ARIZONA DEPARTMENT OF TRANSPORTATION

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# EVALUATION OF INCREASED PAVEMENT LOADING

Volume I - Research Results and Findings

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**Prepared for:**
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
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Federal Highway Administration

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**16. Abstract**

The effects of increased truck loads and higher tire pressures on performance of flexible pavements were investigated in this project. This Volume 1 report presents the research performed and the useful results obtained.

Tire pressure studies were performed using both in-field measurements and theoretical simulations of the effects of tire pressures on pavements. Higher tire pressures were found, in general, to reduce pavement life.

A new mechanistic damage model was developed to allow the evaluation of the effects of loads and tire pressures on pavements. A new set of equivalence factors were developed using the damage models. The resulting equivalence factors were incorporated into a computer program to calculate 18-kip equivalent single axle loads. The programs also have the capability to use the AASHTO equivalence factors for the calculation as a basis for comparison. These programs were developed for both static truck weight measurements and weigh-in-motion measurements. A mechanistic pavement design program was also developed using the damage models in order to generate pavement designs that are compatible with the new mechanistic load equivalence factors.

This volume is the first in a two volume set. Volume 2, provides documentation for all of the computer programs developed on the project.

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# CHAPTER 1. INTRODUCTION

## BACKGROUND

Recent increases in legal truck load limits have raised questions regarding the effects on pavement performance, service life and maintenance costs. There is continuing federal and state legislative and lobby interest in increasing the gross allowable truck load, axle loadings, and vehicle dimensions on the basis of energy conservation, availability of truck equipment, and efficiency within the trucking industry. In addition, there is evidence of an increasing percentage of trucks in the vehicular mix and increasing tire pressures on the trucks. Controversy exists regarding the benefits and lack of benefits associated with the potential impact of the increases on highway safety, transportation economics, and maintenance of highway systems. Legislators must make the ultimate decisions, but they need facts on which to base their decisions. Without facts, the decisions would be made solely on a political basis rather than using engineering and economic analyses.

Highway safety and socio-economic impacts of size and weight changes on the Arizona highway system are considered to be outside the scope of this study. Evaluating the effect of the increased loading on pavement service life is the objective of this research. Increased loads, tire pressures and vehicle dimensions will shorten a highway service life and increase the maintenance requirements. Since additional information is needed to make decisions regarding such load increases, it is beneficial to have an estimate of the effects on pavement life of increasing vehicle weight and tire pressure. This research has attempted to quantify the effects of these changes on the applicability of current flexible pavement design procedures and their effect on pavement performance.

The ultimate analysis of the problem of increasing truck size and legal load limits will be an economic one; however, engineers need to first properly quantify the structural impacts as correctly as possible. Size and weight changes have economic implications on many parts of the transportation system, but the effects of greatest concern to the highway engineer are reduced pavement life and associated increased pavement maintenance and life cycle costs.

## OBJECTIVE

The objective of this study is to determine the effects of changes in truck gross weight, axle weight distribution, tire pressures, tire footprints, and axle configuration on pavement performance and to relate these to impacts on Arizona Department of Transportation (ADOT) pavement design procedures.

## SCOPE

This research was directed toward developing a system for estimating changes in the flexible pavement design process as a result of the noted trends in truck traffic. Maximum use was made of existing Arizona traffic and weight data, with field studies made only where data were not available. Case studies were used to verify the accuracy and sensitivity of the procedures. The work involved; (1) a search of available data on file within the Arizona DOT and from the AASHO Road Test, (2) the collection of pertinent field data, and (3) the analysis of these data to develop a computer simulation procedure for predicting the effects of new truck loading conditions. The output from this research is a model for estimating pavement design loadings (number of 18 kip equivalent single axle loads) using the old and "new" estimation techniques.

## RESEARCH APPROACH

The effects of vehicle size, weight, and configuration on pavement performance and maintenance requirements must ultimately be evaluated by means of an economic comparison. This comparison and evaluation can take place only if the effects of current vehicle parameters can be related to pavement stresses and strains, distresses, and finally, overall pavement performance. This approach was used to analyze pavements from each functional classification. These analyses are the basis for determining the effects of new estimates of the number of 18-kip equivalent single axle loads (18KESAL) on pavement designs. The techniques were largely by simulation, i.e., the use of mechanistic or phenomenological models to predict changes in pavement response. The basic research approach to this problem included:

1. Review current ADOT truck traffic data to ascertain what measurements were required and what data already existed.

2. Review how the number of estimated equivalent axle loads is normally calculated in the ADOT design process.

3. Analyze the loads which occur under the tires of commercial vehicles in Arizona.

4. Estimate the contribution of tire pressure to load effects.

5. Develop a model to allow the comparison of different loading parameters.

6. Estimate the effect of "new" design considerations such as steering axles and tire pressures on estimated pavement life as compared to current design considerations.

7. Develop computerized procedures for estimating the number of equivalent axle loads as a function of all the pertinent variables.

8. Recommend changes to current ADOT flexible pavement design procedures based on the updated procedure for estimating equivalent axle loads.

OVERVIEW OF REPORT

This is Volume 1 of a two-volume final report for a project to evaluate the effects of increased pavement loading. It is organized by the logical progression of tasks to the final results of a computer model which uses the current AASHTO method and the new mechanistic method developed on this project for 18KESAL prediction. Chapter 2 is a discussion of the preliminary studies performed at the beginning of the project. Chapter 3 discusses the development of roughness based damage models. Chapter 4 is a summary of how the new damage models were used to develop mechanistic load equivalence factors. Chapter 5 is a description of the field investigations used in development of the models. Chapter 6 describes some special studies that were performed for various purposes on the project. Chapter 7 covers the development of the computer models resulting from the research. Chapter 8 discusses testing of the computer models for verification of results and sensitivity to inputs. Finally, Chapter 9 presents the conclusions and recommendations including observations concerning ADOT design procedures. Volume 2 (Ref 1) is a users' manual for the computer programs produced on this project.

# CHAPTER 2. PRELIMINARY STUDIES

A number of preliminary studies and background reviews were made at the beginning of the project. These were to provide the research team with current information on highway loading, equivalent load calculation and Arizona's methods of load prediction and pavement design.

## BACKGROUND REVIEWS

Background reviews were made on available literature pertaining to the study and on current ADOT procedures for data analysis and design. The following sections describe those reviews.

### Literature Review

A literature review was made to locate important, applicable references for the project. Many references were obtained and reviewed and are presented in the reference list of this report. These documents were reviewed to extract usable project information. For example, current research at the University of Texas is involved with studying the tire pressure distribution on pavement surfaces and the effect of varying inflation pressures on strains and fatigue life of a pavement (Refs 2, 3, 4, 5, 6, and 7). Also, an experimental study of truck tire pressures on Texas highways was recently done by the Texas Transportation Institute (Ref 8). Another study performed by TTI was titled "Effects of Higher Tire Pressures on Strain in Thin ACP" (Ref 9). These studies produced results applicable to this research project on the effects of increased pavement loading and tire inflation pressures. Other references provided information on subjects such as weigh-in-motion studies, dynamic loading, changes in legal load limits, traffic characteristics and new tire characteristics.

### Review of ADOT Procedures

Current procedures used by ADOT for traffic data analysis and pavement design were reviewed. The ADOT "Materials - Preliminary

Engineering and Design Manual" (Ref 10) was studied to determine how equivalent axle loads were currently used in the new pavement design process. A report entitled "Overlay Deflection Design Method for Arizona" (Ref 11) was also examined for background on ADOT's overlay design method and to choose pavement sections for comparing equivalent load predictions between old and new methods.

Information was obtained from ADOT concerning their traffic data analysis procedures. The following information pertaining to traffic volume, classification, and weight was taken from an ADOT memorandum on this subject.

The Arizona Transportation Planning Division (TPD) is responsible for collection and publication of traffic data. There are three types of traffic data which are collected.

<u>Traffic Volume</u>. The TPD has automatic traffic recording (ATR) devices that obtain samples from 968 locations. This data is published annually in the "Traffic on Arizona Highway System Logbook".

<u>Traffic Classification</u>. Samples of the traffic mix are collected annually at 128 locations. This operation has been done by a manual count of the number of vehicles in each of the following categories:

| | Abbreviation |
|---|---|
| * Light Trucks | LT |
| * Medium Trucks | MT |
| * Tractor Semi-trailer | TS |
| * Tractor Trailer | TT |
| * Tractor Semi-trailer Trailer | TST |
| * Buses | |
| * Automobiles | |

The "commercial vehicles" include the first five vehicle categories shown above.

A five-year moving average of classification data is used to estimate the distribution among vehicle categories.

Figure 2.1 shows typical configurations of each of the vehicle types and their grouping into one of the general categories shown above.

Truck Weight. Every other year, the TPD conducts a truck weight study (also called a loadometer study) which is a sample of the axle weights of 12 vehicle types. These data are sent to Washington D.C. where an FHWA computer program generates a report consisting of six tables of data, labeled W-2 through W-7. The W-4 table contains the information needed to develop the representative equivalent single axle loads for each vehicle category.

## DATA COLLECTION

Early in the project, an effort was made to collect existing data in several important areas. The types of data included the following:

- data from tire manufacturers and researchers concerning current design tire pressures, loads and the shape, size and pressure distribution of tires in contact with a pavement surface,
- vehicle weight data from the 14 port of entry weigh stations in Arizona,
- ADOT traffic volume and classification data from throughout Arizona,
- ADOT overlay design and traffic analysis programs,
- data on typical Arizona pavement cross-sections, and
- rod and level elevation data and Mays Meter roughness measurements on four Arizona highway sections.

## VEHICLE CLASSIFICATIONS

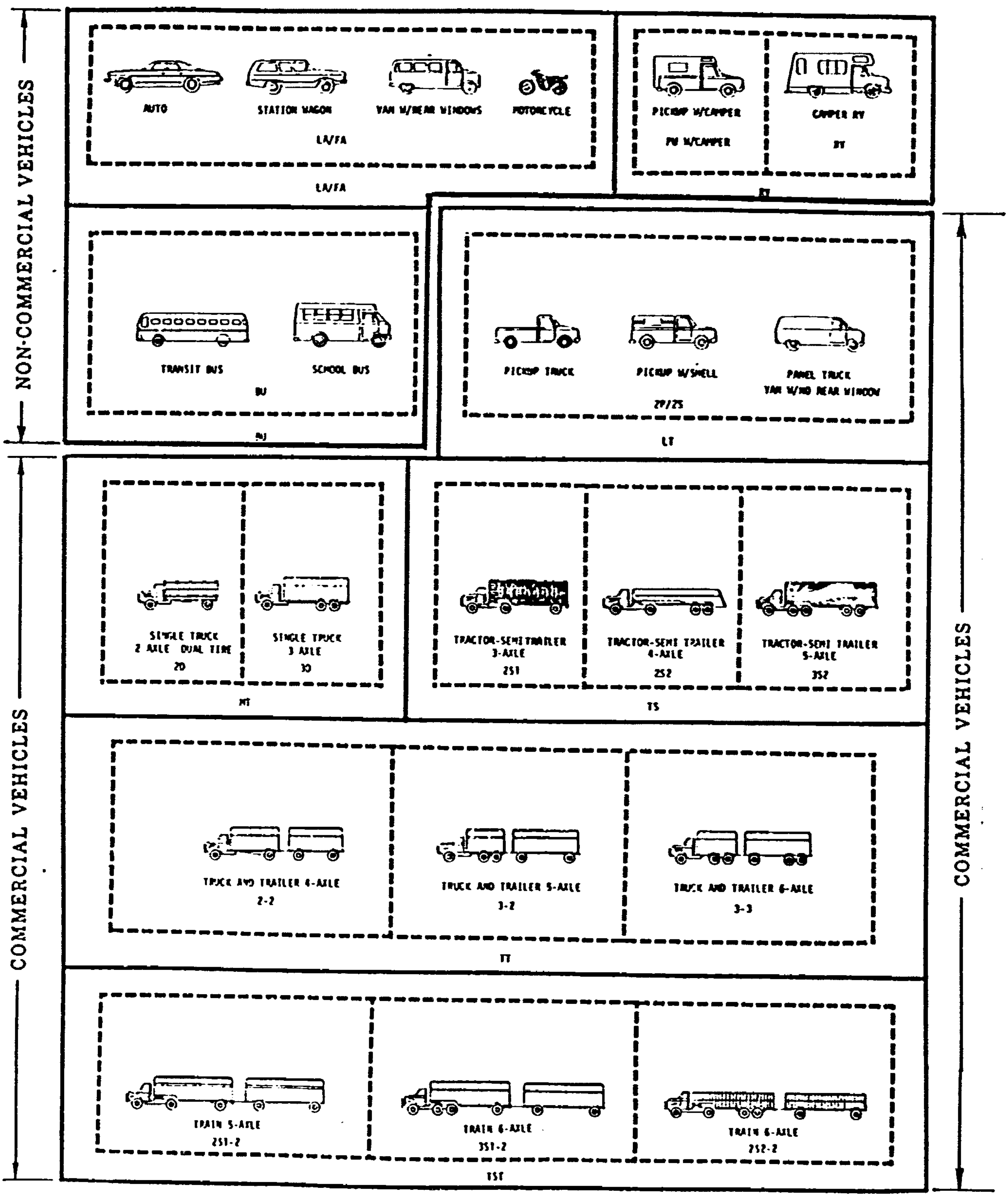



Figure 2.1. Configurations included in the five vehicle classifications of Arizona.

The data were used for different purposes, each described separately in the following sections.

Tire Data

A number of sources were examined for information on truck tire footprint size and shape, and the distribution of pressures over the footprint area. Data was obtained from the AASHO Road Test, the previously mentioned Texas A & M University and University of Texas research studies, tire manufacturing companies, and tire researchers.

