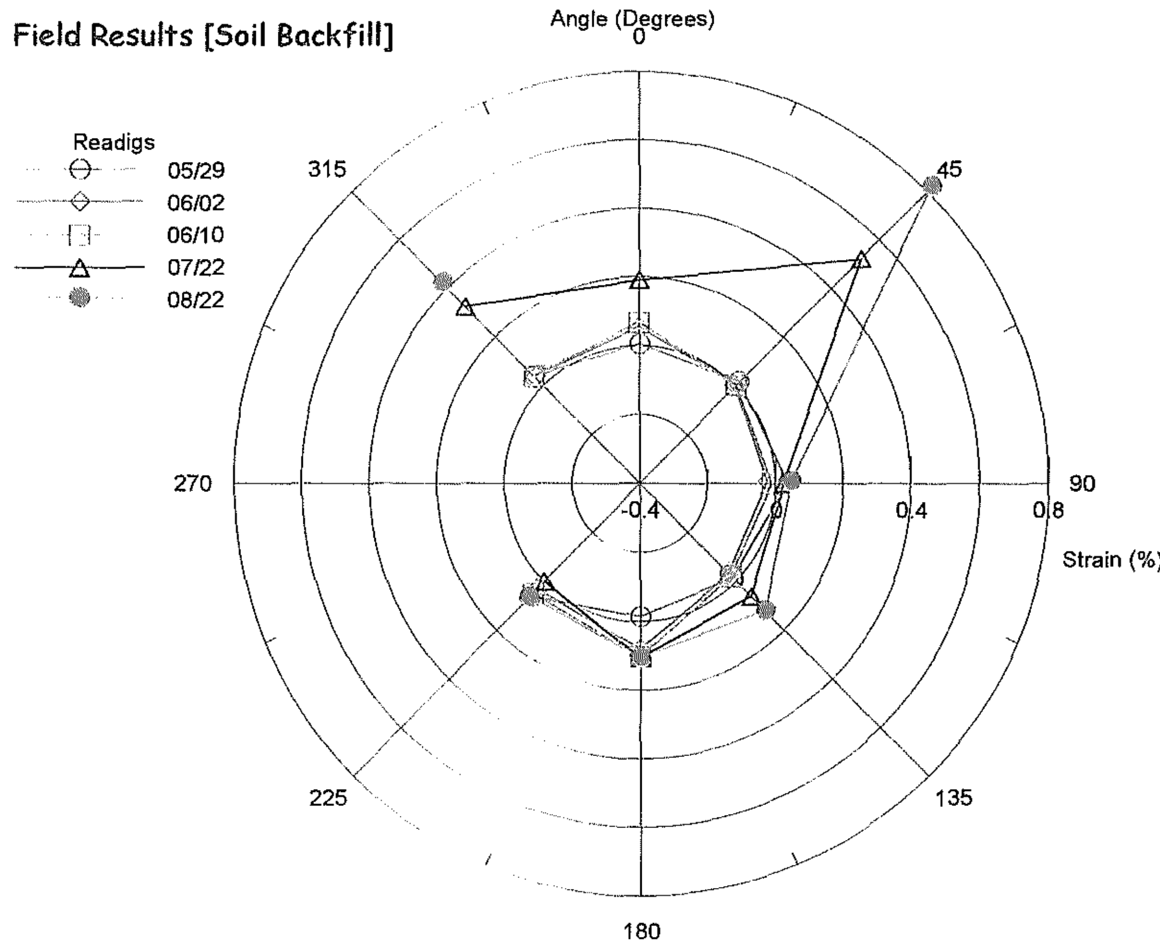


Figure 23. Strain measurements of bottom gages in the soil section

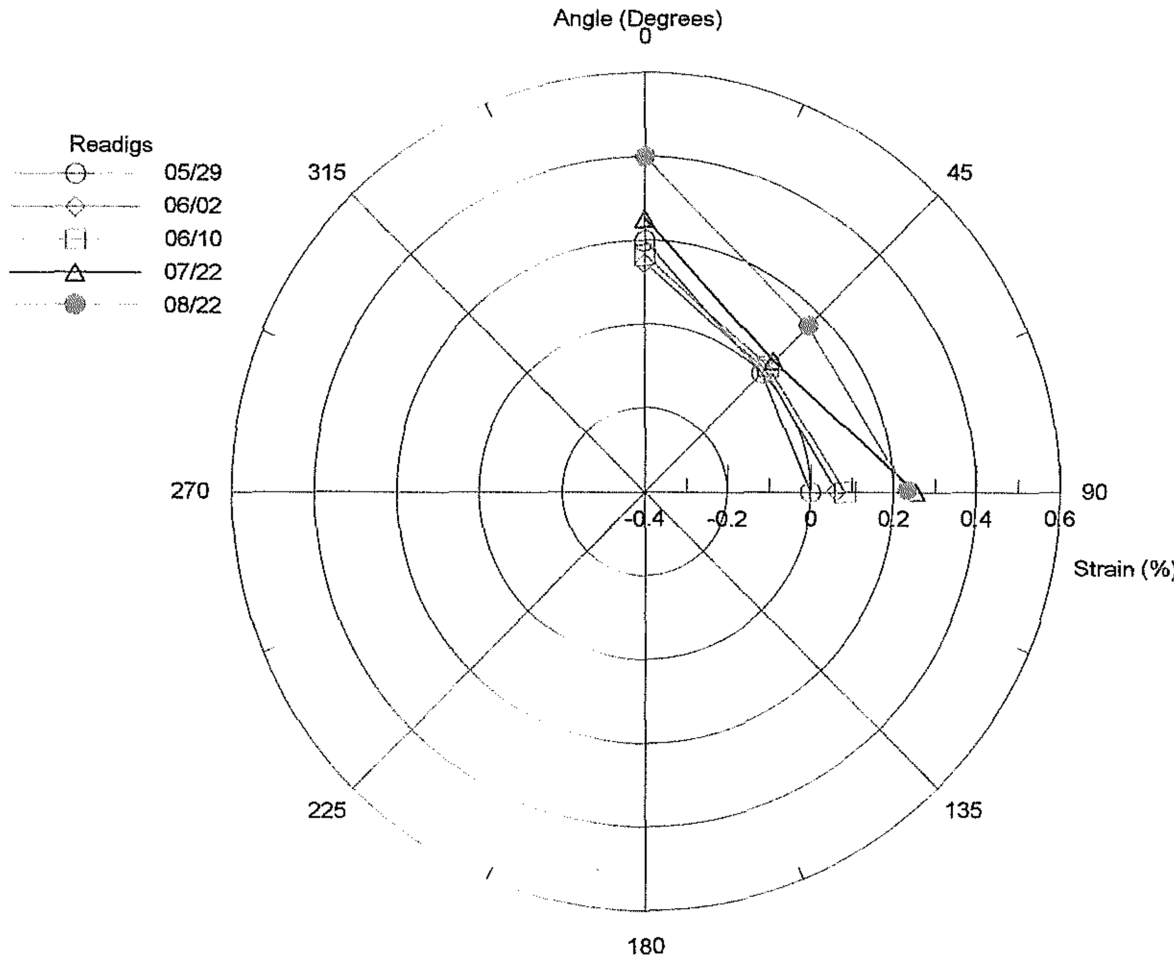


Figure 24. Strain measurements of top gages in the soil section

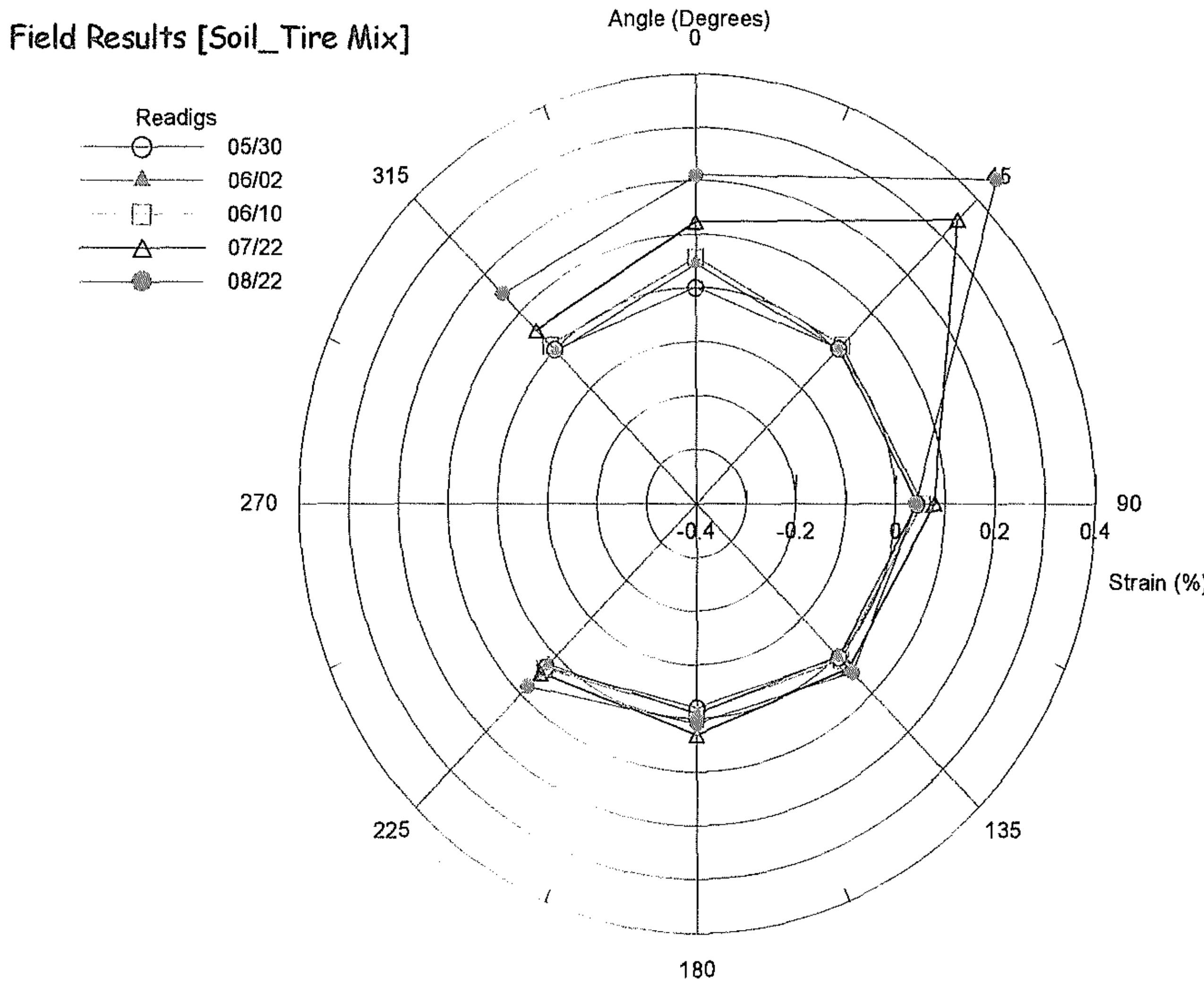


Figure 25. Strain distribution of bottom gages in the soil-tire section

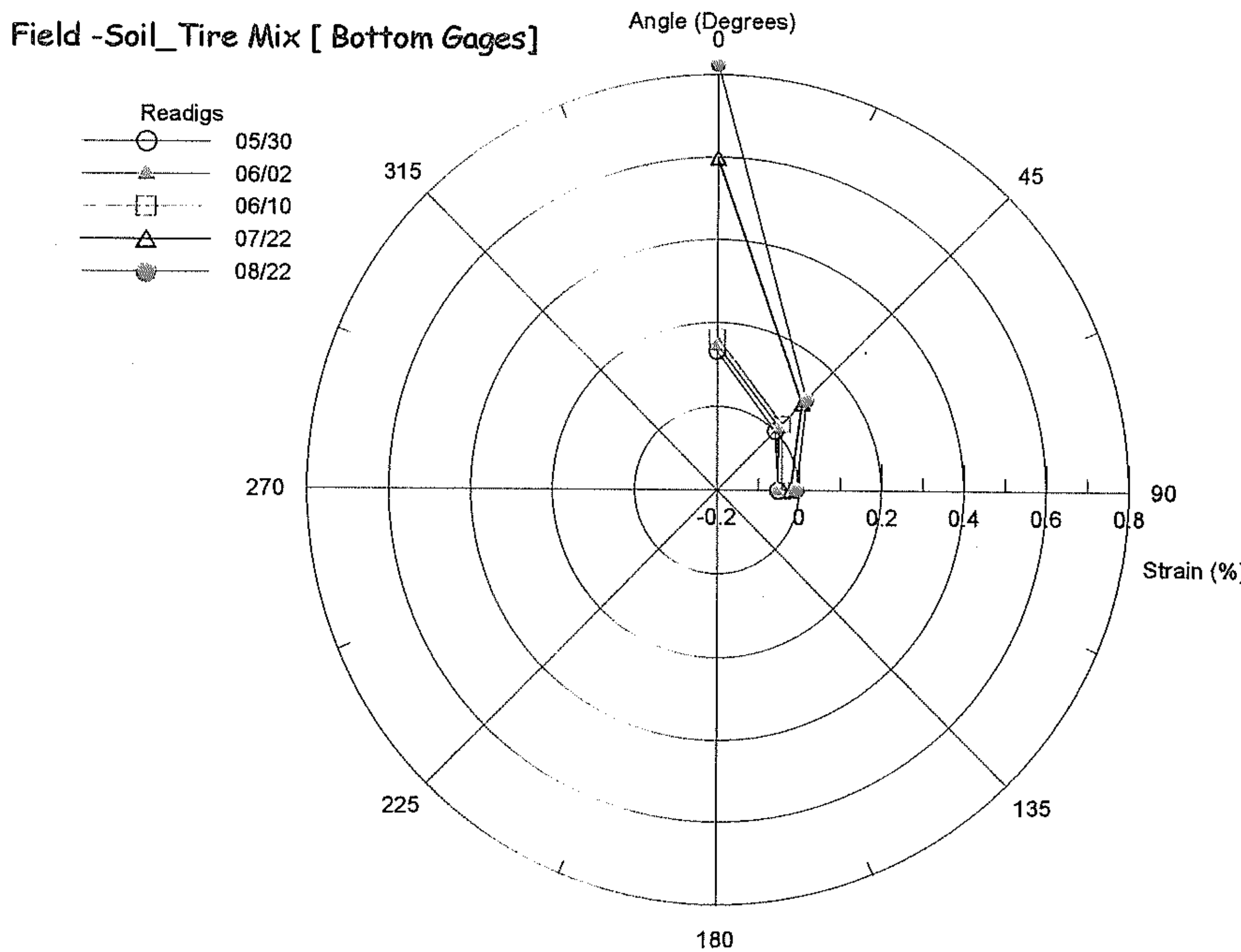


Figure 26. Strain measurements of top gages in the soil-tire section

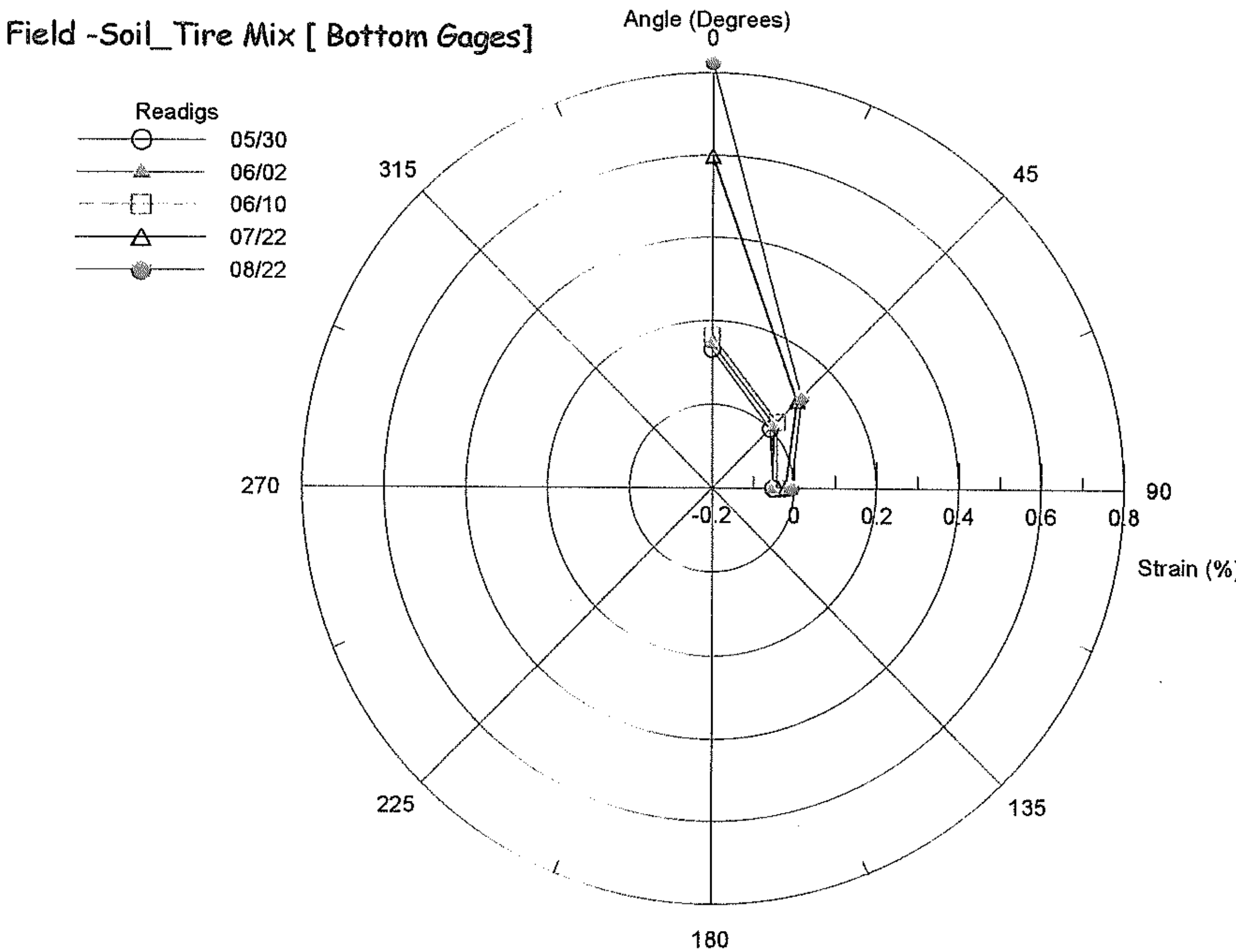


Figure 26. Strain measurements of top gages in the soil-tire section

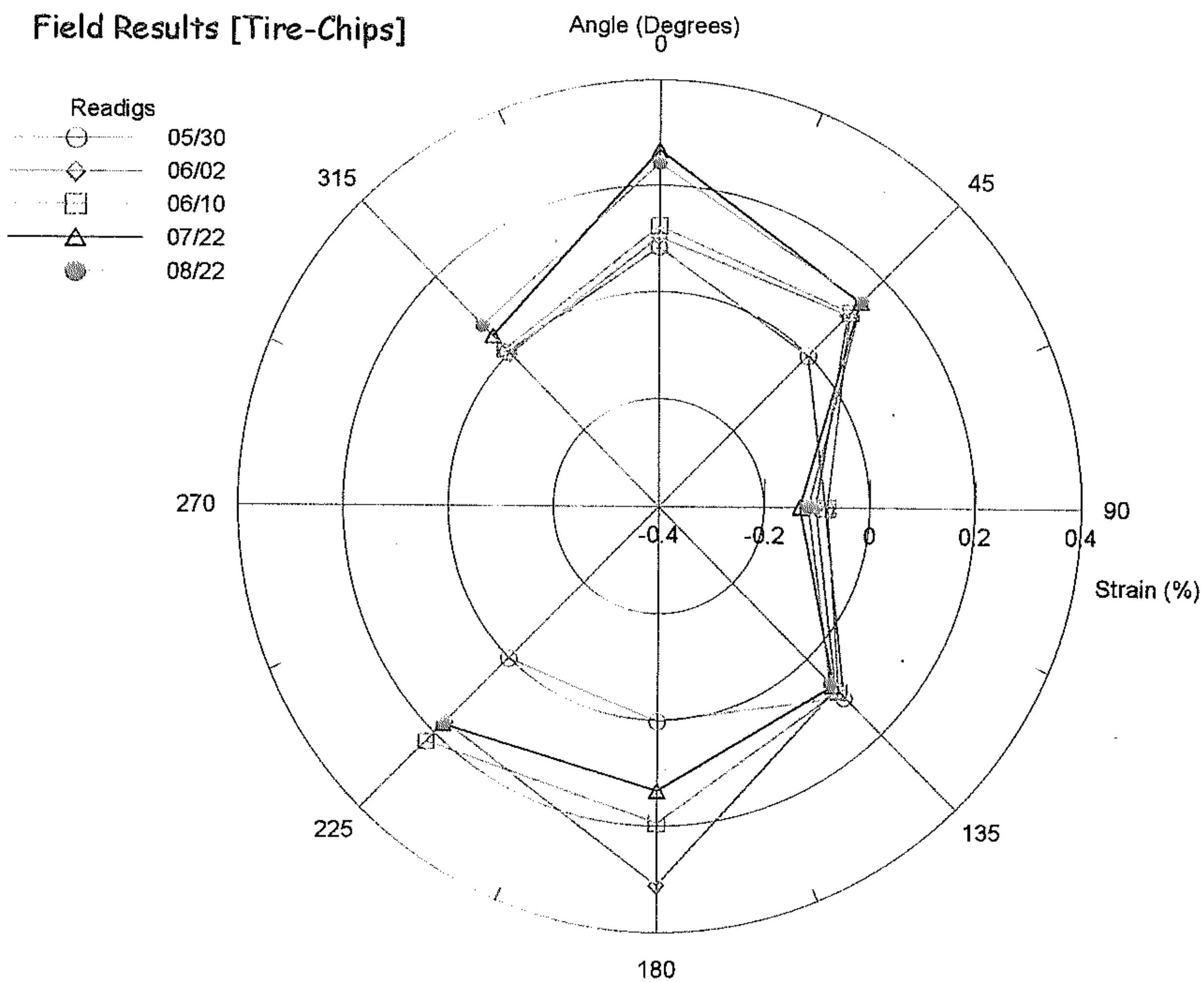


Figure 27. Strain measurements of bottom gages in the tire section

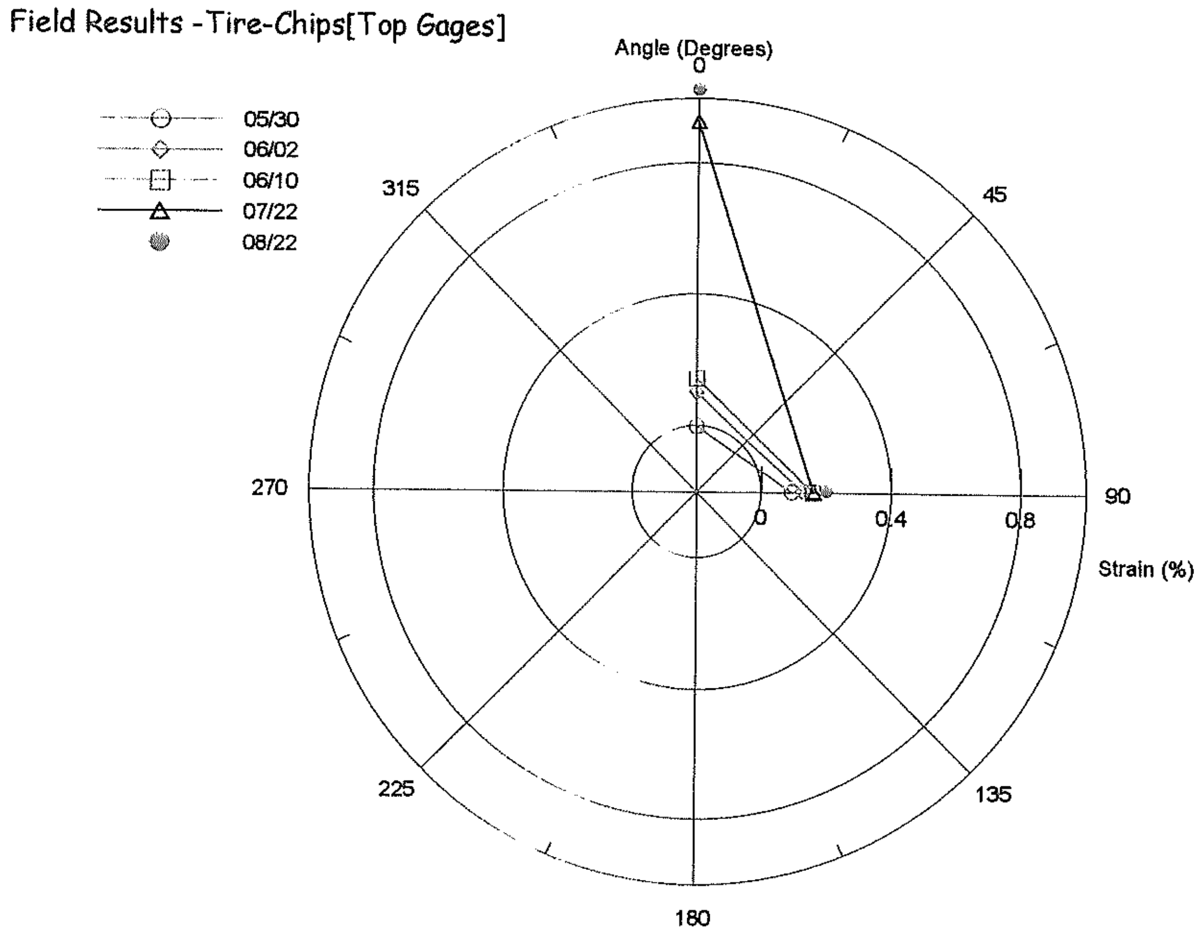


Figure 28. Strain measurements of top gages in the tire section

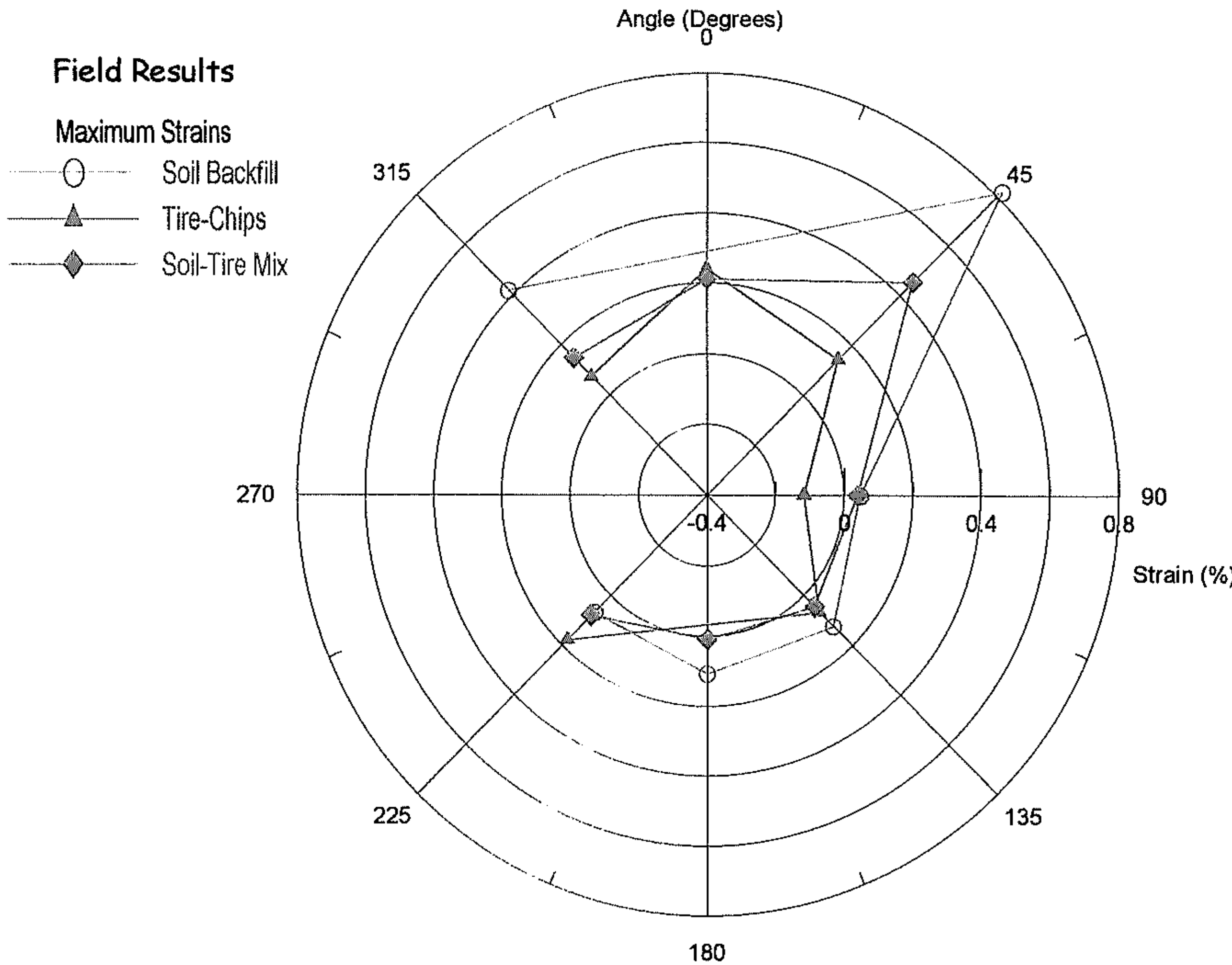