AASHO Road Test Traffic Report. Table 2.1 summarizes the relevant data found in AASHO's "Traffic Operations and Pavement Maintenance" report (Ref 12). This table illustrates tire pressure levels that were used for the AASHO Road Test.

Texas A&M Research. The Texas Transportation Institute (TTI) of Texas A&M University conducted research entitled "Effects of Higher Tire Pressure on Strain in Thin ACP" (Ref 9). Two computer models used in the TTI study were the Tielking Tire Model (Ref 13 and 14) and the ILLIPAVE Model (Ref 15). The Tielking Tire Model (TTM) was used to calculate tire contact boundary and interface pressure distributions for a specified tire deflection given inputs of material properties and shape of the tire. An example of the pressure distribution output from this model is shown in Figure 2.2. The pressure distribution from the TTM was an input to the ILLIPAVE computer program. Results concerning the effects of increased tire pressure on pavement performance as reported by TTI were used to formulate working hypotheses on this project and are presented in Chapter 6, "Tire Pressure Studies".

University of Texas Research. The University of Texas (UT) is currently performing a laboratory study of tire footprint pressure distributions (Refs 2, 3, 4, 5, 6, and 7). The Mechanical Engineering Department and the Center for Transportation Research are collaborating on this project for the Texas Highway Department.

Table 2.1. Summary of loads, tire type, tire pressure and contact area used on trucks in the AASHO Road Test.

| Tire Load(lbs) | Tire Size & Ply Rating | Tire Pressure[1](psi) | Gross Contact Area($in^2$) | Unit Ground[2] Pressure(psi) |
|---|---|---|---|---|
| 1,000 | 6.70 x 15/4[3] | 24 | 36.6 | 29.1 |
| 1,500 | 7.00 x 16/6 | 45 | 37.4 | 42.3 |
| 3,000 | 7.50 x 20/10 | 75 | 45.4 | 65.7 |
| 3,000 | 7.50 x 20/10 | 75 | 45.4 | 65.7 |
| 4,500 | 10.00 x 20/12 | 75 | 67.8 | 67.5 |
| 4,000 | 9.00 x 20/10 | 75[4] | 59.3 | 69.5 |
| 5,600 | 11.00 x 20/12 | 75 | 77.7 | 66.4 |
| 5,000 | 11.00 x 20/12 | 75 | 77.7 | 66.4 |
| 7,500 | 12.00 x 24/14 | 80 | 97.3 | 69.7 |
| 6,000 | 12.00 x 20/14 | 80 | 86.4 | 69.8 |

[1] Taken with tires at approximately the prevailing atmospheric temperatures and do not include any inflation build-up due to vehicle operation as per Tire and Rim Association standard.

[2] Calculated with assumption of uniform pressure.

[3] Tubeless tire; Tire and Rim Association standard inflation pressure is 28 psi for 1,065-lb load.

[4] Tire and Rim Association standard inflation pressure is 70 psi for a recomended maximum load of 3,960 lb. This tire was operated at 75 psi inflation pressure and the data given for this pressure are at a load of 4,120 lb. A measured value of the gross contact area was not available for these conditions, but was assumed to be the same as that for 3,960-lb load at 70 psi.

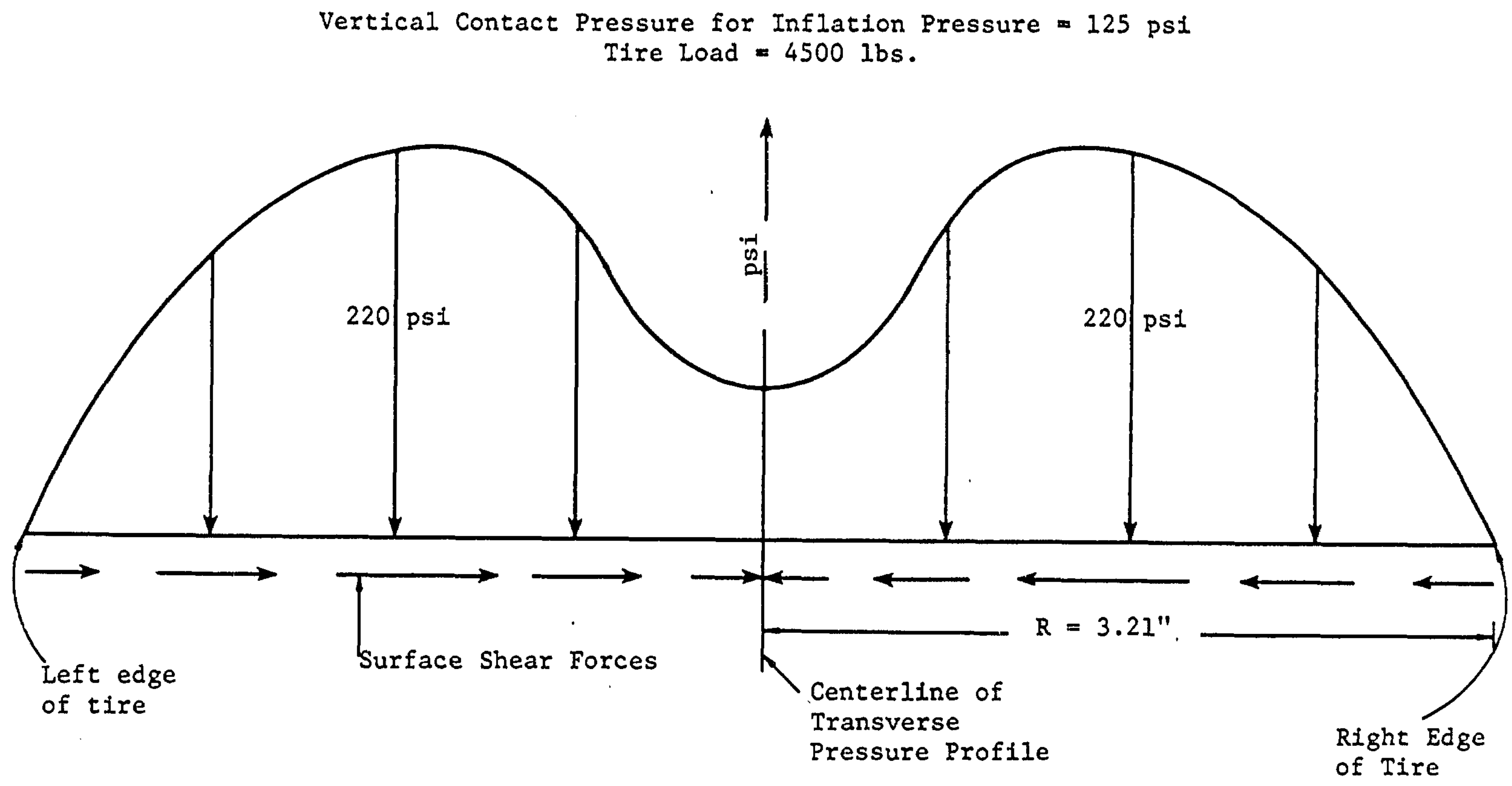



Figure 2.2. Non-linear vertical tire pressure distribution with lateral surface shear forces as developed using finite element model by Tielking (Refs 13 and 14).

The test variables included in this study are tire type, axle load, and inflation pressure. The tires being tested are a bald 10D20 (bias ply) tire and a treaded 10D20 (bias ply) tire. Pressure distribution data was recorded for tire loads of 4500 lb and 5400 lb and tire pressures equal to 75, 90 and 110 psi. Tire pressure distribution was measured with calibrated pressure sensitive paper that becomes darker as pressure is increased. Special optical equipment is used to transform the results on the paper into measurements of pressure.

Preliminary data corresponds well with that from a tire manufacturing company which will be designated as Company B even though the tires being tested are bias ply and those used by Company B were radials. The data supplied by several tire companies is described in the next section. The UT study has found that for the truck tires being studied, static pressure is highest at the tires edge and lowest near the center. More details from this study are discussed in Chapter 6, "Special Studies".

Tire Companies. Information on the contact pressure distributions and footprint shape was requested from a number of tire manufacturers. Two companies which will be designated as A and B sent valuable information. Table 2.2 summarizes the data sent to ARE Inc by Tire Company A. Pressure distribution data for each tire was also included. Figure 2.3 indicates that the area of highest pressure occurs at the edge of a static tire (295/75R22.5) footprint while the highest pressure occurs at the center of a 11R22.5 rolling tire (Figure 2.4). An illustration of these footprints (shown in Appendix A) suggests that the shape is more rectangular than circular.

Company B provided footprint pressure data for a 10.00R20 (radial) rolling truck tire. The pressure data includes normal, lateral, and circumferential pressures (see Figure 2.5). Table 2.3 contains a sample of the data provided by Company B. It shows what the tire company calls "normal stress" at many points under the tire. Normal stress is simply the downward pressure at the tire/pavement interface. Figure 2.6 illustrates a plot of the lateral pressure distribution from the company B data. The two lines represent tire pressures of 65 and 105 psi along the footprint

Table 2.2. Summary of information provided by Company A.

| Tire Load(lb) | Tire Size & Ply Rating | Tire Pressure (psi) | Type of Load |
|---|---|---|---|
| 5300 | 295/75R[2] 22.5 | 87[3] | Static |
| 4780 - 5780[4] | | 90 - 120[5] | |
| 5300 | 11R 22.5 | 95 | Rolling |
| 4760 - 6240 | | 90 - 120 | |

Notes:

[1] See Appendix A for footprint illustrations.

[2] Radial.

[3] See Figure 2.3 for the footprint pressure distribution of a static tire print (275/25R22.5) and Figure 2.4 for the footprint pressure distribution of a rolling tire print (11R22.5).

[4] Load Range.

[5] Tire pressure range.

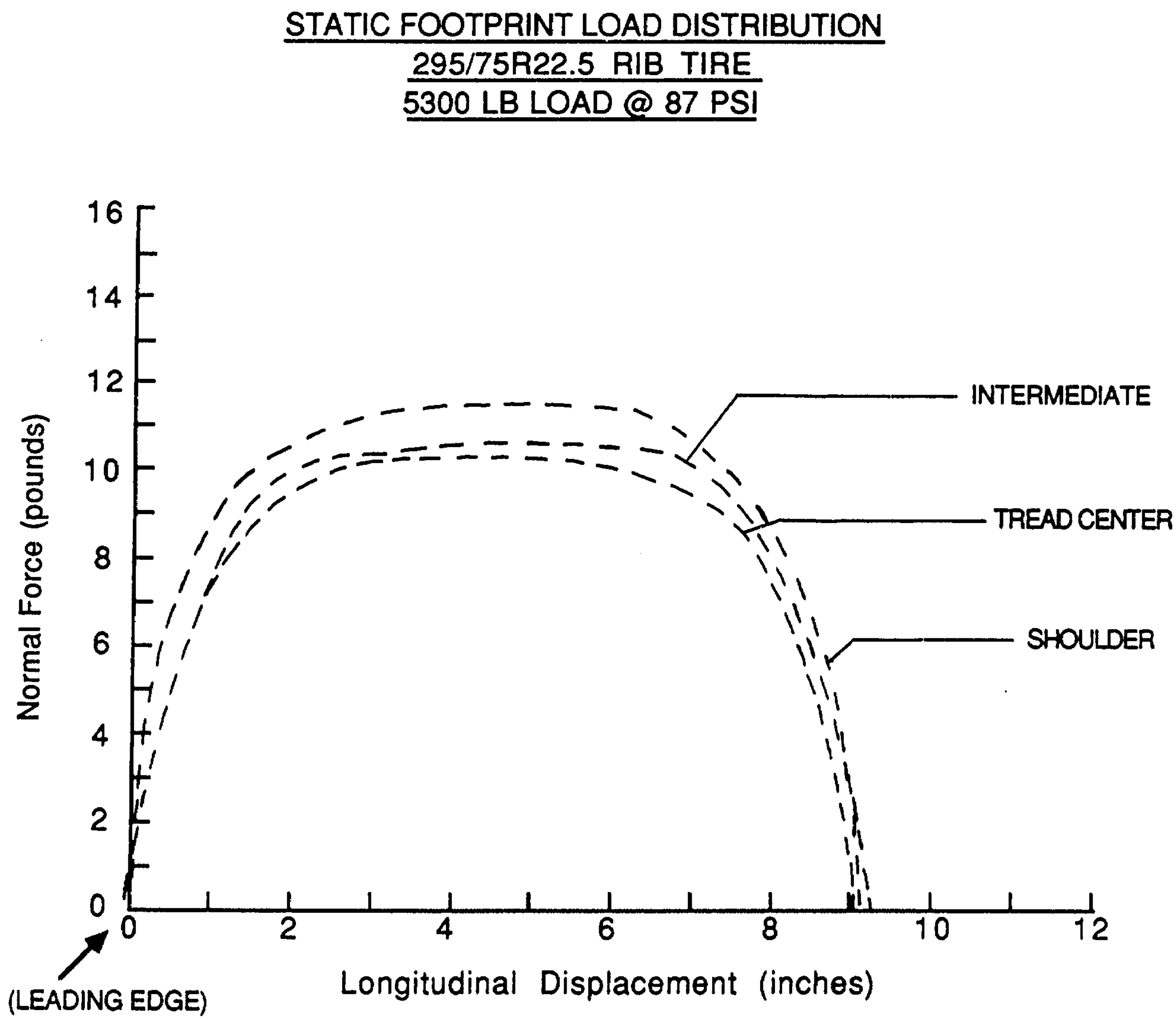



Figure 2.3. Static footprint load distribution (Company A).