Figure 29. Comparison of strains in bottom gages in the three sections

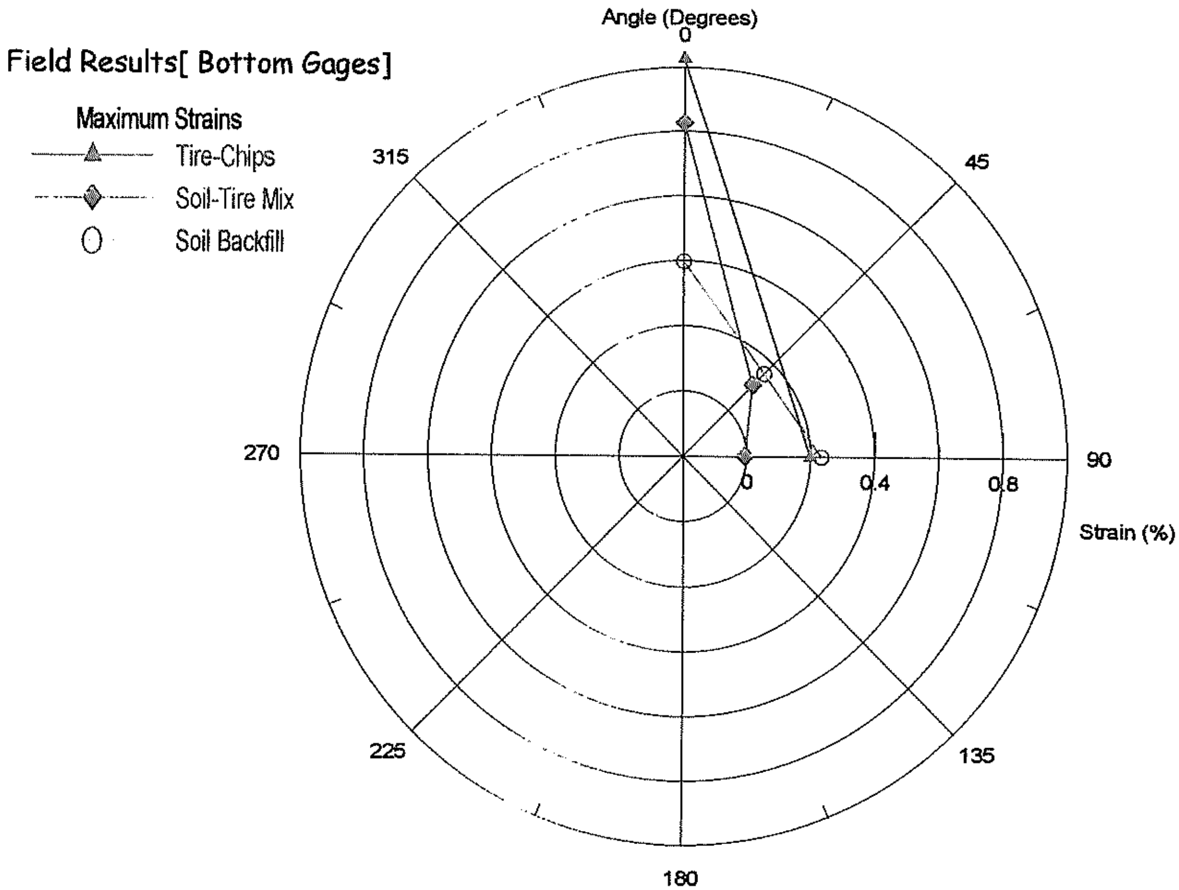


Figure 30. Comparison of strain in top gages in the three sections

CHAPTER 3
LABORATORY TESTS OF METAL PIPE IN TIRE-CHIPS

A. Test Setup

Laboratory tests were conducted on a corrugated metal pipe of 1.35 m (54 in.) diameter and 0.6 m (2 ft) width. The pipe was placed inside a large loading frame to apply incremental vertical loads. The first test was performed without backfill material around the pipe to measure its in-air deformation. Two other tests were performed on the pipe in confined condition with the tire chips and the soil-tire mix as backfill materials. In the confined tests, the pipe was placed inside a large box of 2.6 m (8.5 ft) length, 1.6 m (5.5 ft) height.

The hydraulic loading frame applied the incremental vertical loads on a steel plate placed with a wooden cushion on the top of the pipe. The cushion applied the load on a distributed area of 1 m (3 ft) long and 0.6 m (2 ft) wide. A linear Variable Differential Transducer (LVDT) was installed on the loading frame to monitor the vertical pipe deformation. Strain gages were installed on the metal pipe in similar locations to the ones in the field. Figure 31 shows a schematic diagram of the locations of the strain gages in the pipe. It should be noted that the loading mechanism and the boundary conditions of the setup in the laboratory are different than the conditions associated with the tests in the field. For this reason, no comparison was attempted to relate the deformation measurements in the lab to the ones in the field.

The metal pipe was tested in the air at vertical incremental loads up to 11 kN (2.5 kips) on top of the metal plate. Vertical deformation and strains were monitored with the incremental loads at intervals of two kN (400 lb). The results of the strain gage measurements are plotted in appendix C. Figure 32 shows a view of the metal pipe tested in the air.

Confined tests in tire-chips and in soil-tire mix backfill were performed at similar increments of vertical loads. In these tests, the backfill was manually placed and lightly compacted in the large box. Figure 33 shows a view of the placement of the backfill around the metal pipe in the large box. The results of the strain gage measurements in these tests are plotted in appendix C.

Plots of the measurements of the strain gages around the pipe cross sections are shown in figures 34 and 35 for the in-air test. The results show the measurements of the bottom and top strain gages separately. Similarly, the results of the tests in tire chips and soil-tire mix are shown in figures 36 to 39.

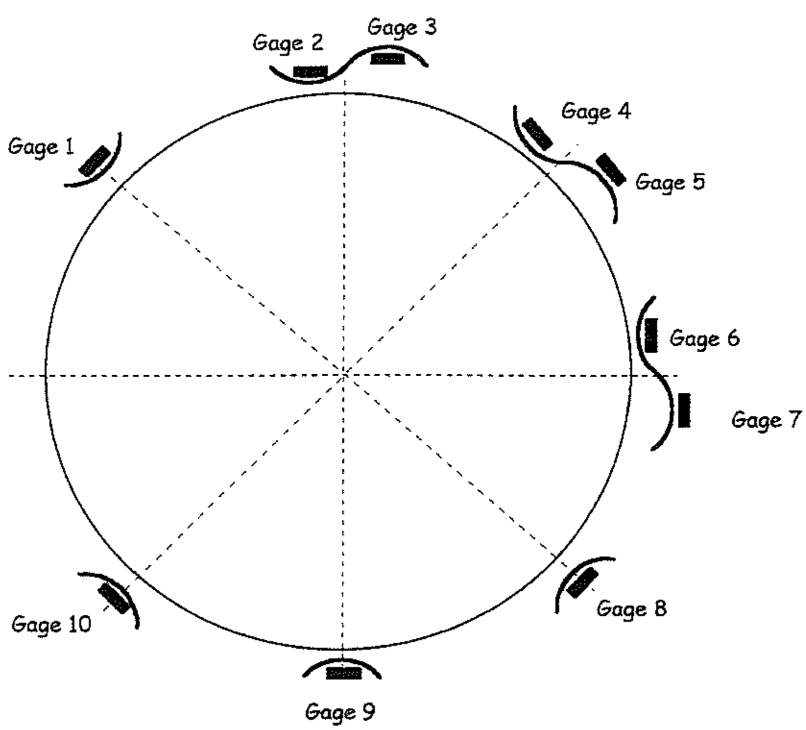


Figure 31. Schematic of the strain gages locations in the lab

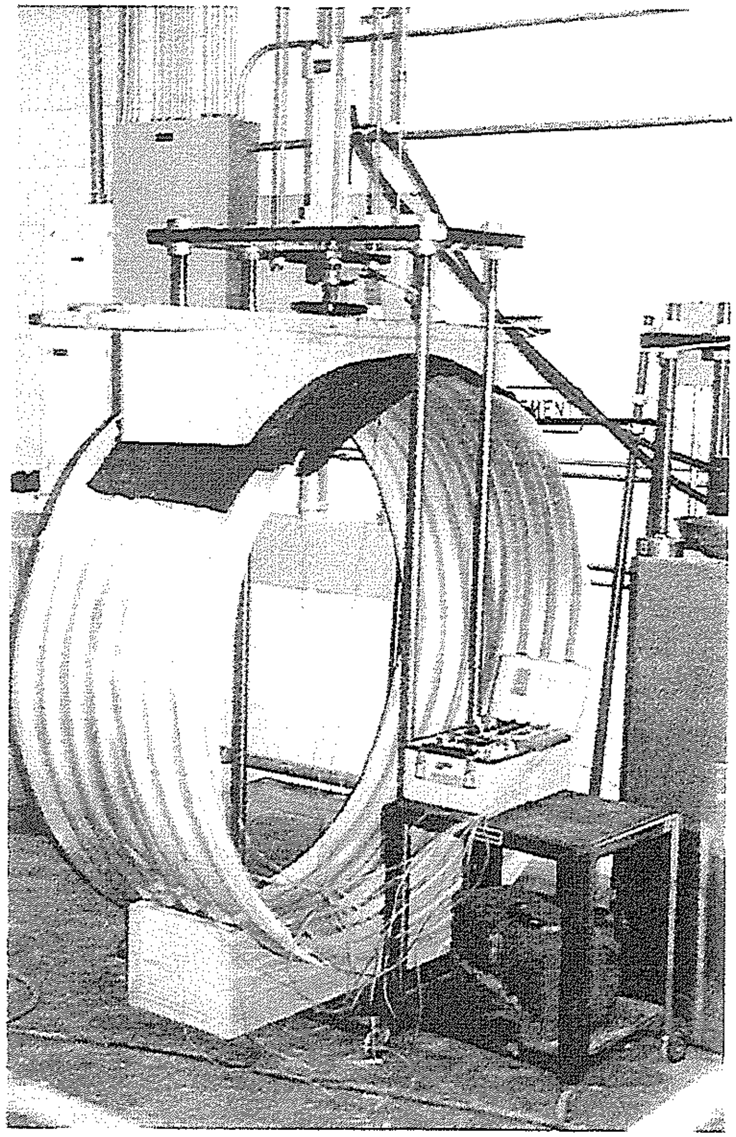


Figure 32. View of the in-air testing of the metal pipe

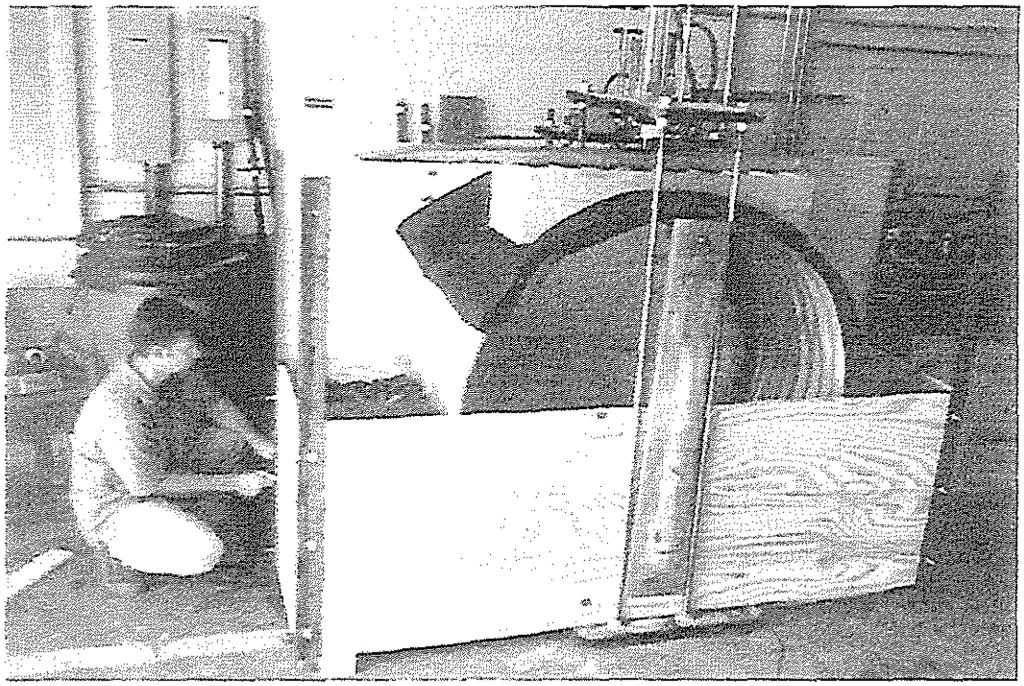


Figure 33. Placement of the tire chips around the pipe in the lab

A comparison of the measurements of the strain gages in the laboratory tests is shown in figure 40. The figure shows the strain gages measurements at each gage location. The LVDT's measurements of the vertical deformation at the top of the pipe are shown in figure 41. The results of the laboratory tests show that pipe deformation in tire chips backfill is comparable to its deformation in the air. Furthermore, field tests demonstrated that the state of stresses in the pipe cross-section in tire chips is fundamentally different than those in soil and in soil-tire mix.

The results suggest that further analysis for the determination of the stresses in pipe when placed in tire chips alone would be required for appropriate safe design of pipes in this type of fill. It is also suggested that a soil-tire mix of similar mix ratio as in this study would behave in a similar fashion as in soil backfill.