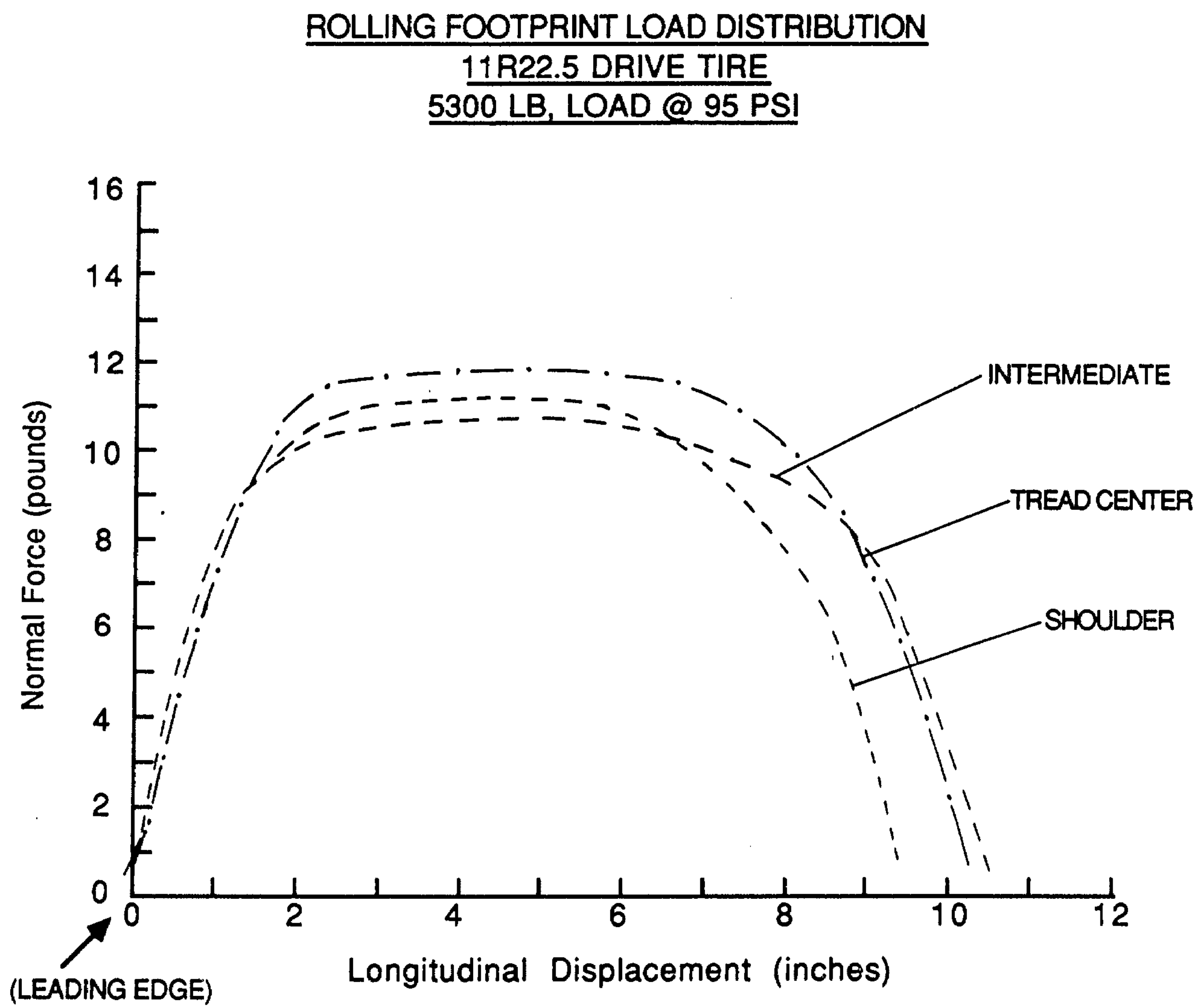



Figure 2.4. Rolling footprint load distribution (Company A).

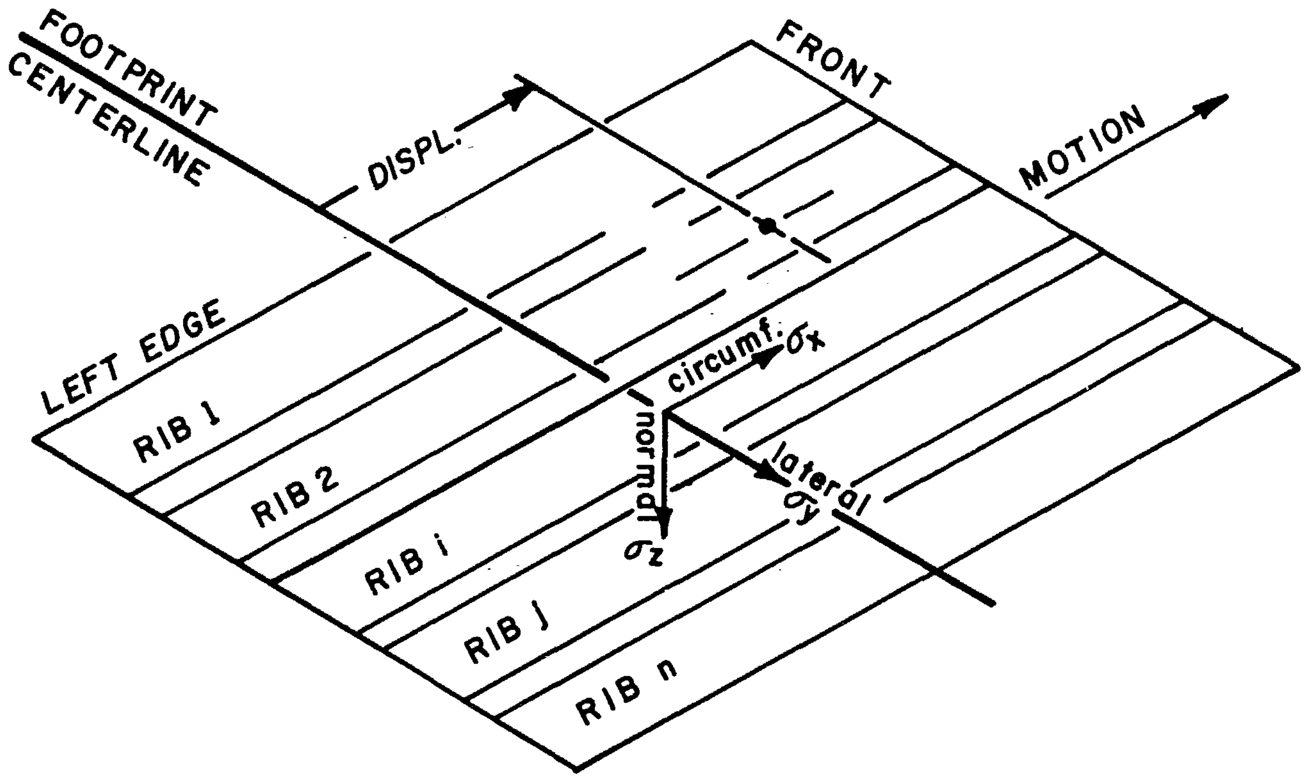



Figure 2.5. Footprint layout used in data reduction (Company B).

Table 2.3. Sample of data from Company B.

AVERAGE TIRE FOOTPRINT STRESS
*****************************

12-APR-84 09:36

INPUT DATA FILES:
CENT1 .FTP CW90R0551-1 POTTINGER 10.00R20 CENTER EDGE OF BLOCKS NOT GLUED 105 PSI
CENT4 .FTP CW90R0551-1 POTTINGER 10.00R20 CENTER EDGE OF BLOCKS NOT GLUED 105 PSI

| I | "DISPL. | NORMAL STRESS AT LATERAL DISPLACEMENT | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | RIB 1 | | | | | RIB 2 | | | | RIB 3 | | | |
| | | 0.20 | 0.40 | 0.60 | 0.80 | 1.00 | 1.80 | 2.00 | 2.20 | 2.40 | 3.40 | 3.60 | 3.80 | 4.00 |
| 1 | 4.80 | -70. | -57. | -50. | -51. | -59. | -24. | -40. | -49. | -50. | -42. | -61. | -70. | -69. |
| 2 | 4.40 | -104. | -87. | -79. | -81. | -92. | -61. | -71. | -77. | -79. | -75. | -88. | -93. | -91. |
| 3 | 4.00 | -127. | -104. | -93. | -95. | -110. | -79. | -87. | -92. | -95. | -95. | -105. | -108. | -105. |
| 4 | 3.60 | -143. | -115. | -102. | -104. | -121. | -92. | -97. | -101. | -105. | -106. | -114. | -117. | -114. |
| 5 | 3.20 | -154. | -123. | -108. | -110. | -128. | -99. | -102. | -106. | -111. | -113. | -120. | -122. | -119. |
| 6 | 2.80 | -164. | -129. | -113. | -113. | -132. | -104. | -106. | -109. | -114. | -117. | -122. | -124. | -121. |
| 7 | 2.40 | -171. | -134. | -116. | -116. | -134. | -106. | -108. | -111. | -114. | -118. | -124. | -125. | -121. |
| 8 | 2.00 | -176. | -136. | -118. | -117. | -135. | -107. | -108. | -111. | -114. | -119. | -124. | -125. | -121. |
| 9 | 1.60 | -180. | -140. | -120. | -118. | -136. | -107. | -108. | -110. | -114. | -119. | -124. | -125. | -121. |
| 10 | 1.20 | -183. | -143. | -121. | -119. | -136. | -108. | -109. | -111. | -114. | -119. | -124. | -124. | -120. |
| 11 | 0.80 | -185. | -144. | -123. | -120. | -136. | -108. | -109. | -111. | -113. | -118. | -123. | -124. | -120. |
| 12 | 0.40 | -187. | -145. | -123. | -120. | -136. | -108. | -109. | -110. | -113. | -118. | -123. | -123. | -119. |
| 13 | 0.00 | -186. | -145. | -123. | -120. | -135. | -109. | -109. | -110. | -112. | -118. | -123. | -123. | -119. |
| 14 | -0.40 | -184. | -144. | -123. | -120. | -135. | -109. | -109. | -110. | -112. | -117. | -123. | -123. | -119. |
| 15 | -0.80 | -183. | -143. | -121. | -118. | -134. | -110. | -110. | -110. | -112. | -117. | -123. | -124. | -119. |
| 16 | -1.20 | -180. | -141. | -120. | -117. | -132. | -110. | -110. | -111. | -111. | -117. | -123. | -123. | -118. |
| 17 | -1.60 | -175. | -138. | -118. | -116. | -130. | -111. | -110. | -110. | -111. | -117. | -123. | -124. | -118. |
| 18 | -2.00 | -170. | -134. | -116. | -113. | -128. | -110. | -110. | -110. | -110. | -117. | -123. | -123. | -118. |
| 19 | -2.40 | -163. | -130. | -113. | -111. | -125. | -111. | -110. | -110. | -109. | -116. | -122. | -123. | -117. |
| 20 | -2.80 | -154. | -125. | -110. | -109. | -122. | -108. | -108. | -108. | -107. | -115. | -121. | -122. | -116. |
| 21 | -3.20 | -143. | -117. | -104. | -103. | -116. | -103. | -104. | -104. | -104. | -110. | -117. | -118. | -113. |
| 22 | -3.60 | -128. | -107. | -96. | -96. | -107. | -93. | -96. | -97. | -96. | -102. | -110. | -111. | -106. |
| 23 | -4.00 | -109. | -93. | -85. | -85. | -94. | -78. | -84. | -86. | -85. | -87. | -97. | -100. | -96. |
| 24 | -4.40 | -83. | -73. | -68. | -68. | -74. | -62. | -67. | -69. | -66. | -65. | -78. | -82. | -78. |
| 25 | -4.80 | -45. | -42. | -41. | -42. | -44. | -23. | -36. | -41. | -40. | -32. | -49. | -56. | -54. |

Note: Negative signs for normal stresses indicate compression.