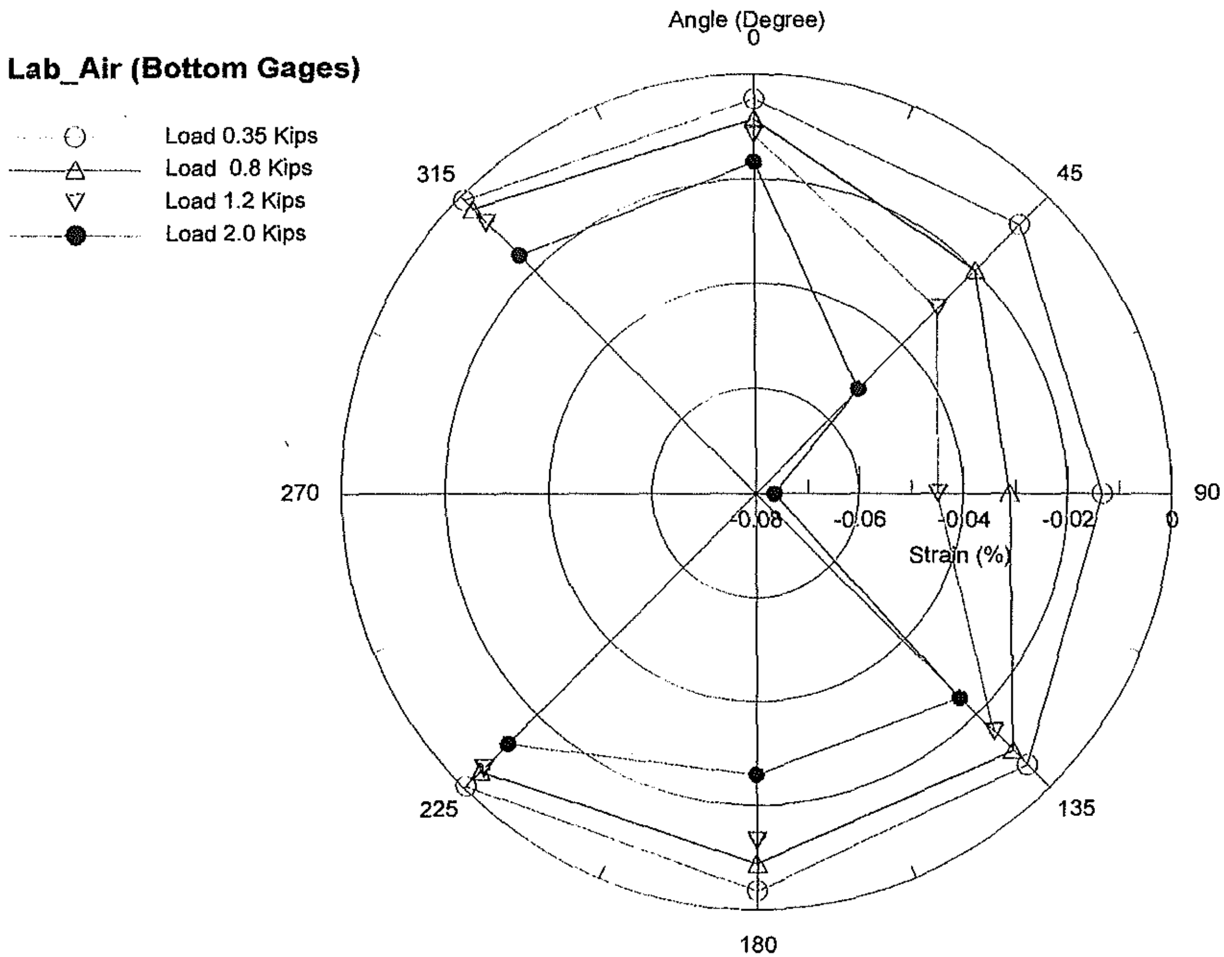


Figure 34. Strain measurements in bottom gages in in-air test

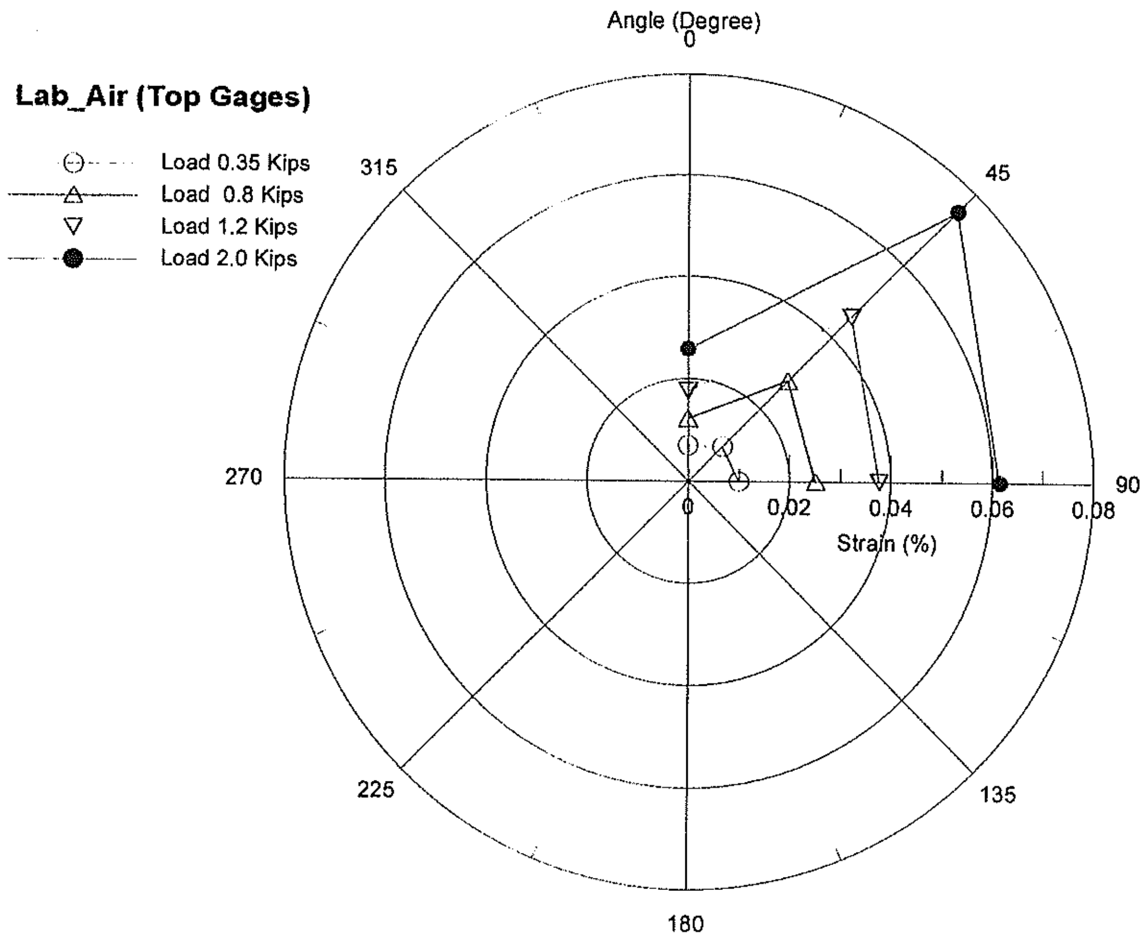


Figure 35. Strain measurements of top gages in in-air test

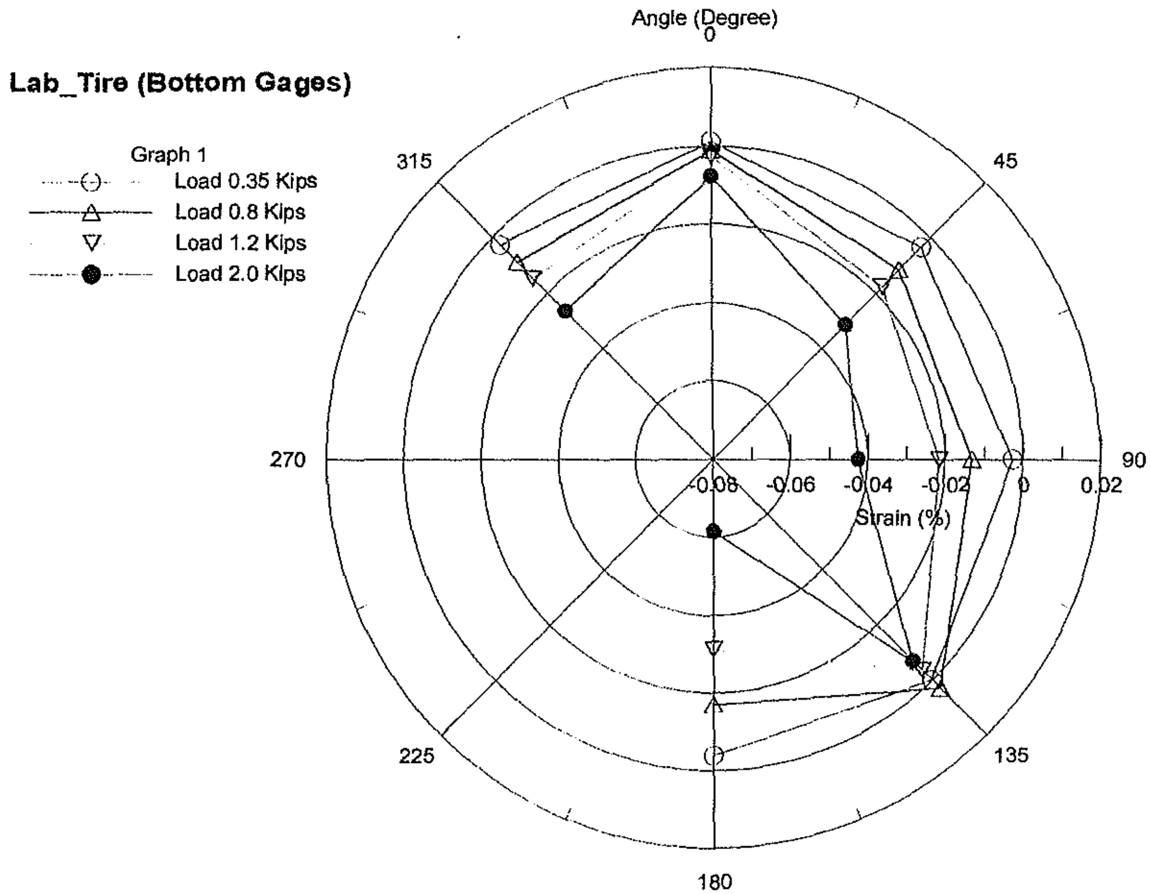


Figure 36. Strain measurements of bottom gages in tire fill

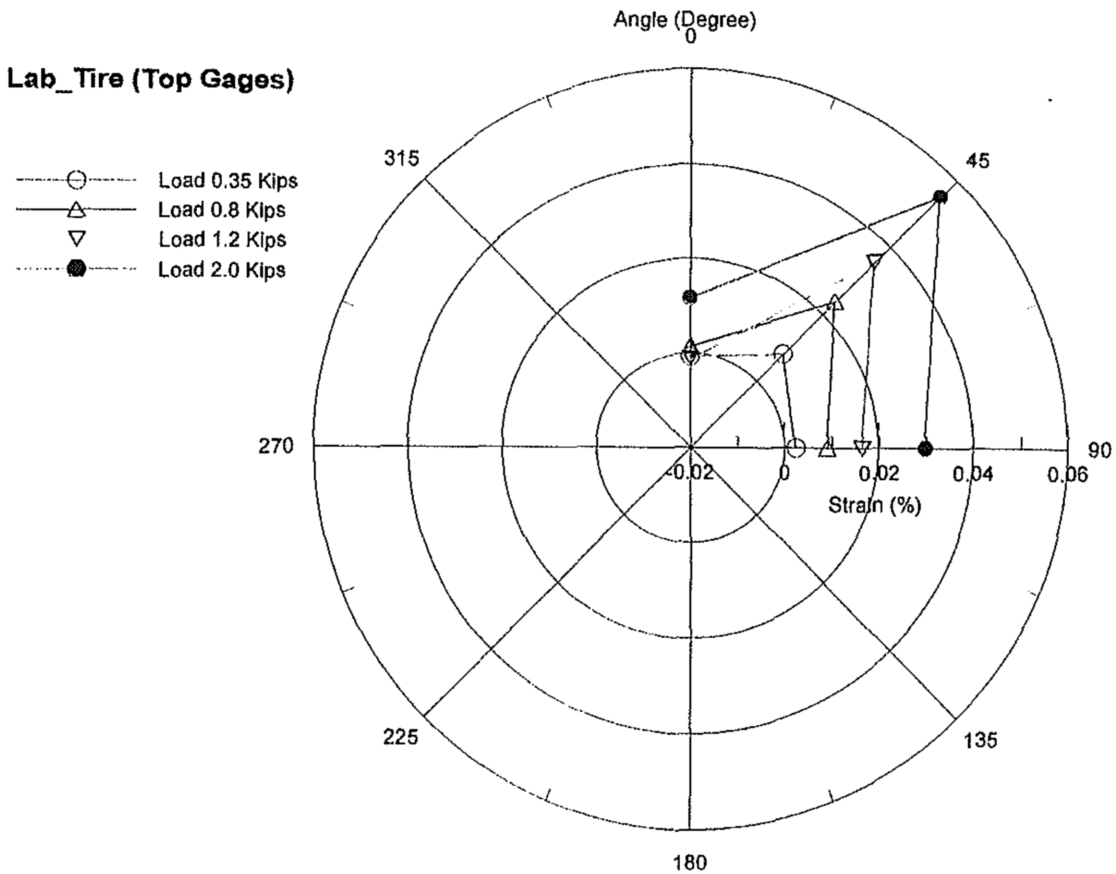


Figure 37. Strain measurements of top gages in tire fill

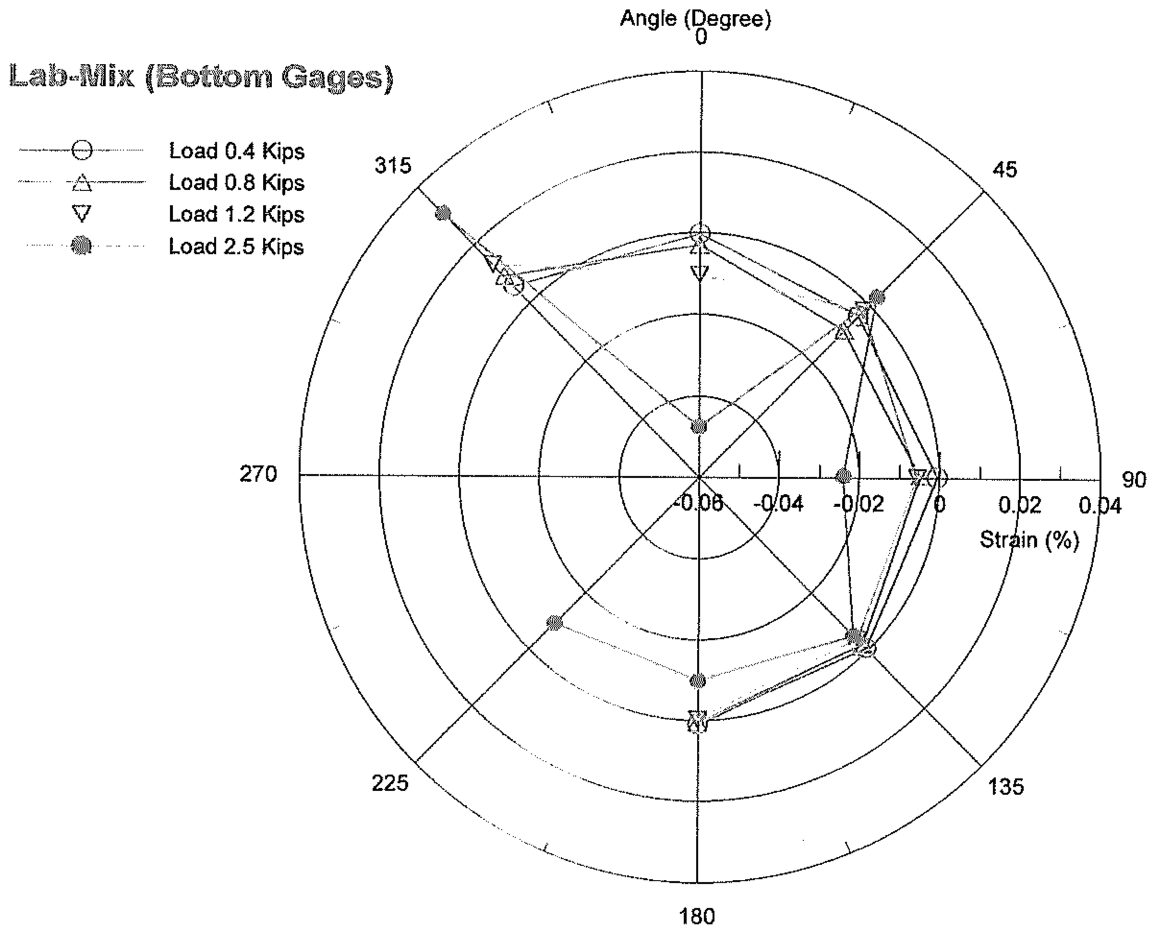


Figure 38. Strain measurements of bottom gages in soil-tire mix

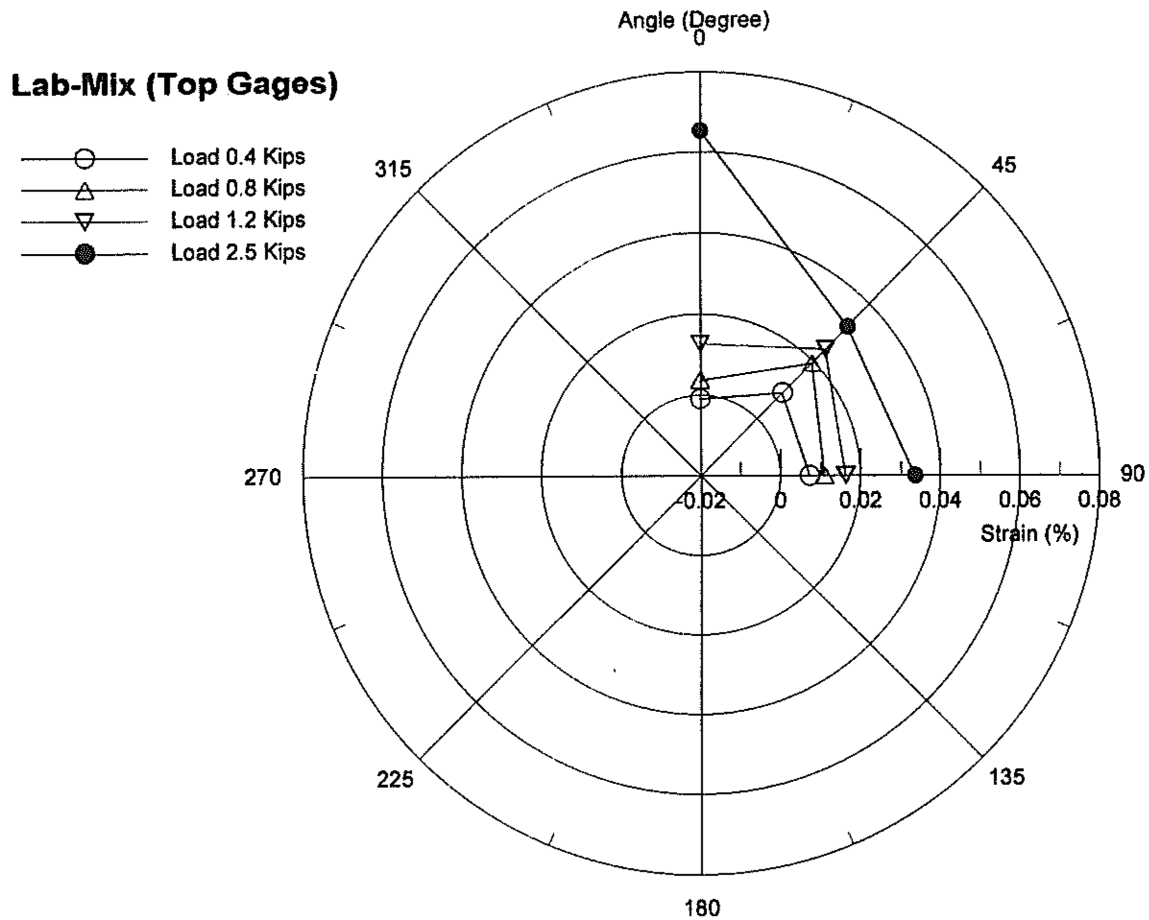


Figure 39. Strain measurements of top gages in soil-tire mix

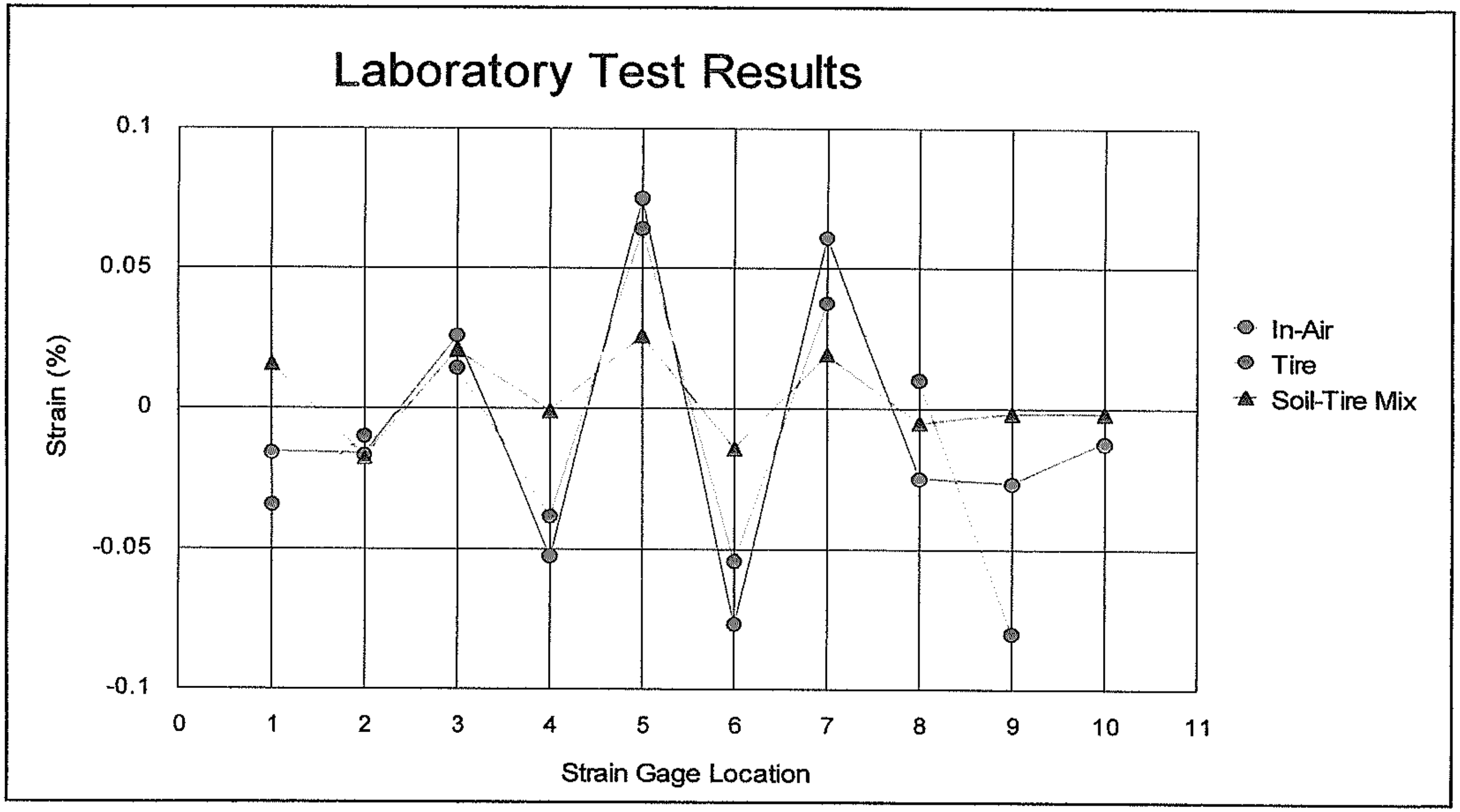


Figure 40. Comparison of strain gages measurements in the laboratory

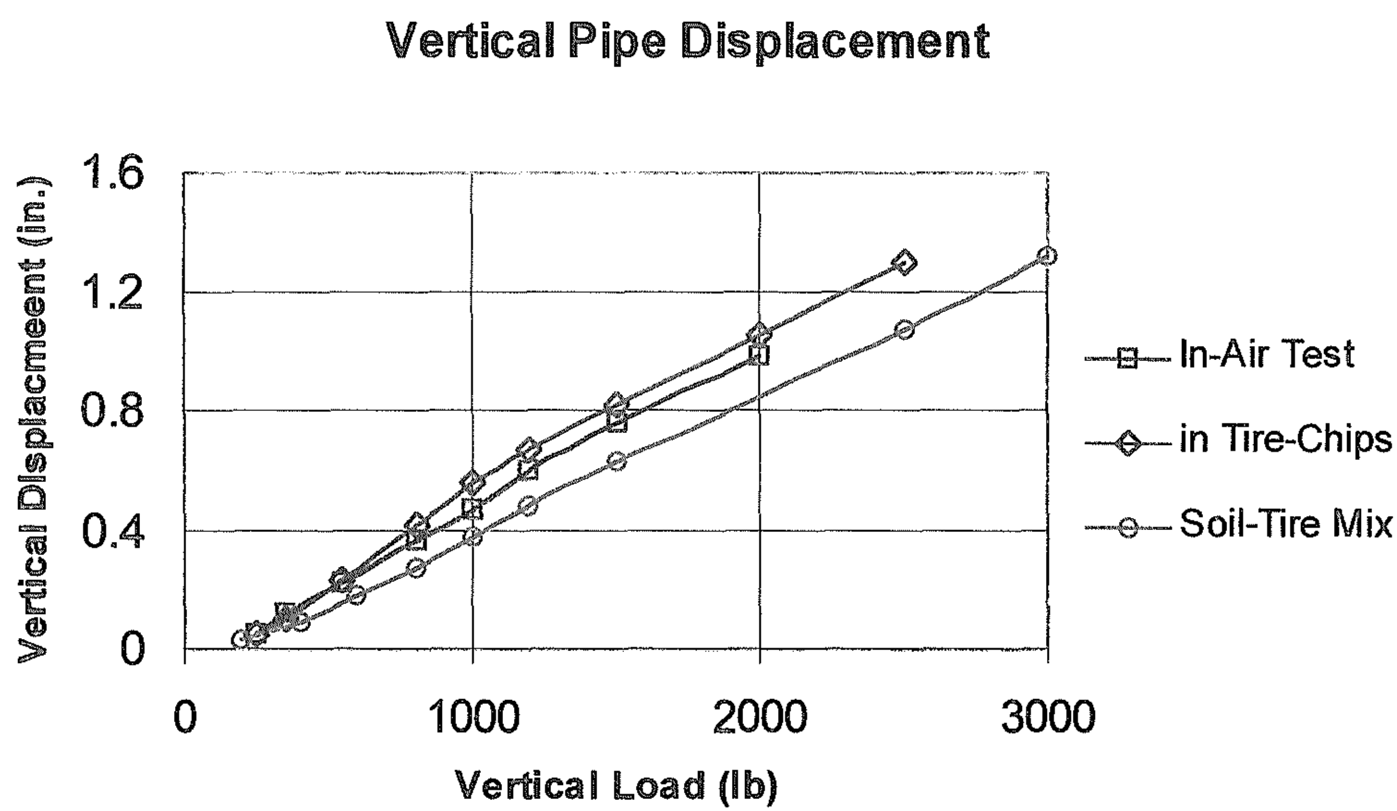


Figure 41. Measurements of vertical pipe displacement by the LVDT

CONCLUSIONS

The research tasks of this study consisted of constructing three test sections with various backfill, monitoring soil and pipe deformation in the field, and monitoring pipe strains under controlled loading in the laboratory. A summary of these tasks and the corresponding conclusions of the study are as follows:

a) Standard equipment and procedures were used in the construction of the test sections. Compaction of the soil section and the soil-tire mix section was performed using a hand-held compactor typically used in compaction of base soils. The compaction of the tire section demonstrated the difficulty of using the standard equipment in compacting tire chips. Tire chips were heaved around the compacted areas due to compactor vibration; and consequently, no improvement in the thickness of the tire layers was observed.

b) Field density was measured in the soil section and the soil-tire mix section using a nuclear density gage. This type of gages was not calibrated to measure the density of tire chips alone and accordingly, no density measurement was taken in the tire section. The study demonstrated the need in developing new procedures for determining the compaction properties of tire chips in the field as well as in the laboratory.

c) The shear strength parameters in the three types of fill were determined in direct shear tests. The tire chips had a frictional angle of 28 degrees with a low cohesion intercept of four kPa (0.6 psi). The silty-clay soil had a friction angle of 27 degrees and cohesion of 20 kPa (3.2 psi). The soil-tire mix was mixed in a ratio of one-to-one by volume and showed a higher friction angle of 39 degrees with similar cohesion intercept of 20 kPa.

d) The vertical deformation at the top of the metal pipe was monitored using the horizontal inclinometer. Measurements at the end of 4 months period after construction showed a vertical settlement of 0.8 inches in the tire section in comparison to an average of 0.45 inches in the soil section. The higher vertical deformation in the tire section can be attributed to the compressibility of the tire cushion under the metal pipe and to the vertical deformation of the metal pipe.

e) Measurements of the settlement plates were not used in the analysis due to difficulties associated with monitoring the initial levels of the plates during construction.

f) Measurements of horizontal soil deformation at the vicinity of the metal pipe were carried out using the vertical inclinometers. The monitoring program continued for a period of one-year after construction. Maximum horizontal movements at the elevation of the pipe were 0.2 inches and 0.35 inches in the soil-tire mix section and soil section, respectively. On the other hand, measurements in the tire section showed a horizontal displacement of 0.65 inches. The higher horizontal displacement in the tire section can be due to the fact that the tire section did not provide sufficient lateral stresses around the metal pipe to restrain its deformation when subjected to the applied vertical pressure.

g) Results of strain gage measurements in the field showed that the pipe deformation in the soil-tire mix section is comparable to the one in the soil section. It can be concluded that the design procedures currently used in estimating stresses in the pipe can also be applied to pipes in soil-tire mix backfill. Further analysis to estimate the stresses in the pipe, based on strain measurements, was not in the scope of this study.

h) The results of strain measurements in the field also showed that pipe deformations in the tire section are fundamentally different than the deformations in soil or soil-tire mix. These results prompted further investigation in the laboratory to compare pipe deformation in the tire with that when the pipe is tested in the air.

i) Strains of the pipe were measured in the laboratory under controlled vertical loads. These tests were conducted with the pipe in the air, in tire chips, and in soil-tire mix. Strain measurements in the pipe with tire chips only showed that the deformations were similar to the ones in the air. It can be concluded that tire chips do not provide the adequate lateral pressures needed to restrain pipe deformation. Alternatively, the use of soil-tire mix provides a better solution than tire chips alone as a fill material. The soil-tire mix demonstrated measurable compaction properties and comparable behavior to the silty soil fill.

REFERENCES

1. Ahmed. I., and Lovell, C., "Use of Waste Materials in Highway Construction: State of the Practice and Evaluation of the Selected Waste Products", Transportation Research Record No. 1345, Transportation Research Board, 1992, pp. 1-9.
2. Upton, R, and Machan, G, "Use of Shredded Tires for Lightweight Fill", Transportation Research Record 1422, 1993, pp. 36-45.
3. Humphrey, D, Sandford. T., Cribbs, M, ands Manion, W. " Shear Strength and Compressibility of Tire Chips for Use as Retaining Wall Backfill", Transportation Research Record 1422, Transportation Research Board, 1993, pp. 29-35.
4. Tatlisoz. N., Benson, C. and Edit, T. " Effect of Fines on Mechanical Properties of Soil-Tire Chip Mixtures", Testing Soil Mixed with Waste or Recycles Materials, ASTM STP 1275, 1997, pp. 93-108.
5. Edit, T., and Bosscher, P., "Engineering Properties of Tire Chips and Soil Mixtures", Geotechnical Testing Journal, ASTM, Vol. 17, No. 4, December 1994, pp. 453-464.
6. Bosscher, P., Edil, T., and Eldin. N., "Construction and Performance of Shredded Waste-Tire Test Embankment", Transportation Research Record No. 1345, Transportation Research Board, 1992, pp. 44-52.