Table 2.3. Sample of data from Company B (contd.),

AVERAGE TIRE FOOTPRINT STRESS 12-APR-84 09:36

INPUT DATA FILES:
CENT1 .FTP CW90R0551-1 POTTINGER 10.00R20 CENTER EDGE OF BLOCKS NOT GLUED 105 PSI
CENT4 .FTP CW90R0551-1 POTTINGER 10.00R20 CENTER EDGE OF BLOCKS NOT GLUED 105 PSI

| I | "DISPL. | NORMAL STRESS AT LATERAL DISPLACEMENT | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | RIB 4 | | | | RIB 5 | | | |
| | | 5.00 | 5.20 | 5.40 | 5.60 | 6.40 | 6.60 | 6.80 | 7.00 |
| 1 | 4.80 | -63. | -64. | -63. | -58. | -68. | -70. | -80. | -98. |
| 2 | 4.40 | -88. | -86. | -84. | -81. | -92. | -90. | -101. | -124. |
| 3 | 4.00 | -104. | -100. | -97. | -95. | -106. | -102. | -115. | -143. |
| 4 | 3.60 | -113. | -108. | -104. | -102. | -115. | -111. | -124. | -156. |
| 5 | 3.20 | -118. | -112. | -108. | -107. | -122. | -117. | -131. | -166. |
| 6 | 2.80 | -121. | -115. | -110. | -108. | -126. | -121. | -137. | -174. |
| 7 | 2.40 | -122. | -116. | -111. | -109. | -128. | -124. | -141. | -180. |
| 8 | 2.00 | -123. | -116. | -112. | -109. | -131. | -127. | -144. | -184. |
| 9 | 1.60 | -123. | -116. | -111. | -108. | -132. | -128. | -147. | -188. |
| 10 | 1.20 | -122. | -116. | -111. | -108. | -133. | -130. | -149. | -190. |
| 11 | 0.80 | -122. | -116. | -111. | -107. | -134. | -130. | -150. | -193. |
| 12 | 0.40 | -123. | -116. | -111. | -107. | -134. | -131. | -150. | -193. |
| 13 | 0.00 | -122. | -115. | -110. | -106. | -134. | -130. | -150. | -193. |
| 14 | -0.40 | -122. | -115. | -110. | -106. | -134. | -130. | -149. | -191. |
| 15 | -0.80 | -122. | -116. | -110. | -105. | -132. | -128. | -147. | -190. |
| 16 | -1.20 | -122. | -115. | -110. | -105. | -132. | -127. | -145. | -186. |
| 17 | -1.60 | -122. | -115. | -109. | -104. | -130. | -124. | -142. | -182. |
| 18 | -2.00 | -121. | -115. | -109. | -104. | -126. | -122. | -138. | -177. |
| 19 | -2.40 | -121. | -114. | -108. | -103. | -125. | -119. | -134. | -170. |
| 20 | -2.80 | -120. | -113. | -107. | -102. | -121. | -115. | -128. | -161. |
| 21 | -3.20 | -116. | -110. | -105. | -100. | -117. | -110. | -121. | -151. |
| 22 | -3.60 | -109. | -104. | -99. | -93. | -109. | -102. | -112. | -138. |
| 23 | -4.00 | -97. | -94. | -89. | -83. | -97. | -92. | -100. | -121. |
| 24 | -4.40 | -76. | -76. | -72. | -66. | -81. | -78. | -84. | -100. |
| 25 | -4.80 | -50. | -51. | -49. | -42. | -55. | -56. | -60. | -69. |

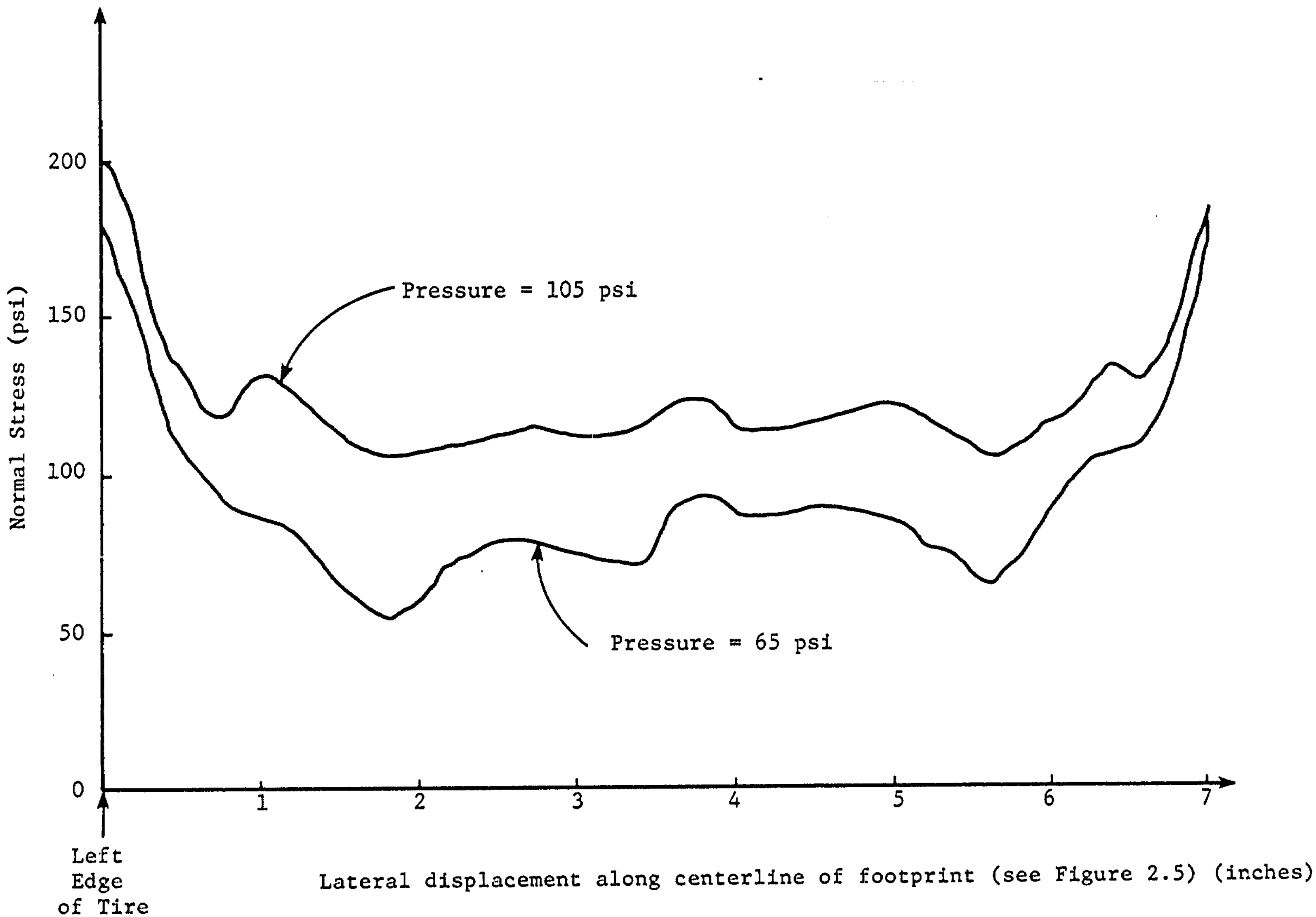



Figure 2.6. Tire pressure profile along lateral footprint centerline (Company B).

centerline (Figure 2.5). Figures 2.7 and 2.8 show the longitudinal footprint load distribution (Figure 2.5) for the 10.00R20 tire. These figures are comparable to Figures 2.3 and 2.4 from the Company A data in that they illustrate the pressure distribution along the length of the tire at four transverse positions. Figures 2.7 and 2.8, however, seem to contradict the data from Company A (Figure 2.4) which predicted the maximum normal stress occurring at the midpoint of the footprint centerline on a rolling tire. These differences could be due to testing differences between the companies or some other unidentifiable reasons.

Smithers Scientific Services Inc. Smithers Scientific Services Inc. provided performance specifications for five different brands of radial truck tires. The relevant data is summarized in Table 2.4. It can be seen from this data that the inflation pressure is approximately equal to the load divided by the net contact area. The assumption that is normally used in layer theory analysis is that inflation pressure is equal to the load divided by total footprint area. All of the tires compared are type 11R24.5. An example footprint shape of each is shown in Appendix A.

Tire Data Summary. The data collected shows that truck tire pressures have increased substantially in the past 25 years and are likely to go higher in the future. A recent study by the Texas Transportation Institute found that average truck tire pressures are 120 psi on some Texas highways (Ref 8). This study also predicted that tire pressures could go as high as 150 psi in the next five years. The effect of these higher pressures on pavement performance is addressed in this project.

### Weight Data

A request was made to the FHWA for five separate years of Truck Weight data from Arizona's fourteen loadometer stations. Data for the years 1976, 1978, 1980, 1982 and 1984 was received in the form of printed W-2, W-3, W-4, and W-5 tables and as raw, unanalyzed data on computer tape. The raw data was down-loaded to microcomputer and used for the development and testing of the microcomputer program to calculate average number of equivalent loads for this project. The W-4 tables were used to

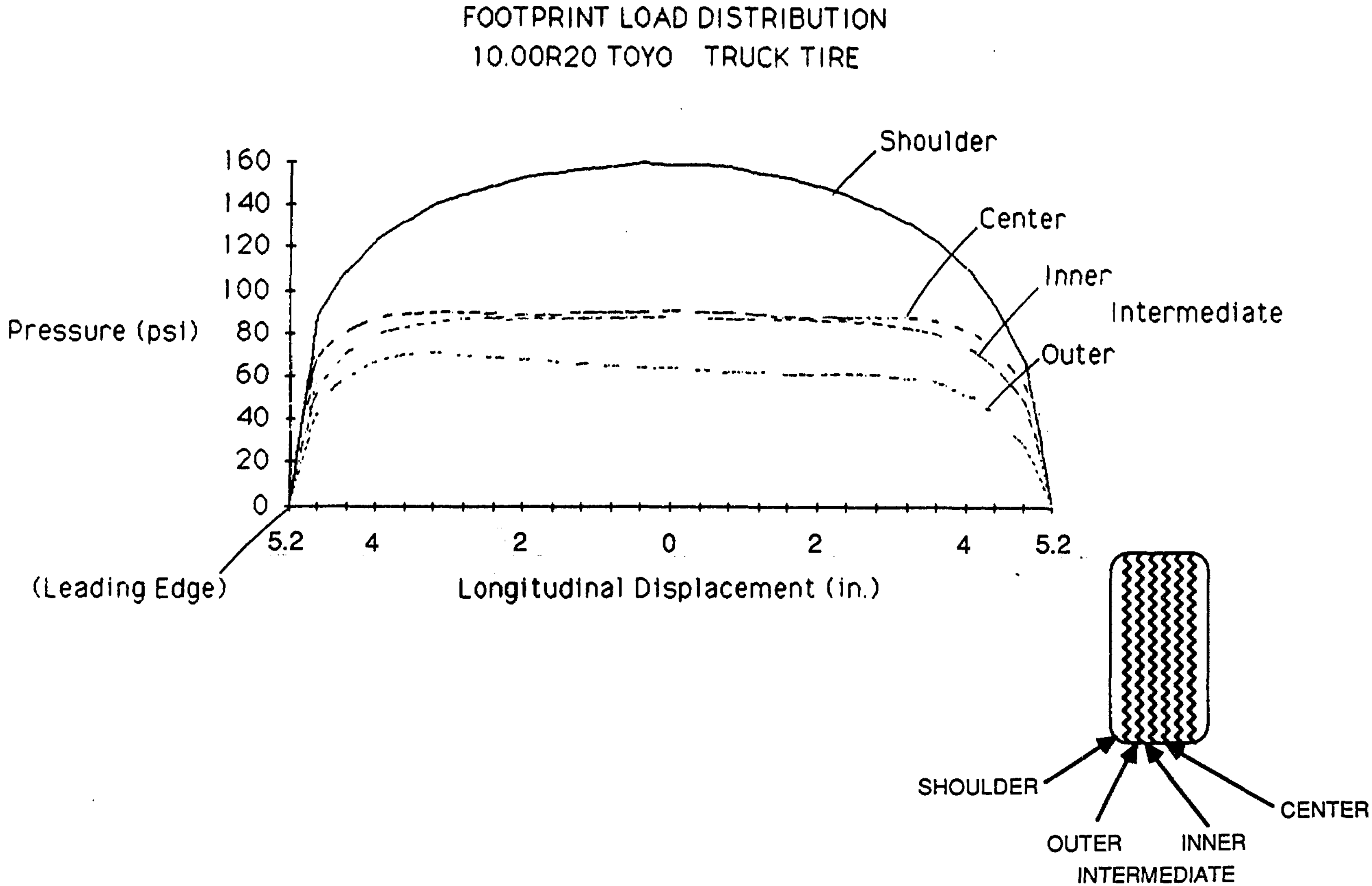



Figure 2.7. Rolling footprint pressure distribution (65 psi).

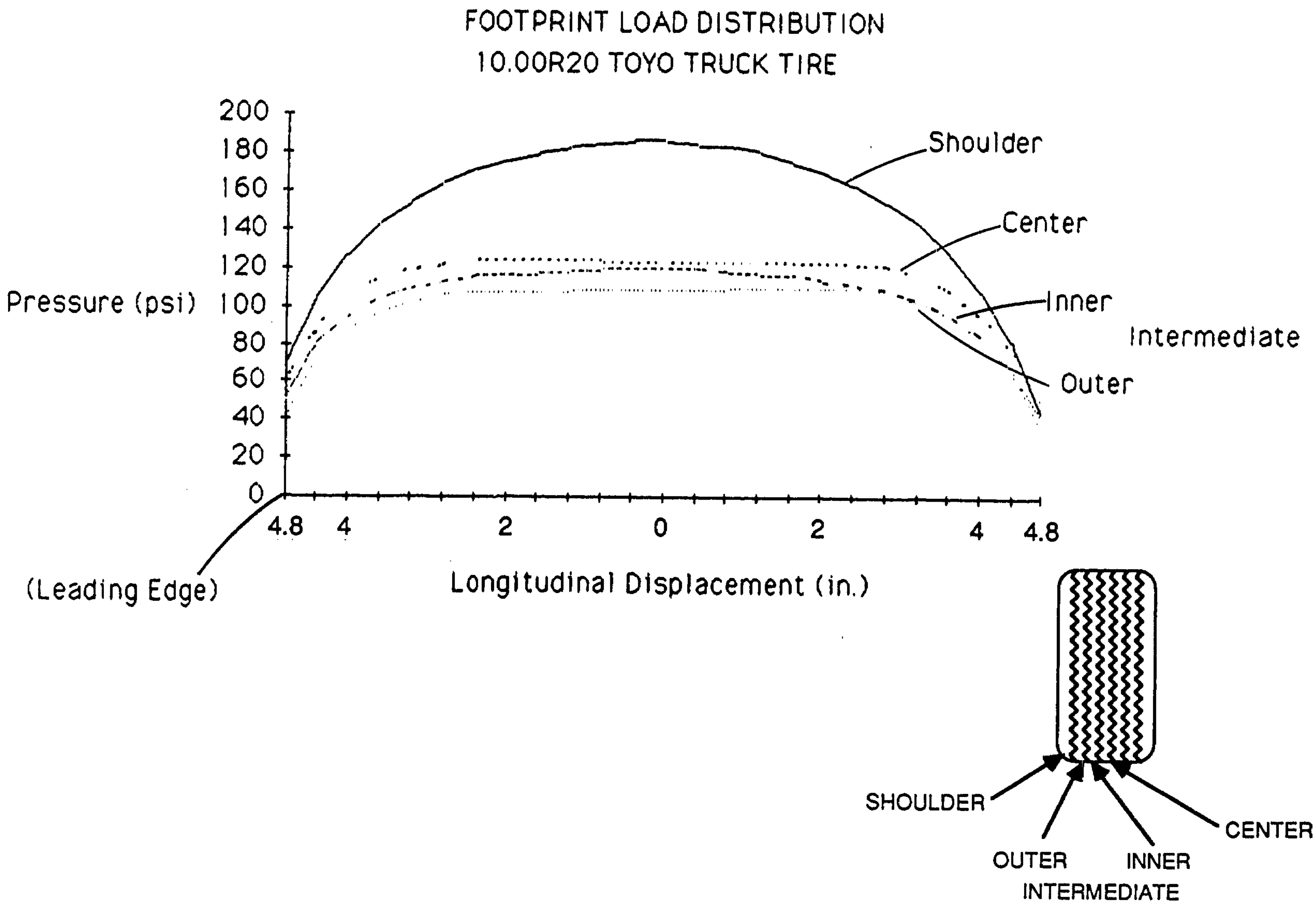



Figure 2.8. Rolling footprint pressure distribution (105 psi).

Table 2.4. Summary of relevent information provided by Smithers Scientific Services.

| Brand | Total Footprint Area(in$^2$) | Net Contact Area(in$^2$) | Load on Tire(lb) | Infl. Pressure (psi) |
|---|---|---|---|---|
| Bridgestone | 78.04 | 59.56 | 5640 | 95 |
| Goodyear | 72.62 | 53.37 | 5640 | 95 |
| Michelin | 79.15 | 57.95 | 5790 | 100 |
| Firestone | 81.52 | 61.65 | 5640 | 95 |
| General | 73.39 | 57.06 | 5640 | 95 |

compare with the output from the algorithms of our program. These comparisons showed that the ARE programs were producing correct results.

### Traffic Data

ARE Inc requested traffic volume and classification data from the Arizona Transportation Planning Division (TPD). Volume data from 968 sampling locations and classification data from 128 classification stations throughout Arizona was sent by TPD. The data was on microcomputer disk and in computer printout form. The traffic data was used to make equivalent load computations for highway sections using the new procedure. The results were compared to equivalent loads calculated with Arizona's existing procedure. A discussion of these comparisons is given in Chapter 8 of this report.

A traffic analysis program was sent to ARE Inc by ADOT on computer tape. The FORTRAN source code was put on microcomputer and modified to Microsoft FORTRAN. This program was used to calculate cumulative equivalent loads on the Arizona Highway Sections for comparing the existing ADOT and new ARE methods as discussed in the previous section. The program was made to be user friendly and is submitted to ADOT as program TRAF18K to be used for equivalent load calculations on the Arizona traffic sections. This program is described in Chapter 7 of this report and in Volume 2 (Ref 1).

### Pavement Design Program

A computer program called SODA, which performs overlay design analyses for ADOT, was obtained. The program was used for comparison of the new equivalent load calculation procedures.

The SODA overlay design program was put on computer from the listing given in the report "Overlay Deflection Design Methods for Arizona" (Ref 11). The code was modified to be compatible with the IBM BASICA interpreter. The SODA program was used to examine the effect of the new equivalent load calculation procedure on overlay thickness design as calculated by the SODA method. The problem with such a comparison is that the SODA method was developed empirically using regression analysis on real data and the AASHTO method of equivalent load calculation. For this reason, it should give reasonable results when equivalent loads are calculated with the AASHTO method. The results of these design comparisons are presented in Chapter 8.

## SUMMARY

This chapter has described the preliminary studies, background reviews, and existing data collection that was done for this project. Background reviews included a literature review and examination of ADOT's traffic, load and design computation procedures. Data or items collected include current truck tire data, Arizona weight data, Arizona traffic data, and Arizona overlay design and traffic programs. As these reviews and data collection were proceeding, work was also underway on development of new roughness based damage models. The development and application of these models is presented in the next chapter.

# CHAPTER 3. DEVELOPMENT OF DAMAGE MODELS

This chapter discusses the research approach that was followed during the course of this study to develop improved damage models for flexible pavements. Actual application of these damage models in generating a revised set of load equivalency factors for the state of Arizona is covered in the next chapter.

## BACKGROUND

A damage-based pavement performance prediction model (or damage model, as it will sometimes be referred) is an equation that can be used to predict the number of load applications that can be sustained by a given pavement structure in a given environment before it reaches a certain failure criterion. In this context, a damage model does not have to be one that is based on fatigue cracking. It only has to be one that considers cumulative load applications as a dependent or independent variable.

The primary and most obvious application of a damage model is in the pavement structural design process where it provides a means for the determination of pavement layer thicknesses. Depending on the nature of the model, it also provides a basis for determining the relative effects of different wheel loads, tire pressures and load configurations on a pavement's load-carrying capacity. This second use provides a means for converting mixed axle load traffic into an equivalent design number of axle load repetitions of a uniform magnitude.

The nature of existing pavement damage models varies between empirical (relying on experience or observation alone) to mechanistic (relying on engineering mechanics or the physical science theories that associate force, mass and energy). Historically, pavement damage models have been empirically derived, however, there is now a trend towards developing what is referred to in the new AASHTO Guide for Design of Pavement Structures (1986) as "mechanistic-empirical" models. These are damage models that are based on mechanistic pavement response factors (i.e., stress, strain and deformation), but are statistically calibrated to observed performance.

Existing pavement damage models have one of two general criteria for failure; one is pavement condition (i.e., extent and severity of distress), the other is pavement roughness (i.e., ride quality or serviceability). The AASHTO flexible pavement performance algorithm (Ref. 16) is an example of an empirical damage model having terminal serviceability as its failure criteria. Fatigue damage equations developed under NCHRP Project 1-10B (Ref. 17) are examples of mechanistic-empirical models having an allowable level of cracking as their failure criteria.

In general, empirical models are adequate for predicting future performance under conditions similar to those under which the observations were made, however, they are not necessarily reliable for predicting performance under conditions outside those inherent in their development. Mechanistic (or mechanistic-empirical) models are better suited for predictions outside the range of the data from which they were developed since they rely on pavement responses generated by proven theoretical models for their extrapolation. Because of the need to consider loads and tire pressures significantly higher than those commonly used in the past, a mechanistic approach was selected for developing the damage-based prediction models in this study.

CRITERIA FOR DAMAGE MODEL DEVELOPMENT

In addition to the use of a mechanistic approach, the following criteria were selected for the development of improved damage-based pavement performance prediction models for Arizona DOT.

1. Use AASHO Road Test Data. Although 25 years old, the data base of information from the AASHO Road Test experiment is still the best organized, most extensive, thorough and accurately collected set of roadway performance data. Consequently, this data was selected as a basis for model development.

2. Consider seasonal variation of roadbed soil support. To develop a mechanistic damage model with a potentially higher degree of accuracy than that of previous research efforts, it was considered essential that the seasonal variation of roadbed soil support at the Road Test be evaluated. To accomplish this, it was necessary to translate seasonal deflections and laboratory test results into pavement material properties so that the resulting variation of critical pavement stresses and strains could be considered. Miner's linear damage hypothesis (Ref 18) was assumed to be valid, thus allowing the individual seasonal damages for each AASHO Road Test section to be accumulated and used in the analysis process.

3. Consider effects of steering axles independently from load axles. Since steering axle loads ranged as high as 12,000 pounds at the Road Test, it was decided that their effects should be considered separately from the trailing load axles. This was accomplished within the same linear damage framework used for considering seasonal effects.

4. Use serviceability as the performance criteria. Traffic repetitions corresponding to a serviceability index of 2.5 were used in developing the damage models. Traditionally, pavement damage has been associated with the development of cracking, however there was no fundamental reason why it could not also be associated with serviceability loss.

5. Develop separate damage models for both single and tandem axle loads. This was included in the criteria for model development in order to maximize precision and to provide a better basis for evaluating the relative difference between single and tandem axle loads.

ANALYSIS PROCEDURE

Overview

This section describes the details of the rigorous analysis procedure that was used to develop new mechanistic-empirical damage models for flexible pavement performance prediction.

The objective of the procedure was to develop an equation that can be used to predict the number of loads (of a given magnitude and configuration) that can be sustained by a pavement section in a given constant (unchanging) environment. The basis for developing the equation is a data base of behavior and performance measurements from a series of road test sections subjected to varying loads and environmental conditions.

To develop the equation, a mechanistic-empirical analysis procedure was selected because of its capacity to treat the effects of varying loads and changing environment. The adoption of this mechanistic-empirical approach meant that a fundamental material response (i.e., stress, strain or deformation) could be used as an independent variable in the equation. This, in turn, meant that the equation would be better suited for application outside the range of the original data than just an empirical equation, so long as the input variables are determined in a manner consistent with the original development.

This brings us to the problem of developing an equation from the original data of the form:

Load Applications to "Failure" = f (pavement response)

Because each pavement section in the data base was subjected to varying (but known) loads as well as a changing environment, any pavement response that might be considered, will likewise exhibit a wide range of variation. In developing the damage equation, the only way to accurately treat this variation is within the linear damage framework provided by Miner's hypothesis (Ref 18).

The pavement response variables considered in this project were generated through an elaborate process involving:

1) An elastic layer theory based back-calculation technique to derive seasonal material properties corresponding to measured deflections and laboratory test results, and

2) A forward calculation technique to generate the response variables for each axle load (steering and trailing axles) and each season (fall, winter-frozen, spring-thaw, etc.) of each section.

Next, consider a potential model for the damage equation:

$$N_f = a_o + a_1*R \tag{3.1}$$

where:

$N_f$ = number of applications of a given load to "failure",
$R$ = a particular mechanistic pavement response (i.e., stress or strain), and
$a_o, a_1$ = coefficients determined through a least squares regression analysis.

Applying Miner's hypothesis, the total damage, D, due to applications of varying loads during varying seasons may be expressed as follows:

$$D = \sum_{j=1}^{m} [n_j/(N_f)_j] \tag{3.2}$$

where:

$n_j$ = the actual number of applied loads of a given magnitude during a given season,

$(N_f)_j$ = the allowable number of repetitions of that load during that season that can be sustained before "failure" occurs, and

m = product of the number of different seasons times the number of different axle loads.

Under this formulation, a section is said to have "failed" when D is equal to or greater than 1. Thus, if the actual load applications ($n_j$) during each season are known and assumed coefficients, $a_o$ and $a_1$, in the damage equation are used to calculate the corresponding $(N_f)_j$, the total damage for each road test section can be determined. If the assumed values of $a_o$ and $a_1$ are reasonable, some of the D values for each section will be greater than 1 and some less than 1 (due to the experimental nature of the data). The approach then is to apply an iterative process that will result in a set of $a_o$ - $a_1$ values in which the sum of the section differences squared $\sum (D-1)^2$ will be minimized. Furthermore, if different types of R variables (i.e., tensile strain, shear strain, etc.) are considered, a damage equation will ultimately be found that provides the least squares overall and, therefore, the highest predictive accuracy.

[Note: Detailed descriptions of the analysis procedure provided later refer to "effective" response factors and a more complex damage model. Effective response factors are a technique used to mathematically simplify the iterative process. The more complex damage model presented is the result of attempts to achieve an equation with the highest predictive accuracy.]

Nine basic tasks were required to develop the damage models using the general approach described above. The details of each of these tasks are discussed below.

<u>Task 1 - Section Selection</u>

The AASHO Road Test pavement data base consisted of separate sets of sections having either single or tandem axle loads. All of the primary flexible pavement sections consisted of cross sections having three pavement layers: asphalt concrete surface, granular base and granular subbase. In choosing sections for detailed analysis, only those meeting the following layer thickness constraints were included.

| | |
|---|---|
| AC Surface Thickness: | $D_1 \geq 2$ inches |
| Base Thickness: | $D_2 \geq 6$ inches |
| Subbase Thickness: | $D_3 \geq 8$ inches |

These layer thickness constraints were selected in order to confine the analysis to sections having significant load-carrying capacity. Since several of these sections did not reach a terminal serviceability of 2.5 during the two-year traffic loading period, only 33 single axle and 27 tandem axle sections were considered.

Task 2 - Season Delineation

Primary seasonal divisions were established based on a detailed examination of seasonal deflections and on the findings of NCHRP Project 1-10B (Ref. 17). These divisions are depicted in Figure 3.1. Note first that because of the different rates of thawing associated with section thickness, there is a variable division between the first winter-frozen and the first spring (Feb. 25 - March 6, 1959). This variation was handled on a section by section basis. Generally, the thinner pavement sections thawed sooner and were assigned the Feb. 25 division date. Secondly, note that these are primary seasonal divisions for assigning seasonal asphalt concrete elastic modulus values. Depending on the actual variation of deflection with a season for a given section, that season may have been further subdivided into subseasons as part of a subsequent task.