APPENDIX A

SOIL CHARACTERIZATION

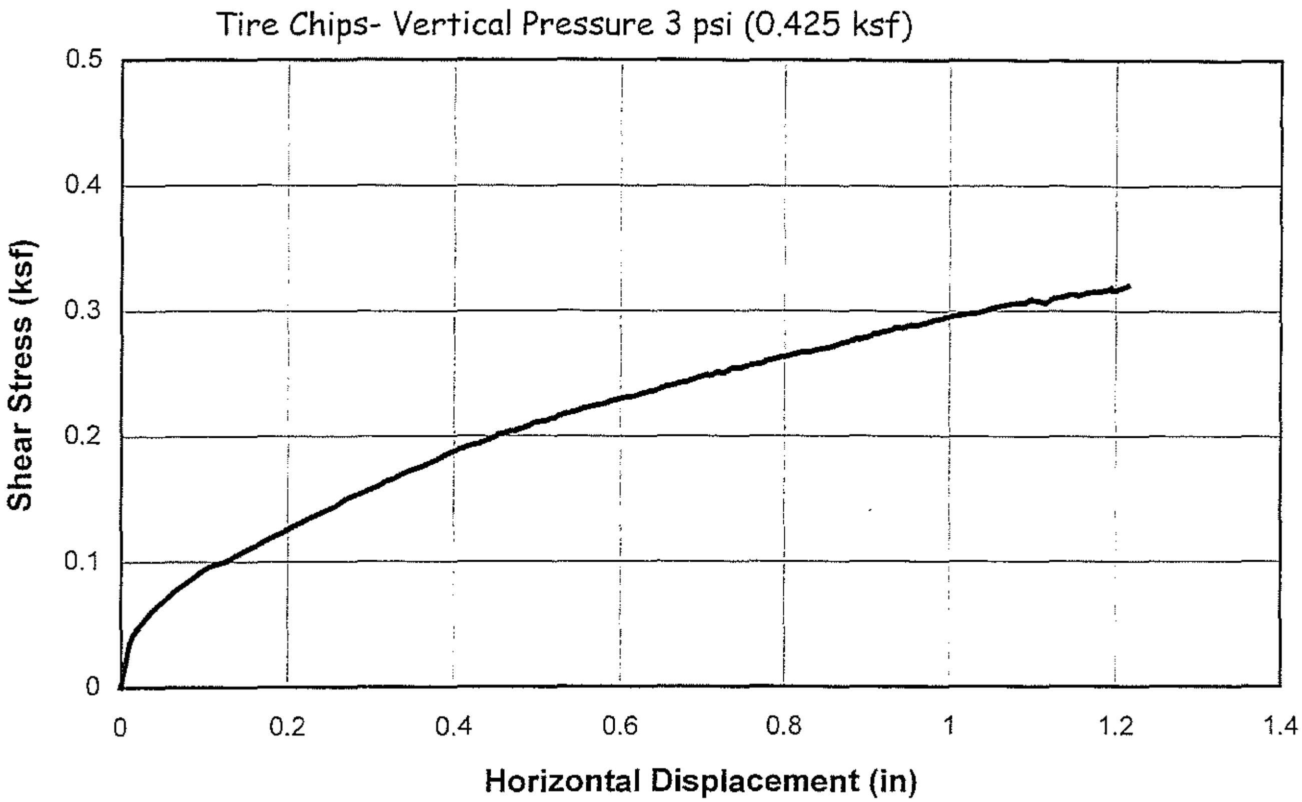


Figure A-1 Direct shear test on tire chips

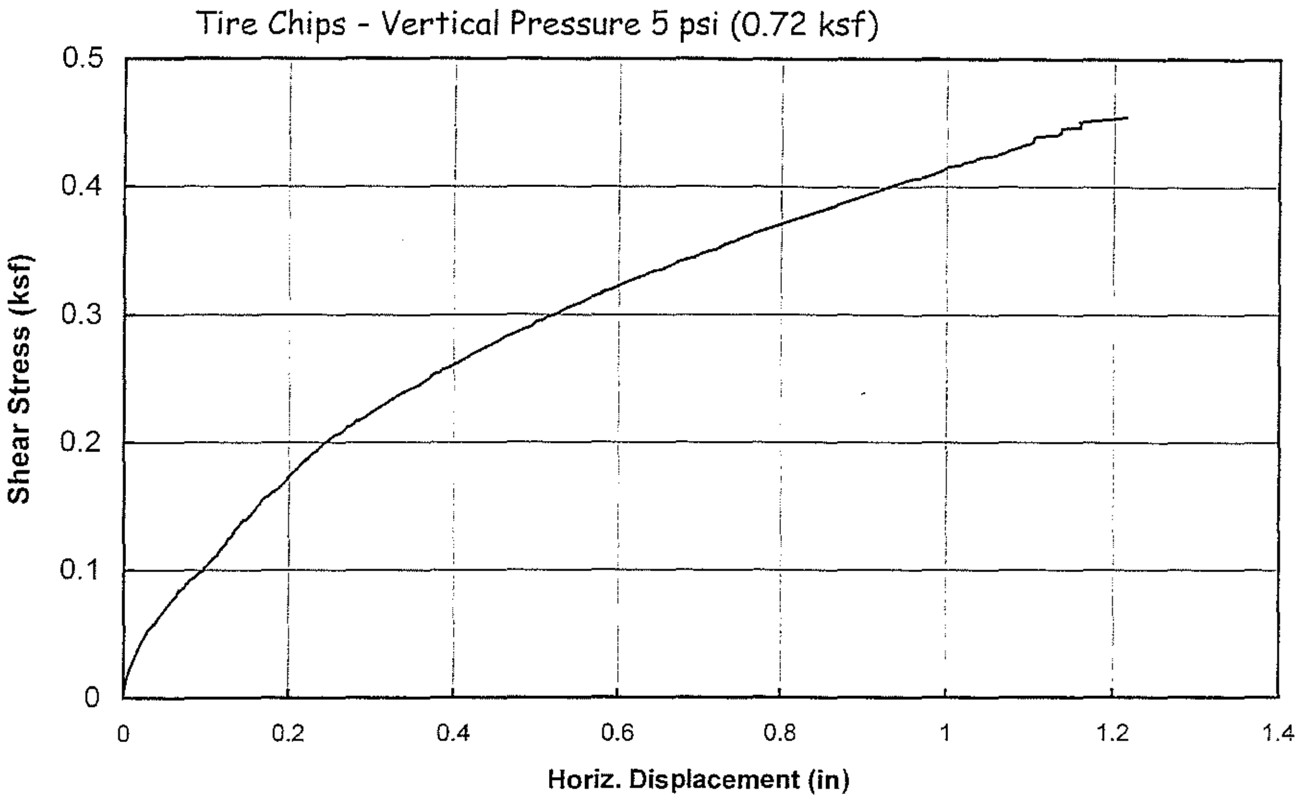


Figure A-2 Direct shear test: on tire chips

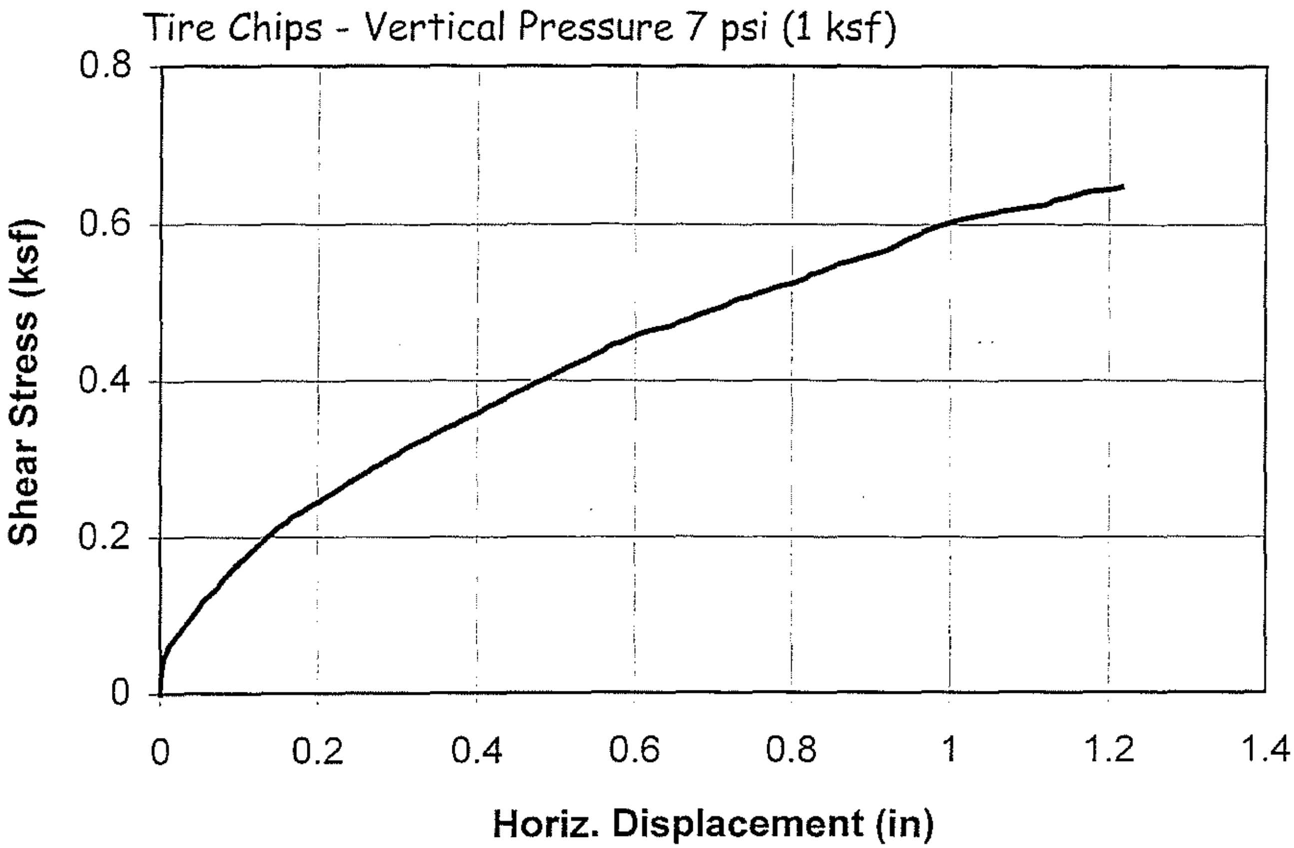


Figure A-3 Direct shear test on tire chips

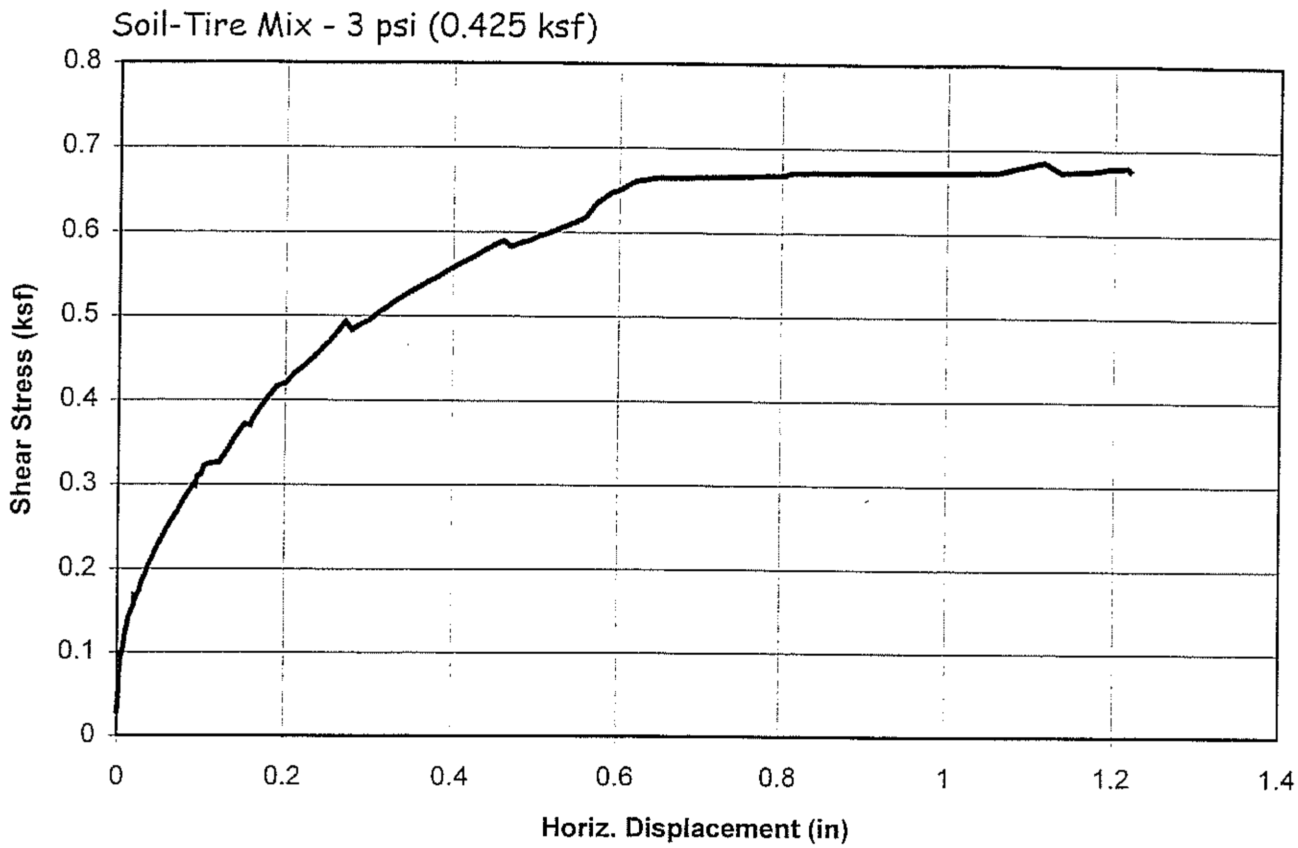


Figure A-4 Direct shear test on soil-tire mix

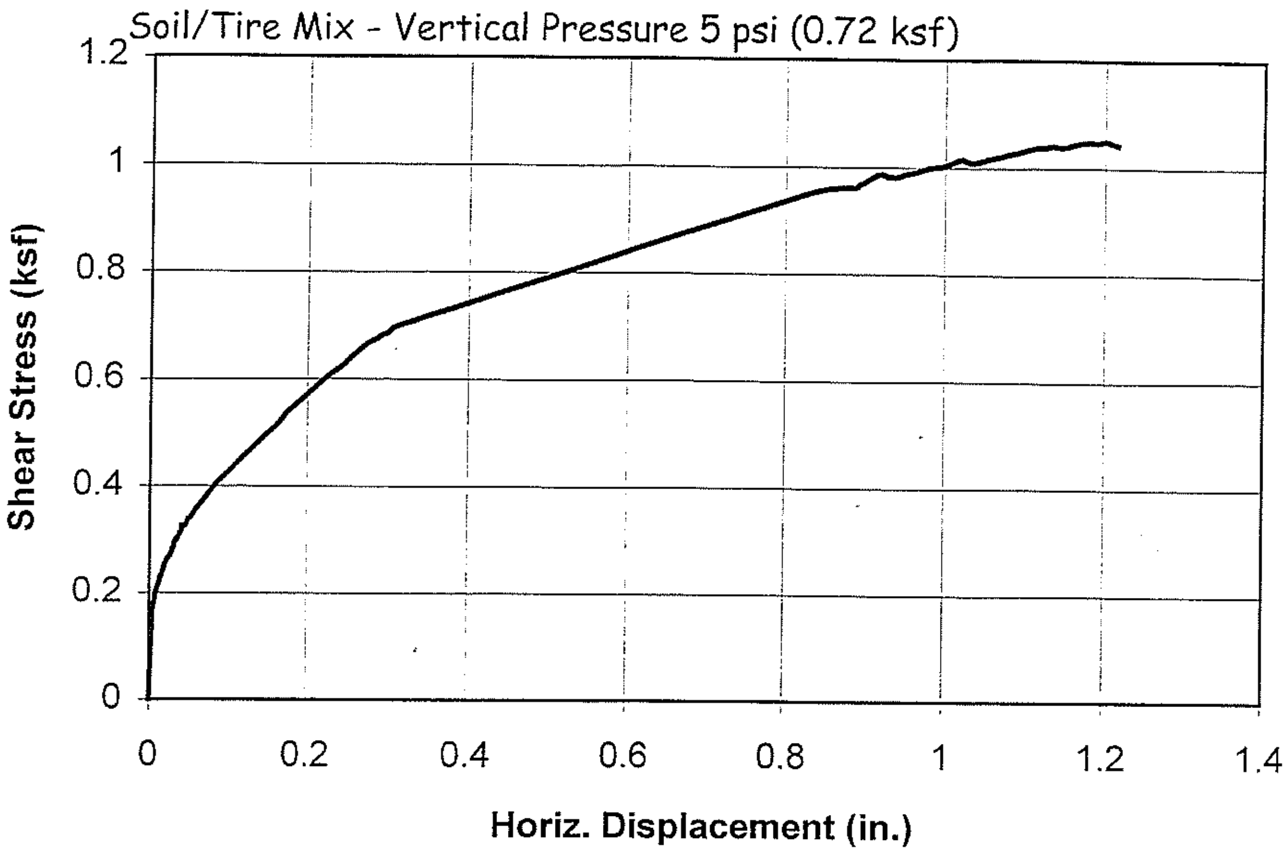


Figure A-5 Direct shear test on soil-tire mix

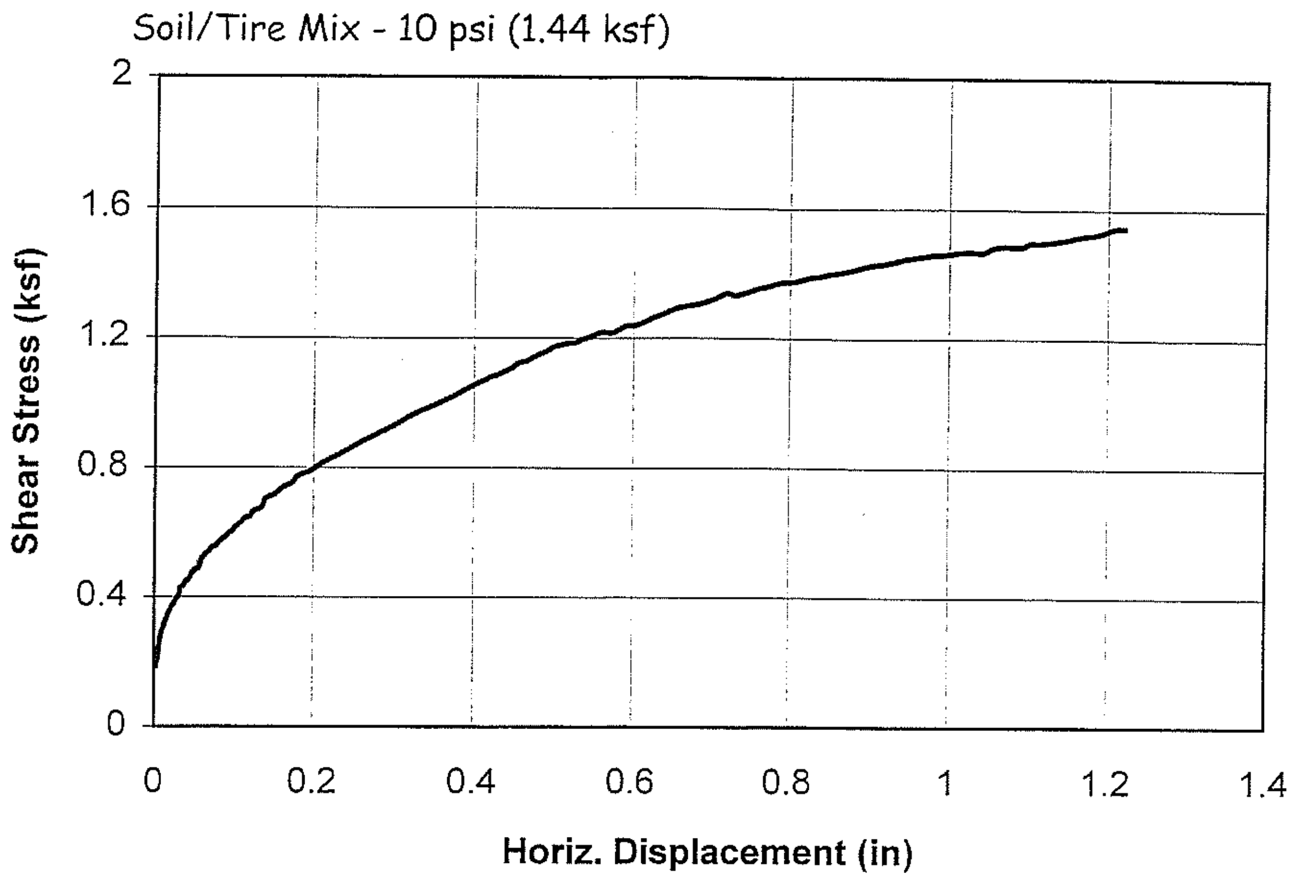


Figure A-6 Direct shear test on soil-tire mix

APPENDIX B

FIELD MEASUREMENTS

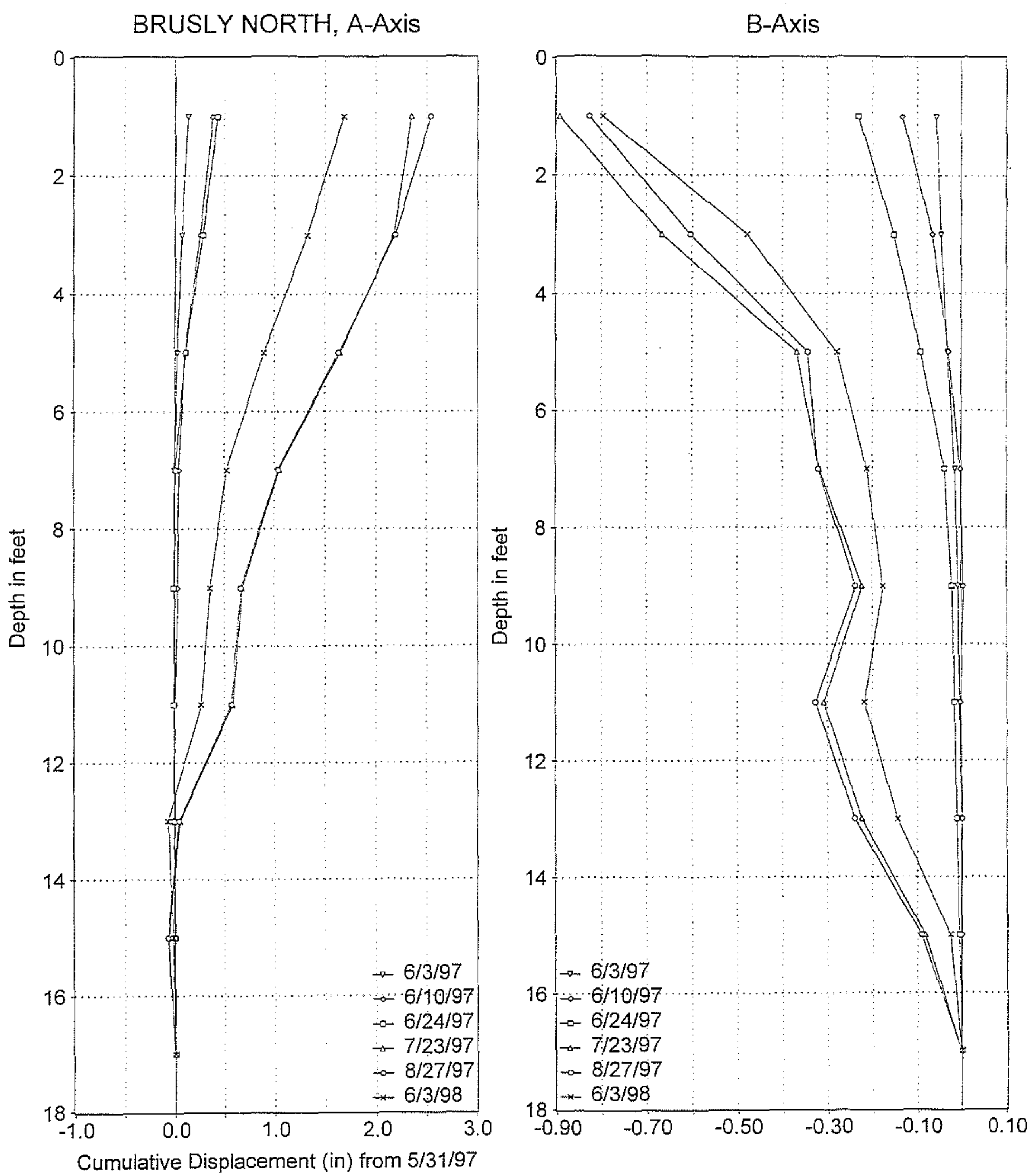


Figure B-1 Vertical inclinometer readings in tire-section

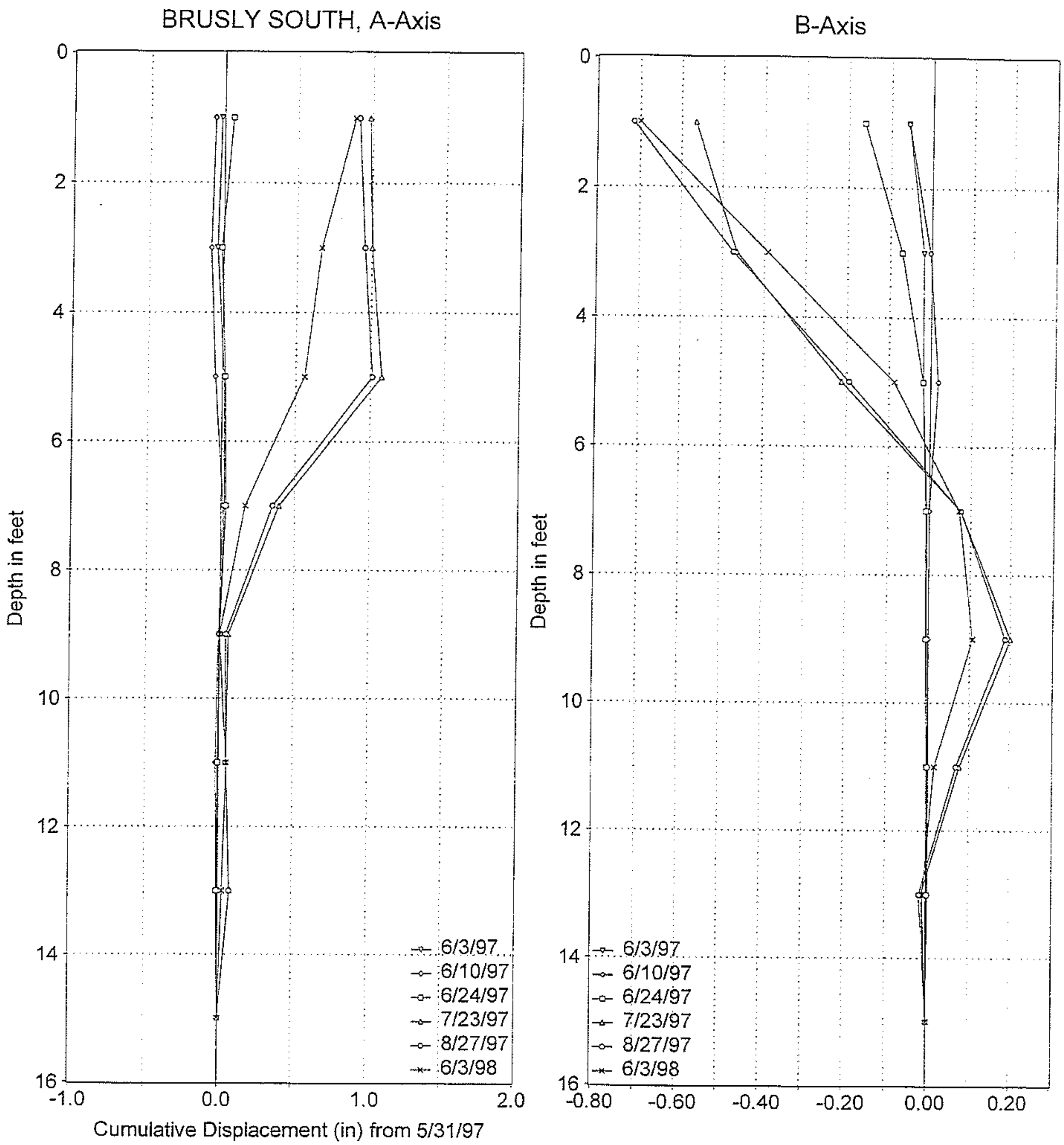


Figure B-2 Vertical inclinometer readings in soil-tire section

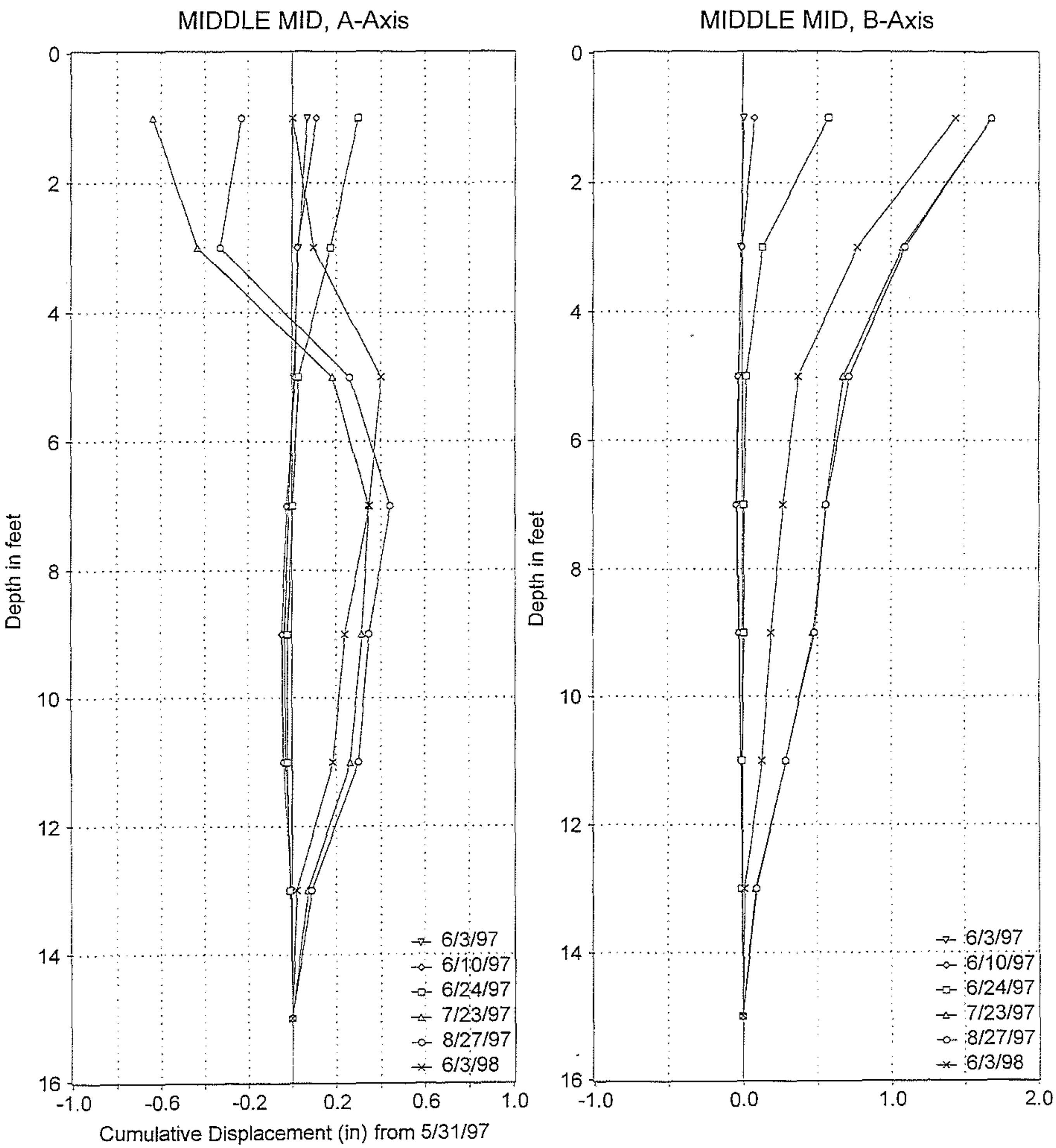


Figure B-3 Vertical Inclinometer readings in soil section

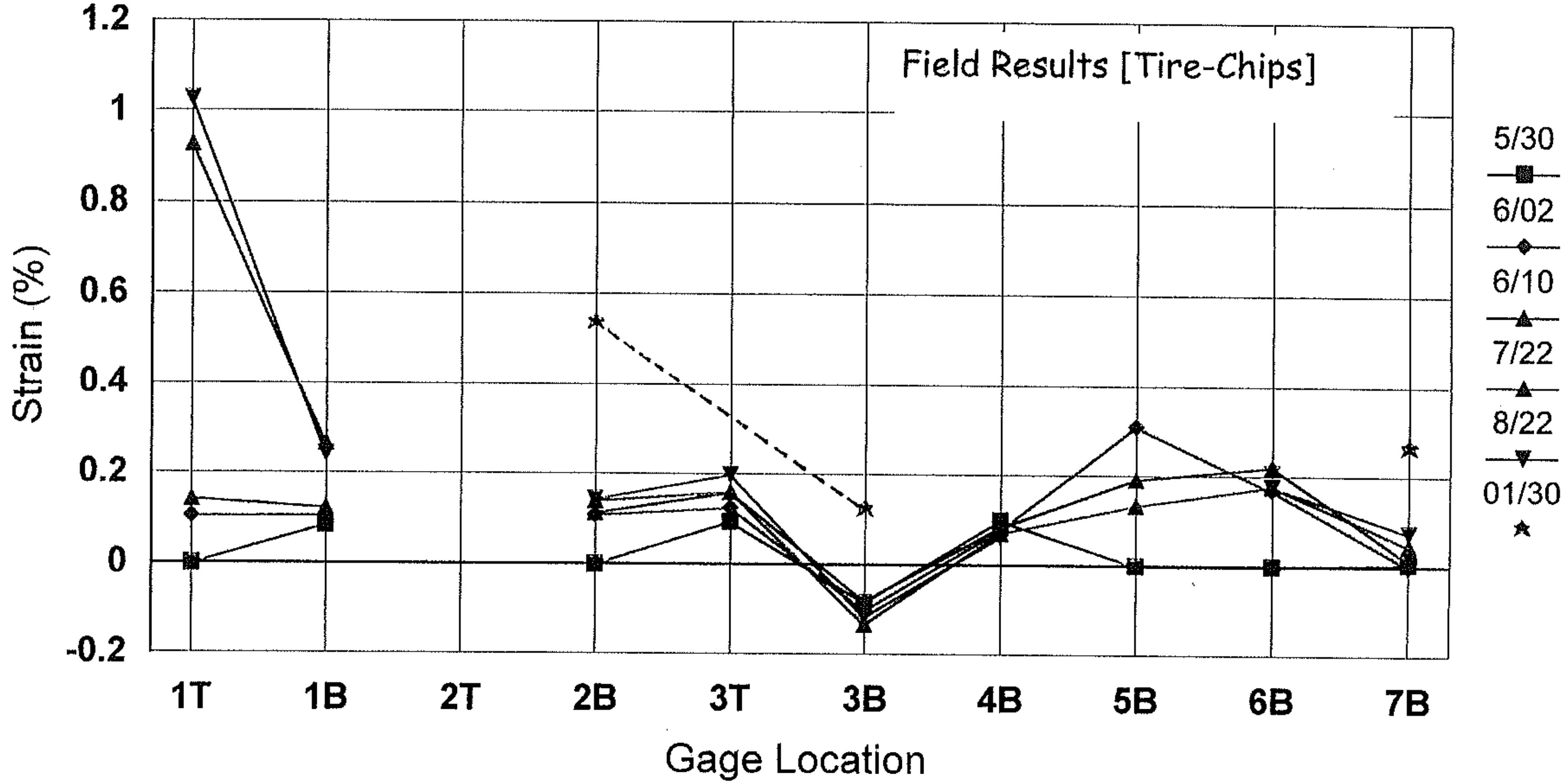


Figure B-4 Strain gage readings in tire section [see figure 14 for gage locations]