The asphalt concrete elastic modulus values for each of the seasons were based on the laboratory test results and recommendations in the NCHRP 1-10B Report (Ref. 17):

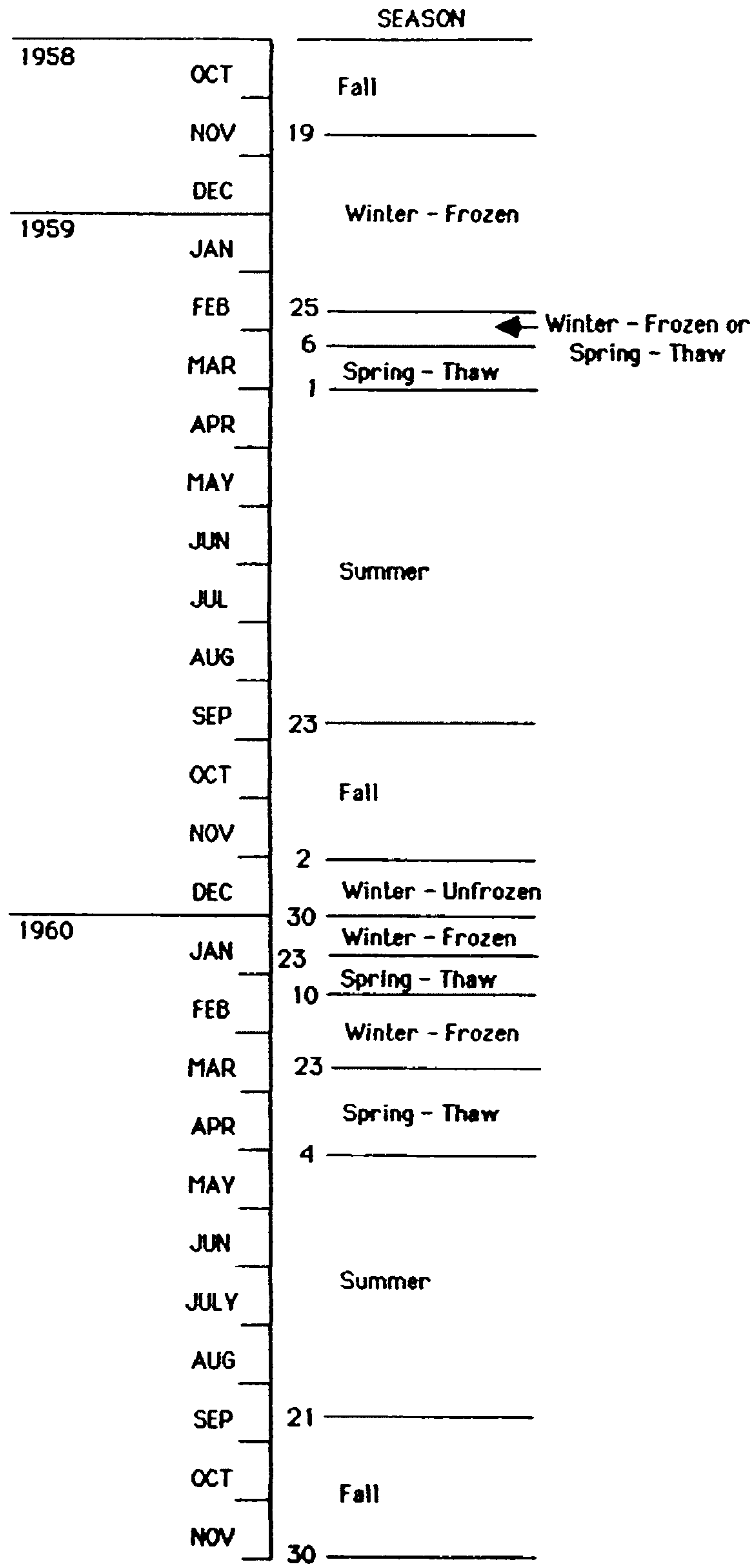



Figure 3.1. Seasonal divisions established for AASHO Road Test experiment.

| Season | Asphalt Concrete Elastic Modulus (psi) |
|---|---|
| Fall | 450,000 |
| Winter | 1,700,000 |
| Spring | 710,000 |
| Summer | 230,000 |

Task 3 - Determine Cumulative "Failure" Load Applications

Appendix A of AASHO Road Test Special Report 61E (Ref. 19) provides data on the cumulative number of wheel load applications sustained by a section until it reached a serviceability of 2.5. Table 3.1 presents a summary of these cumulative "failure" load applications for each section considered.

Task 4 - Determine Seasonal Deflections

Figure 3.2 provides an example of a deflection versus time graph for Section 253. This plot represents the pavement surface deflection under a 30-kip single axle load measured using a Benkelman beam. The plot indicates the critical deflection values that were selected for each season. Note that in one case, summer of 1959, deflections were subdivided into two sub-seasons because of a significant difference in deflection at the beginning and end of the season. This subdivision was considered necessary because of the potential impact on materials characterization and was performed on several other sections.

Seasonal deflection estimates were made for all sections under the different deflection loads. Table 3.2 identifies the single axle loads that were used to measure deflection on each of the sections. Recall that Lane 1 was loaded solely with single axle load groups while Lane 2 was loaded primarily with tandem axle load groups. (The tandem axle trucks did have single axle steering axles.)

Table 3.1. Load applications to "failure" (serviceability of 2.5) for each AASHO Road Test section considered.

| | Single Axle Sections | | Tandem Axle Sections | |
|---|---|---|---|---|
| | Section No. | "Failure" Applications | Section No. | "Failure" Applications |
| 1. | 111 | 621,000 | 112 | 500,000 |
| 2. | 155 | 637,000 | 156 | 492,000 |
| 3. | 623 | 83,000 | 624 | 137,000 |
| 4. | 601 | 621,000 | 602 | 569,900 |
| 5. | 577 | 760,000 | 578 | 716,000 |
| 6. | 625 | 679,000 | 420 | 76,000 |
| 7. | 419 | 73,000 | 488 | 458,000 |
| 8. | 487 | 77,000 | 472 | 85,300 |
| 9. | 471 | 79,000 | 456 | 92,900 |
| 10. | 455 | 96,600 | 454 | 151,200 |
| 11. | 453 | 90,600 | 426 | 182,000 |
| 12. | 425 | 505,000 | 418 | 123,000 |
| 13. | 417 | 168,000 | 470 | 373,000 |
| 14. | 477 | 1,099,000 | 446 | 764,000 |
| 15. | 469 | 560,000 | 304 | 114,000 |
| 16. | 445 | 701,000 | 324 | 88,300 |
| 17. | 303 | 80,000 | 254 | 217,000 |
| 18. | 323 | 80,000 | 322 | 119,000 |
| 19. | 253 | 451,000 | 268 | 233,000 |
| 20. | 321 | 80,000 | 260 | 100,000 |
| 21. | 267 | 108,000 | 308 | 505,000 |
| 22. | 309 | 1,023,000 | 306 | 601,000 |
| 23. | 259 | 91,000 | 328 | 575,000 |
| 24. | 307 | 585,000 | 314 | 594,000 |
| 25. | 305 | 126,000 | 332 | 270,000 |
| 26. | 327 | 676,000 | 326 | 120,000 |
| 27. | 313 | 441,000 | 272 | 618,000 |
| 28. | 331 | 557,000 | | |
| 29. | 325 | 102,000 | | |
| 30. | 257 | 713,000 | | |
| 31. | 263 | 512,000 | | |
| 32. | 271 | 705,000 | | |
| 33. | 311 | 670,000 | | |

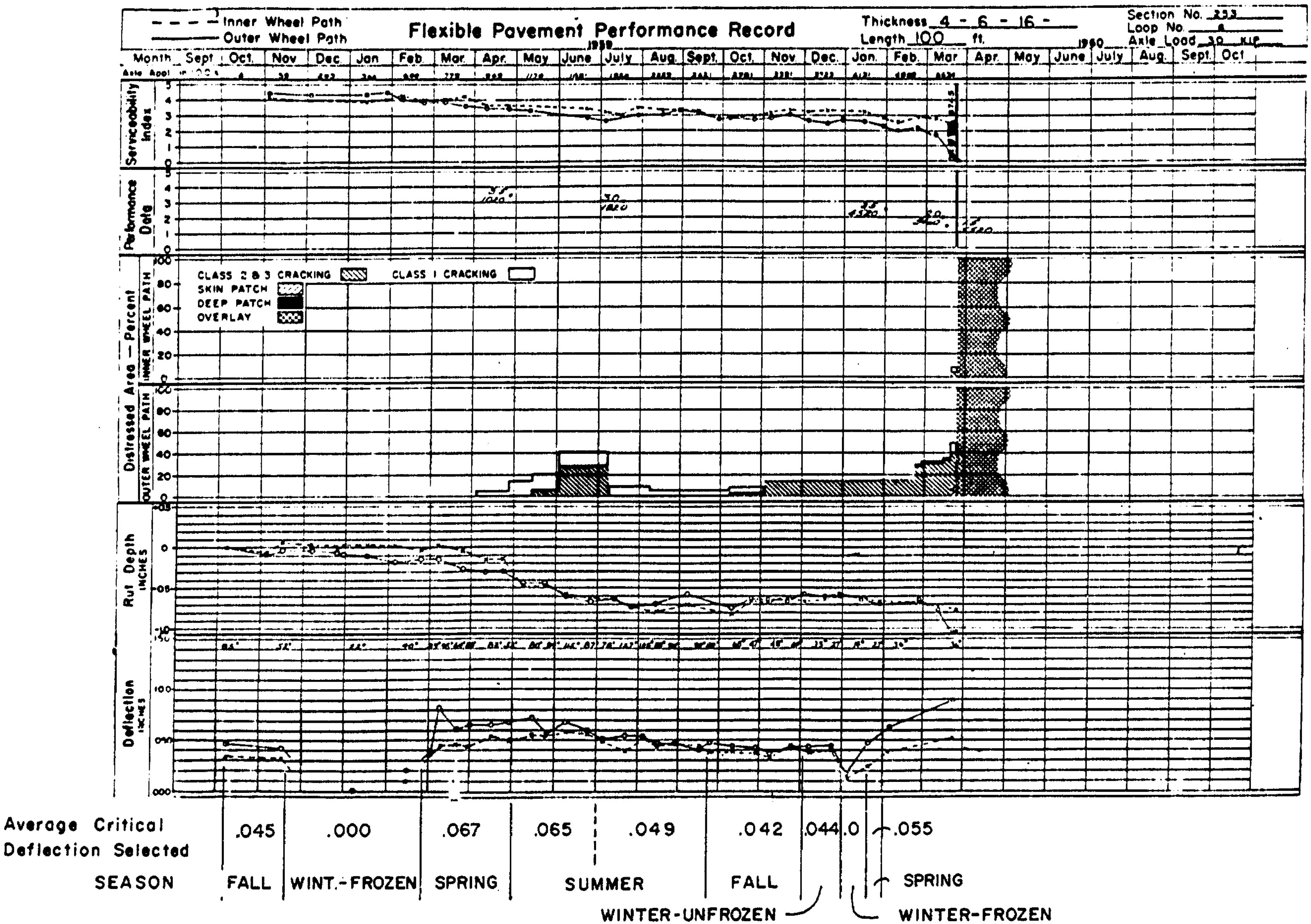



Figure 3.2. Example selection of average critical deflection value for each season.

Table 3.2. Axle loads used in AASHO Road Test deflection studies (after Ref 19).

| Loop | Lane | Single Axle Load (kips) |
|---|---|---|
| 2 | 1 | - |
| | 2 | 6 |
| 3 | 1 | 6, 12 |
| | 2 | 6, 12 |
| 4 | 1 | 12, 18 |
| | 2 | 12 |
| 5 | 1 | 12, 22.4 |
| | 2 | 12 |
| 6 | 1 | 12, 30 |
| | 2 | 12 |

Task 5 - Characterize Seasonal Material Properties Under Deflection Loads

To characterize the seasonal material properties of each section, a computer program, MODEST-1 was developed which uses an elastic layer theory model, ELSYM5 (Ref 20), to identify a unique set of pavement layer moduli that will match the specified critical seasonal deflections and satisfy the bulk stress relationships established in NCHRP Project 1-10B (Ref. 17) for base and subbase materials at the Road Test. Figure 3.3 provides a flow diagram of the iterative deflection matching process used by the MODEST-1 program. The tolerances selected for satisfying the bulk stress and deflection criteria were 5 and 3 percent, respectively.

Table 3.3 contains the $k_1$ coefficients for the seasonal bulk stress relationships developed in NCHRP Project 1-10B (Ref 17) for the AASHO Road Test base and subbase materials. The equation for modulus (E) as a function of bulk stress is:

$$E = k_1 \, \theta^{k_2} \tag{3.3}$$

where:

$\theta$ = bulk stress (i.e., the sum of all three axial stresses, $\sigma_1 + \sigma_2 + \sigma_3$), psi,
$k_1, k_2$ = bulk stress test result coefficients,
$k_2$ = 0.6 for both base and subbase,
$k_1$ = values shown in Table 3.3, and
E = elastic modulus value for base and subbase layers, psi.

It is pertinent to note that although the $k_1$ coefficients for the base are lower than those for the subbase, the bulk stress in the base is always significantly higher than the subbase producing a higher modulus.

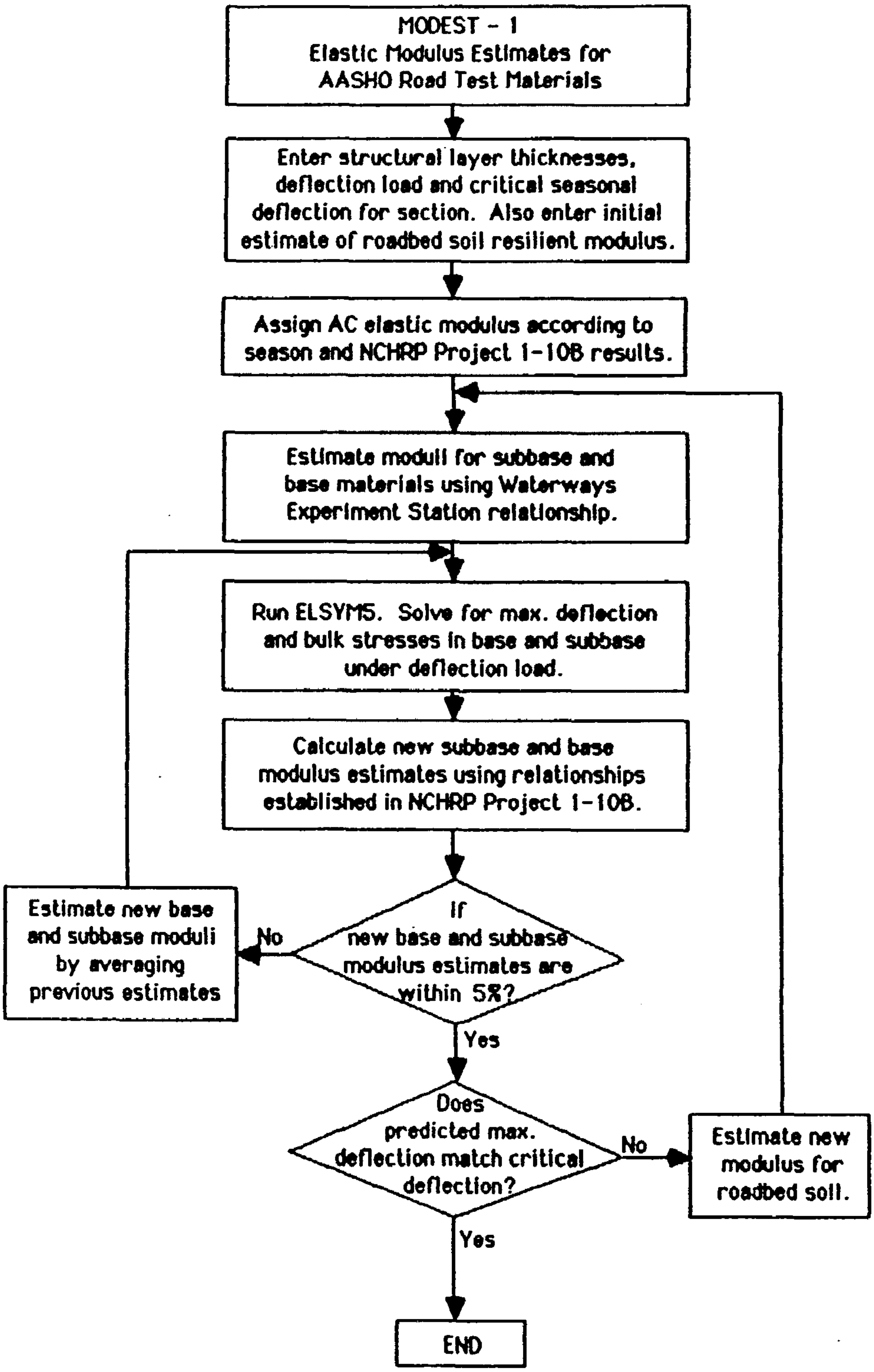



Figure 3.3. Flow diagram of MODEST-1 program.

Table 3.3. Seasonal $k_1$ values for AASHO Road Test base and subbase materials (after Ref 17).

| Season | Base | Subbase |
| --- | --- | --- |
| Fall | 4000 | 5400 |
| Spring | 3200 | 4600 |
| Summer | 3600 | 5000 |
| Winter* | - | - |

*Elastic modulus values for both base and subbase during the winter-frozen season were assumed to be 50,000 psi.

Task 6 - Solve for Material Properties Under Actual Wheel Loads Applied to Each Lane 1 (Single Axle Load) Section

Unfortunately, because of nonlinear behavior of the materials (i.e., stress sensitivity) and the fact that the deflection loads were not always equivalent to the actual wheel loads (compare Table 3.4 with Table 3.2), it was necessary to include this additional task as part of the materials characterization process. To predict material properties under the actual wheel loads applied to a given section. Two additional computer programs were developed, STAX-1 and TANDAX-1. STAX-1 is for estimating the properties under steering axle loads while TANDAX-1 is for tandem axle loads (see Task 7). (Note: It was not necessary to develop a program for the load axles in Lane 1 since some of the loads used to measure deflection were identical to the actual single axle wheel loads). Both the STAX-1 and TANDAX-1 programs were designed to individually analyze every season of every section.

Figure 3.4 provides a roadbed soil resilient modulus versus deviator stress diagram which illustrates the solution process used to treat nonlinear behavior of the soil. The solid line shown was established by plotting the resilient modulus - deviator stress values generated in Task 5 for the two deflection loads. The theoretical steering axle relationship (dashed line) was generated using ELSYM5 to solve for the deviator stress values corresponding to the same two roadbed soil modulus values but with a simulated steering axle load. (This theoretical relationship is one of a family of parallel lines corresponding to different loading conditions). The intersection of the solid and dashed lines defines the point at which roadbed soil stress conditions under the steering axle are consistent with the in-situ behavior of the soil. Thus, the roadbed soil resilient modulus and corresponding base and subbase modulus values at this point represent the material properties associated with steering axle load conditions. A detailed example of the solution process for one season of a single section is presented in Appendix I.

The actual stresses and strains for each load and season of each section were generated using the same elastic layer theory based ELSYM5

Table 3.4. Test vehicle loadings at AASHO Road Test (after Ref 19).

| Loop | Lane | Weight in Kips: Front Axle | Load Axle | Gross Weight |
|---|---|---|---|---|
| 2 | 1 | 2 | 2 | 4 |
| 2 | 2 | 2 | 6 | 8 |
| 3 | 1 | 4 | 12 | 28 |
| 3 | 2 | 6 | 24 | 54 |
| 4 | 1 | 6 | 18 | 42 |
| 4 | 2 | 9 | 32 | 73 |
| 5 | 1 | 6 | 22.4 | 51 |
| 5 | 2 | 9 | 40 | 89 |
| 6 | 1 | 9 | 30 | 69 |
| 6 | 2 | 12 | 48 | 108 |

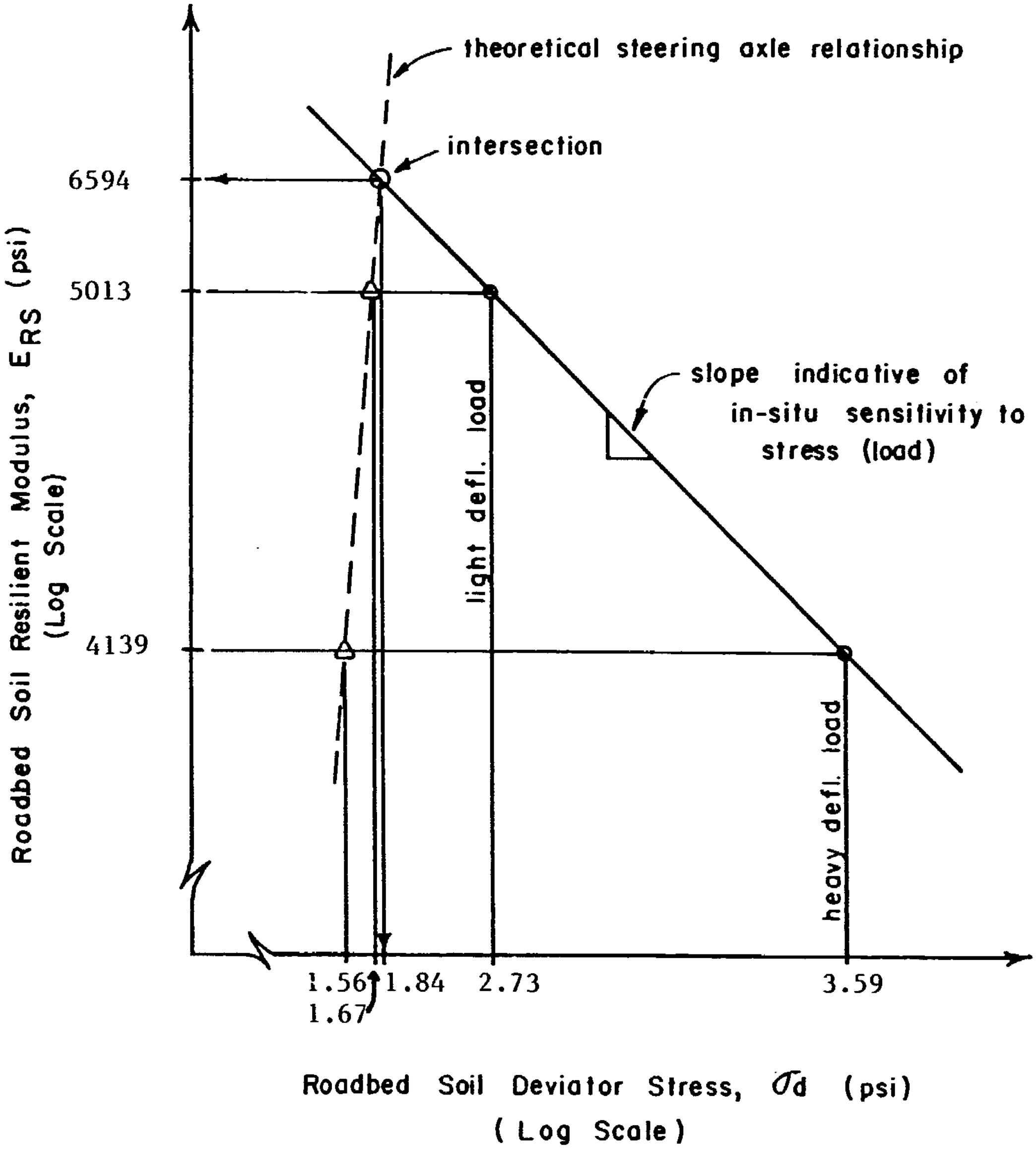



Figure 3.4. Graph of roadbed soil resilient modulus versus deviator stress illustrating the technique used to solve for material properties under steering axle loads in lane 1 sections.

subprogram used in both the MODEST-1 and STAX-1 programs. The results for all single axle (Lane 1) sections, are presented in Appendix B.

Appendix C presents a summary of all the stress sensitivity (slope) values resulting from the MODEST-1 analysis. These stress sensitivity values are provided to give an indication of the in-situ variability of the soil, both from section to section and from season to season.

Task 7 - Solve for Material Properties Under Actual Wheel Loads for Each Lane 2 (Tandem Axle Load) Section

Unlike the single axle sections, neither the steering nor the tandem axle loads in Lane 2 were the same as the loads used to measure deflection. Consequently, it was necessary to incorporate a slightly different approach into the TANDAX-1 program in order to solve for the material properties required for the Lane 2 sections. As can be seen in Table 3.2, most of the deflections in the Lane 2 sections were measured using only a 12-kip single axle. Thus, to solve for the material properties under the steering and tandem axle loads, the single resilient modulus versus deviator stress point (derived from the MODEST-1 program for the 12-kip single axle) had to be combined with an estimate of roadbed soil's stress sensitivity. Figure 3.5 illustrates the technique that was used.

The single resilient modulus versus deviator stress point from the MODEST-1 deflection analysis is plotted and a straight line corresponding to the estimated stress sensitivity (slope) is drawn through the point. This line represents the in-situ resilient modulus versus deviator stress relationship for that section during that season. Since the stress sensitivity for most of the Lane 2 sections was unknown, individual estimates were made based on the calculated stress sensitivity of the adjacent Lane 1 sections. For the cases where Lane 1 information was unavailable, stress sensitivity estimates were made based on trends observed on other Lane 1 sections. A table of the estimated stress sensitivity values used for Lane 2 is presented in Appendix D.

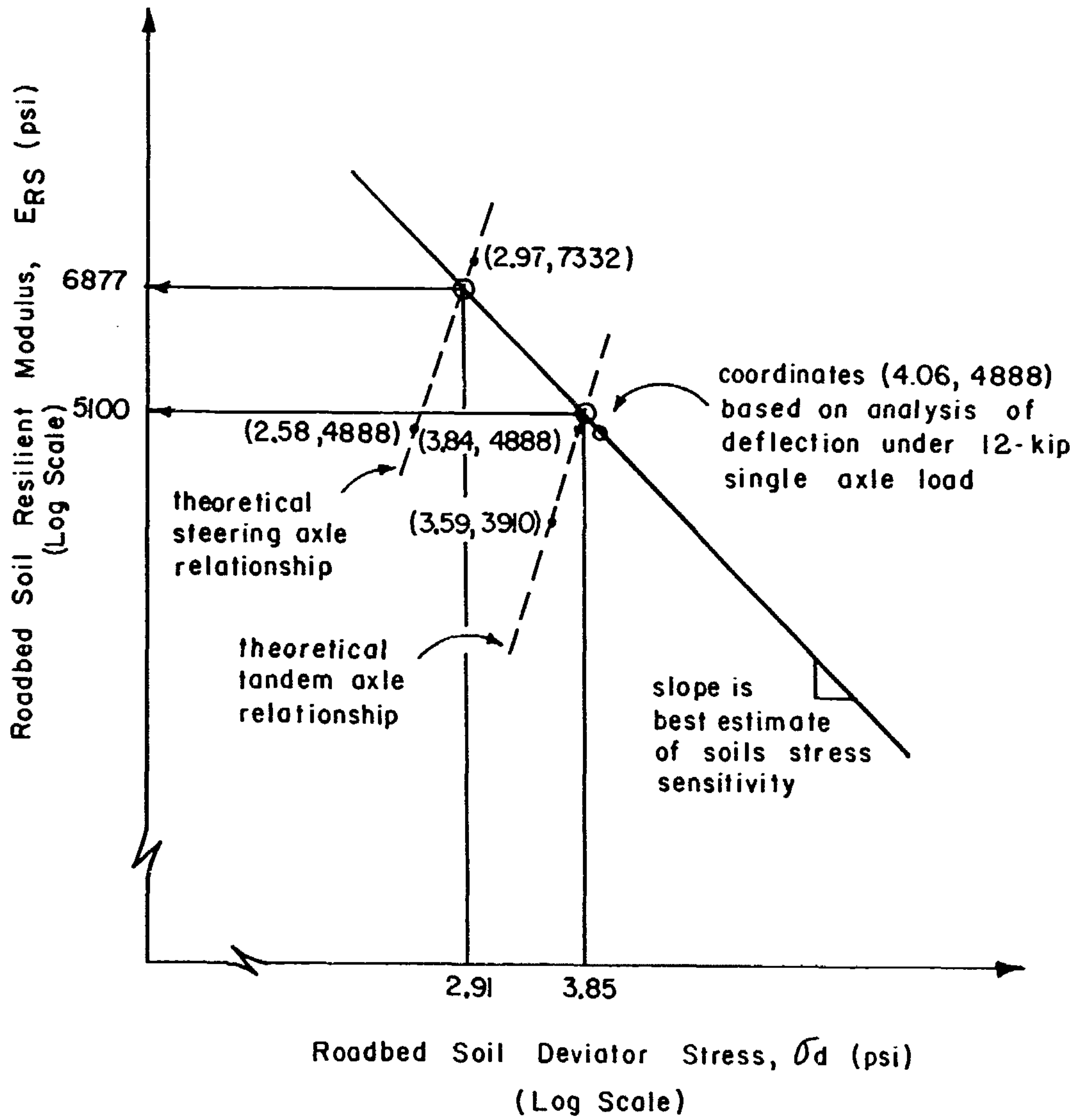



Figure 3.5. Graph of roadbed soil resilient modulus versus deviator stress illustrating the technique used to solve for material properties under steering and tandem axle loads in lane 2 sections.