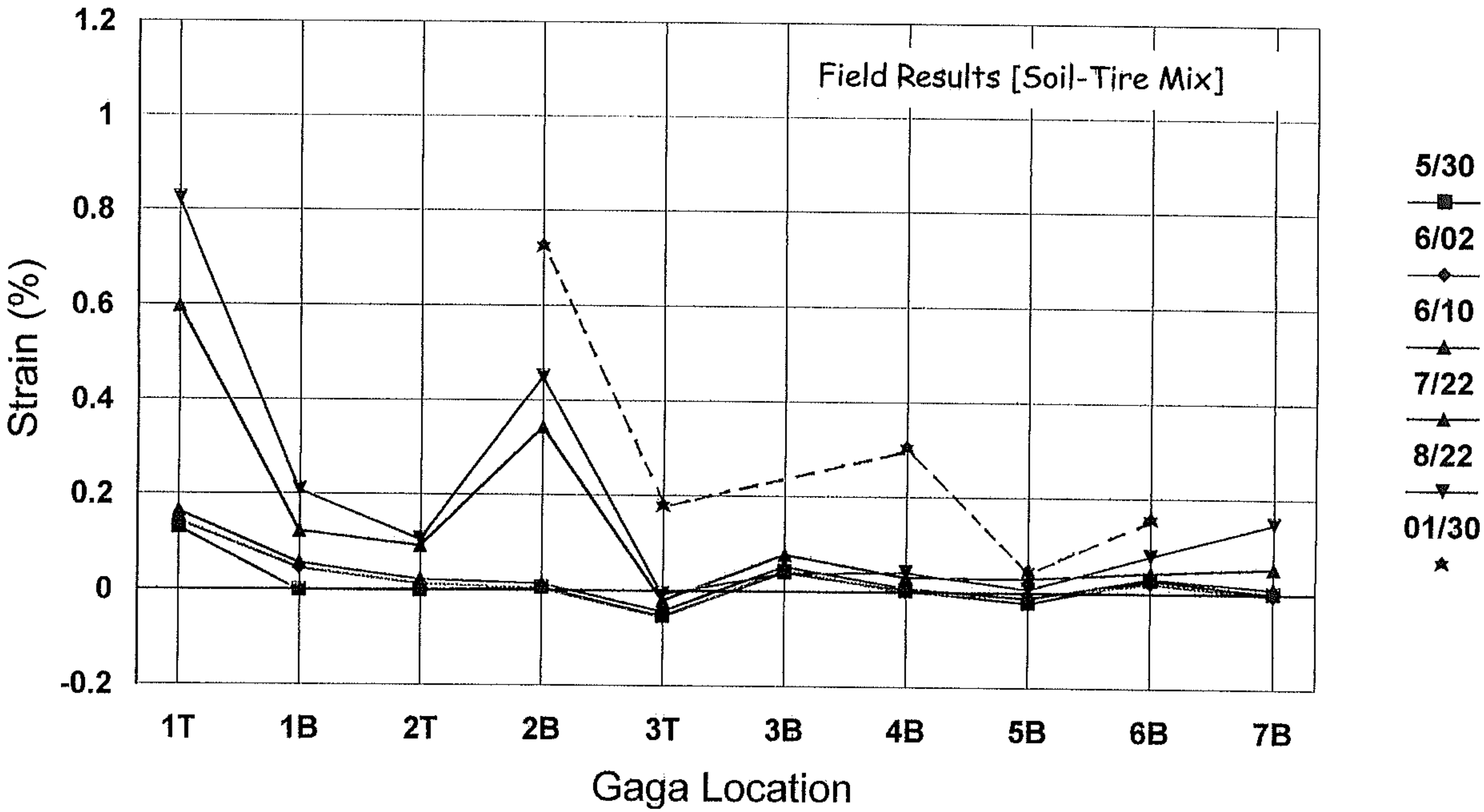


Figure B-5 Strain gage readings in soil-tire section

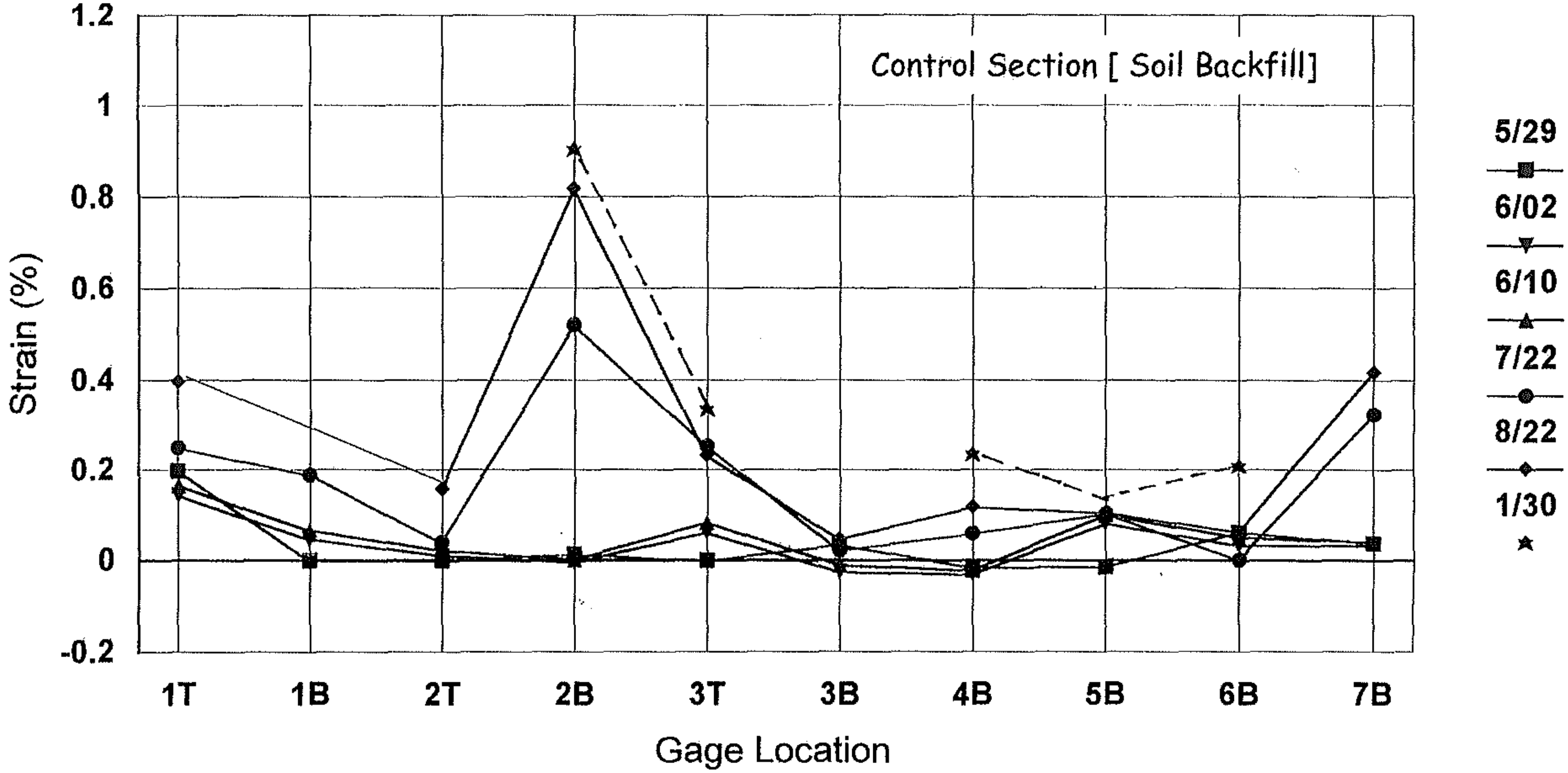
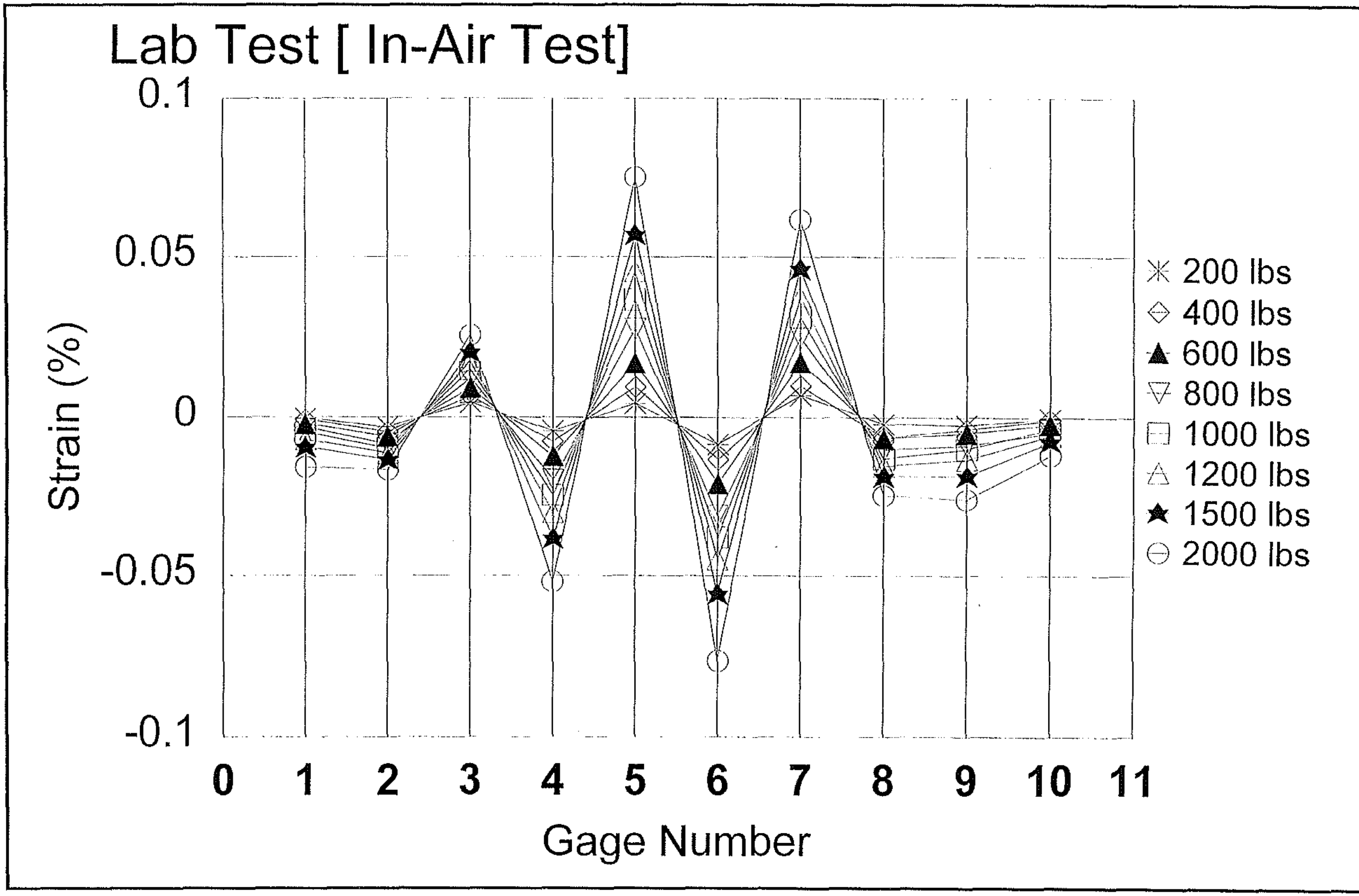
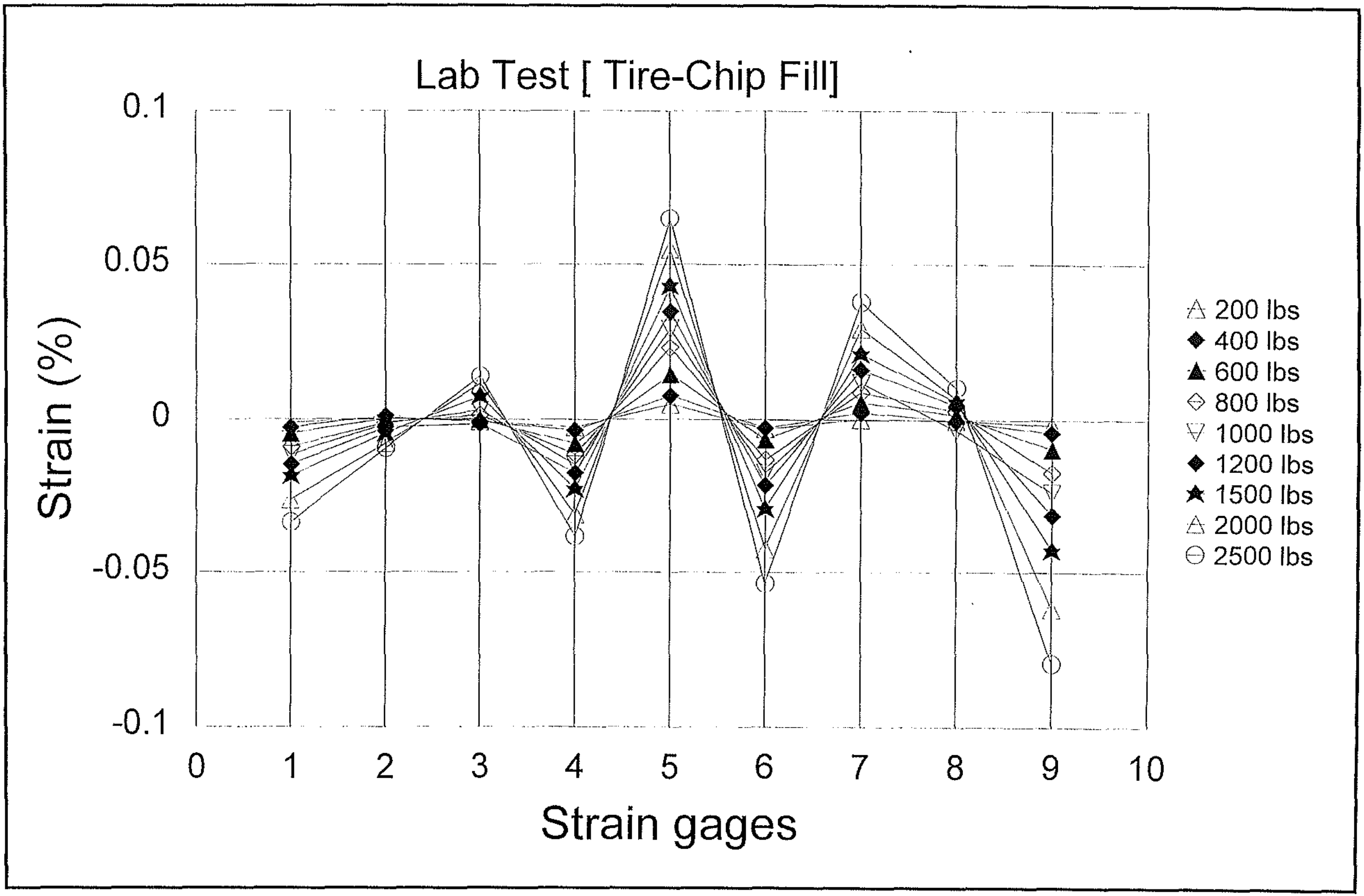


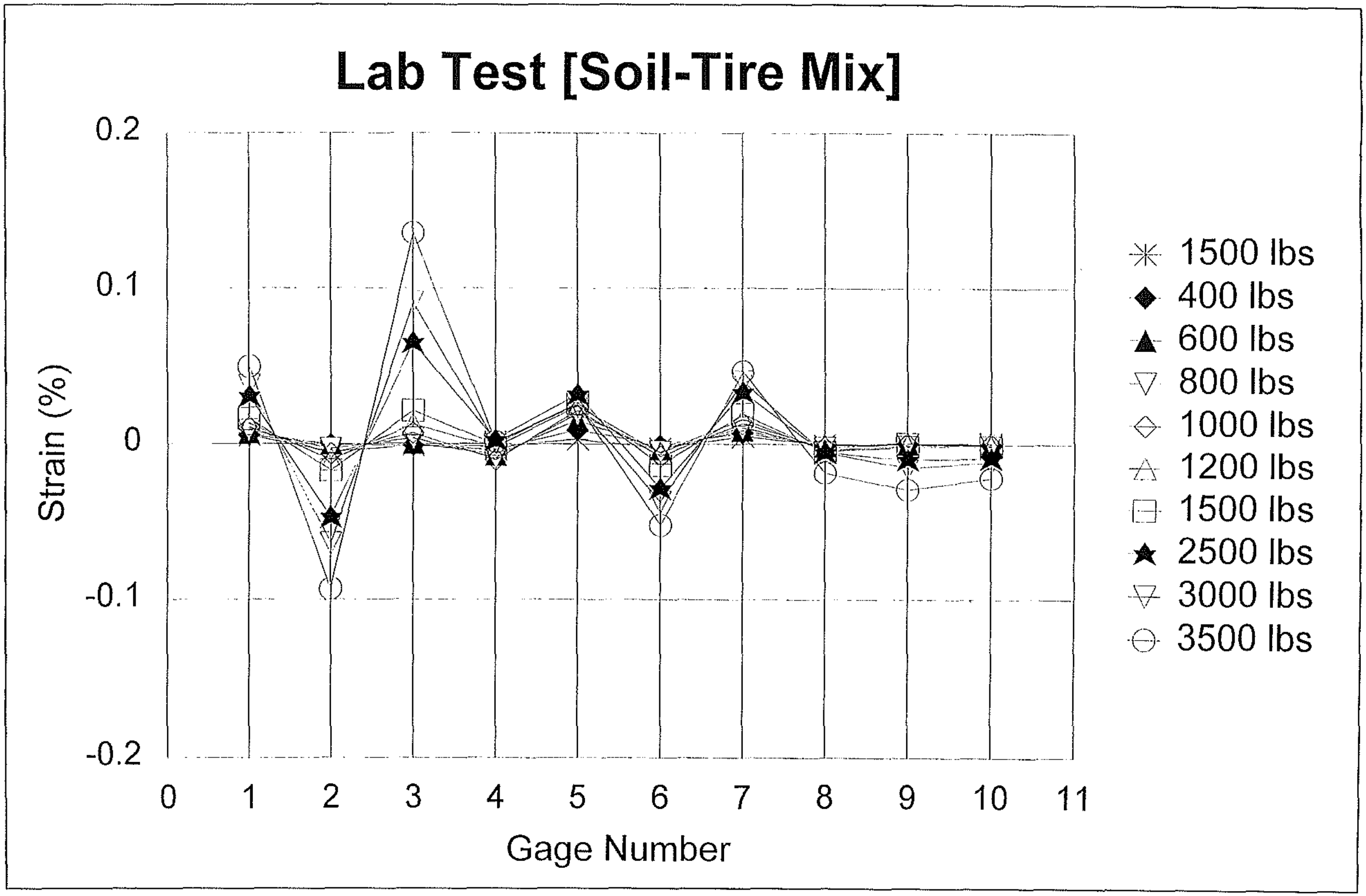
Figure B-6 Strain gage readings in soil section

APPENDIX C

RESULTS OF LABORATORY TESTS


Lab Test [In-Air Test]
0.1
0.05
0
-0.05
-0.1
Strain (%)
0
1
2
3
4
5
6
7
8
9
10
11
Gage Number
200 lbs
400 lbs
600 lbs
800 lbs
1000 lbs
1200 lbs
1500 lbs
2000 lbs


Lab Test [Tire-Chip Fill]
0.1
0.05
0
-0.05
-0.1
Strain (%)
0
1
2
3
4
5
6
7
8
9
10
Strain gages
200 lbs
400 lbs
600 lbs
800 lbs
1000 lbs
1200 lbs
1500 lbs
2000 lbs
2500 lbs


Lab Test [Soil-Tire Mix]
0.2
0.1
0
-0.1
-0.2
Strain (%)
0
1
2
3
4
5
6
7
8
9
10
11
Gage Number
1500 lbs
400 lbs
600 lbs
800 lbs
1000 lbs
1200 lbs
1500 lbs
2500 lbs
3000 lbs
3500 lbs