Once the in-situ relationship for the roadbed soil was established, the theoretical steering and tandem axle relationships were generated and plotted in the same way the steering axle relationship was produced for the Lane 1 sections (two separate lines from the family of parallel lines corresponding to different loading conditions). Similarly, the intersections of the two theoretical relationships (dashed lines) with that established for the in-situ soil (solid line) represent the points at which the roadbed soil stress conditions under the given steering and tandem axle loads are consistent with the in-situ behavior of the soil. Thus, the roadbed soil modulus values and their corresponding base and subbase moduli at these two points are the material properties required for the two particular loading conditions.

The actual stresses and strains for each load and season of each section were generated using the same elastic layer theory based ELSYM5 subprogram used to develop the the TANDAX-1 program. The results for all tandem axle (Lane 2) sections are presented in Appendix E.

<u>Task 8 - Develop Single Axle Damage Models</u>

Separate damage models were developed for single and tandem axle loads. This allows an independent examination of the effects of single and tandem axles. A combined model would have required some assumption as to the relative impact on pavement performance of positioning two single axle loads of a given magnitude in a tandem configuration. This assumption would have introduced an additional source of error into the analysis and made it impossible to use the model to examine the effects of axle configuration.

To apply a mechanistic analysis approach using elastic layer theory and Miner's linear damage hypothesis, it was first necessary to assume a form for the damage model. Previous research efforts, including NCHRP Project 1-10B, suggested a form which was adopted for this study:

$$\log(N_f) = a_0 + a_1 * \log(R) + a_2 * \log(E_{AC}) \tag{3.4}$$

where, in this case,

$N_f$ = estimated number of load repetitions to a terminal serviceability of 2.5,

$R$ = selected mechanistic response (i.e., stress or strain),

$E_{AC}$ = estimated elastic modulus of the asphalt concrete during a given season (see Task 2) and

$a_0$, $a_1$ and $a_2$ = coefficients to be determined through statistical analysis.

The mechanistic responses that were considered in developing damage models (for both the single and tandem axle loads) include:

1) Maximum asphalt concrete tensile strain, $\varepsilon_{AC}$,
2) Maximum asphalt concrete tensile stress, $\sigma_{AC}$ (psi),
3) Maximum asphalt concrete shear strain, $\gamma_{AC}$,
4) Maximum asphalt concrete shear stress, $\tau_{AC}$ (psi), and
5) Maximum vertical strain on roadbed soil, $\varepsilon_{RS}$.

The first four of these mechanistic responses were considered in order to determine if any one in particular was a better predictor of pavement performance than the other. The last response, vertical strain on the roadbed soil, was considered because of its applicability in predicting the performance of flexible pavements with thin surfaces.

As discussed in Task 6, seasonal values for all the mechanistic responses were generated using a computer program, ELSYM5 (Ref 20), based on elastic layer theory. Actual values for each load and season combination for each section are contained within the single axle data base presented in Appendix B.

The calculations to produce the $a_0$, $a_1$ and $a_2$ coefficients for the damage models was incorporated into a program called DAMOD-4. Figure 3.6 provides a flow diagram of the major steps of this interactive program.

In the first step, the user identifies what mechanical response is desired and for a specified trial $a_2$-value, also estimates the initial values for both $a_0$ and $a_1$. The program then goes through every season for a given section and calculates the allowable load repetitions for both the steering and single axle loads (steps 2 and 3). The next two steps (4 and 5) require an explanation of a technique derived by Taute (Ref. 21) which uses Miner's linear damage hypothesis (Ref. 18) to consider multiple seasons and non-uniform axle loads in developing a new damage model.

The linear damage hypothesis assumes that one repetition of a given stress or strain produces the same amount of damage to a pavement whether it is applied at the beginning, middle or end of a pavement's life. It can be expressed mathematically as follows:

$$D = \sum_{j=1}^{m} \frac{n_j}{(N_f)_j} \tag{3.5}$$

where, in this case,

$D$ = total damage to the $i^{th}$ section,

$n_j$ = actual number of stress or strain repetitions of a given load during a given season,

$(N_f)_j$ = allowable number of stress or strain repetitions of a given load during a given season, and

$m$ = product of the number of different axle loads times the number of different seasons (on the $i^{th}$ section).

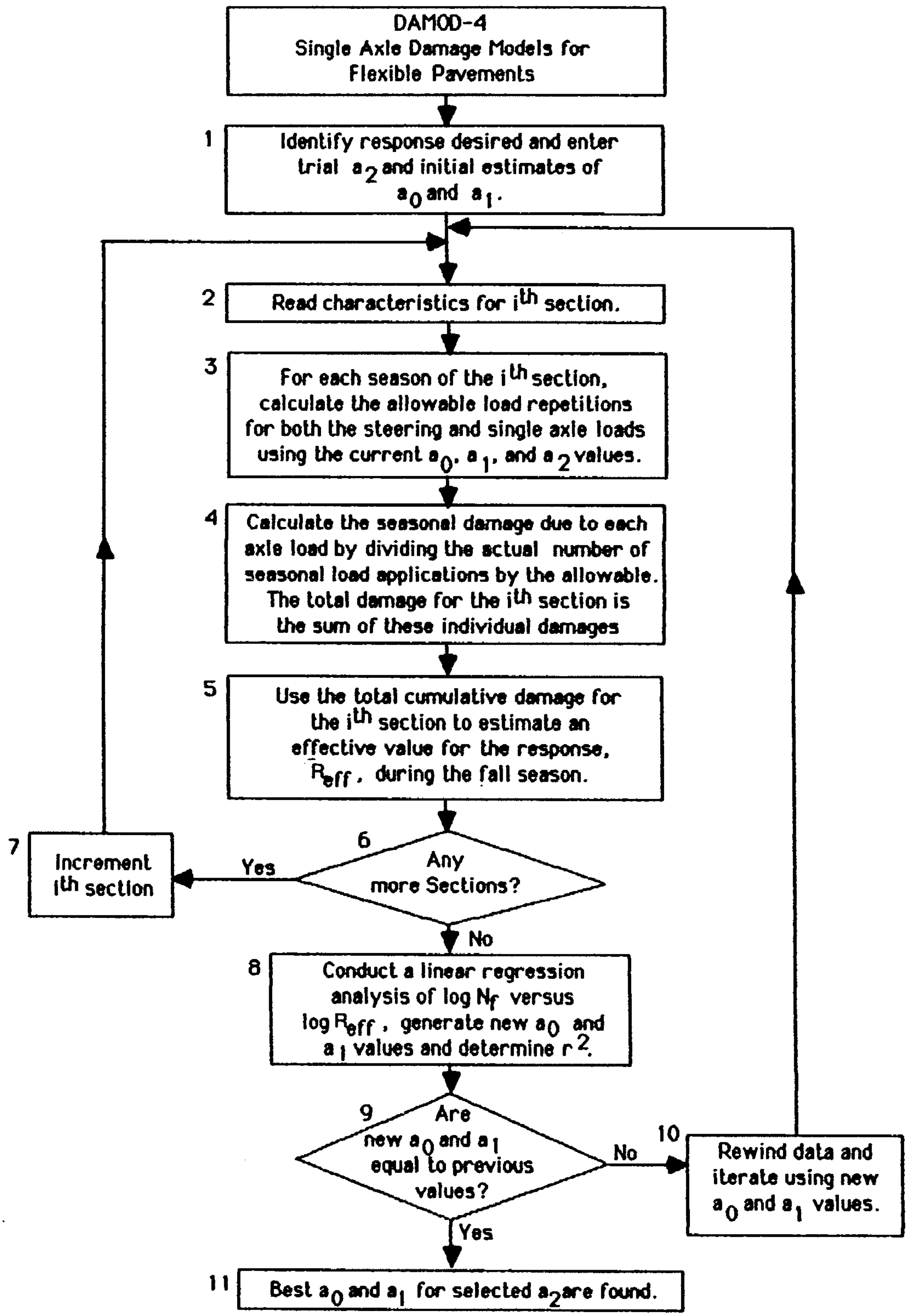



Figure 3.6. Flow diagram of DAMOD-4 program.

The allowable number of repetitions, $(N_f)_j$, is determined by solving the damage model (Equation 3.4) for the stress or strain level corresponding to a given axle load and season. The key to estimating the $a_0$, $a_1$ and $a_2$ coefficients in the damage model, then, is to find an effective stress or strain level that would produce the same amount of damage to the section as the combination of all the axle load repetitions during the different seasons. This means that the total damage (to the $i^{th}$ section) can also be expressed as:

$$D = \frac{\sum_{j=1}^{m} n_j}{(N_f)_{eff}} \qquad (3.6)$$

where $(N_f)_{eff}$ is the allowable number of load repetitions corresponding to the "effective" stress or strain level.

Rearranging the terms to solve for $(N_f)_{eff}$ and recognizing that the total damage is calculated using Equation 3.5 gives:

$$(N_f)_{eff} = \frac{\sum_{j=1}^{m} n_j}{D} \qquad (3.7)$$

Substituting the form of the damage model for $N_f$ (Equation 3.4) and solving for the effective stress or strain, $R_{eff}$, results in:

$$R_{eff} = \left[ \frac{\sum_{j=1}^{m} n_j}{10^{a_0} * (E_{AC})^{a_2} * D} \right]^{1/al} \qquad (3.8)$$

Note that because asphalt elastic modulus, $E_{AC}$, is in the equation, it is necessary to calculate the effective stress or strain, $R_{eff}$, for an elastic modulus value corresponding to a particular season. Since it lies between the extreme seasons, fall (autumn) was selected as the season for $R_{eff}$ calculations. Thus, the asphalt elastic modulus value used was 450,000 psi. It should be recognized that selection of fall as the season for $R_{eff}$ calculations theoretically has no effect on the ultimate predictive accuracy of the damage model.

Steps 2, 3, 4 and 5 (of the flow diagram in Figure 3.6) are carried out for one Road Test section at a time. Steps 6 and 7 provide a means for incrementing through each Road Test section analyzed.

Once effective stress or strain values are calculated for each section, then a regression analysis (step 8) can be performed on $N_f$ (in this case, the actual number of load repetitions experienced by the section before it "failed") versus $R_{eff}$ to generate new $a_0$ and $a_1$ coefficients for the damage model. A measure of the "fit" of the model to the data, the coefficient of determination or $r^2$, is also generated as part of this regression analysis.

Step 9 tests whether the new $a_0$ and $a_1$ values are significantly different from the initial values assumed. If they are, then the process must be re-executed using the new $a_0$ and $a_1$ values as the initial estimates (step 10). Once the $a_0$ and $a_1$ values are essentially equivalent to the initial values assumed (step 11), then they represent the "best" solution for the trial $a_2$ value.

Table 3.5 provides an example output from the DAMOD-4 program for one of the initial asphalt concrete tensile strain models. For the trial $a_2$ value of -3.97, eight iterations were required before the final $a_0$ and $a_1$ values matched the values specified at the beginning of the iteration. These values, then, represented the best combination of $a_0$ and $a_1$ for the selected trial value of $a_2$.

Table 3.5. Example DAMOD-4 output for single axle model.

CRITICAL RESPONSE FOR DAMAGE MODEL: AC TENSILE STRAIN
TRIAL NO. 8

A0 6.890
A1 -6.210
A2 -3.970
SEASONAL EFFECTS:
SPRING -23.2295000
SUMMER -21.2860600
FALL -22.4432500
WINTER -24.7348800

| NSEC | D1 | D2 | D3 | TRSUM | DAMSUM | TRPRIM | STREF | X | Y | YPRIM |
|---|---|---|---|---|---|---|---|---|---|---|
| 111 | 2. | 6. | 8. | .9315E+06 | .3528E+01 | 264037. | .000419 | -3.37760 | 28.41244 | 5.96918 |
| 155 | 3. | 6. | 8. | .9555E+06 | .1587E+01 | 602083. | .000367 | -3.43525 | 28.42348 | 5.98023 |
| 623 | 3. | 6. | 8. | .1245E+06 | .4273E+00 | 291340. | .000413 | -3.38449 | 27.53842 | 5.09517 |
| 601 | 3. | 6. | 12. | .9315E+06 | .1739E+01 | 535789. | .000374 | -3.42709 | 28.41244 | 5.96918 |
| 577 | 4. | 6. | 8. | .1140E+07 | .1891E+01 | 602814. | .000367 | -3.43534 | 28.50016 | 6.05690 |
| 625 | 4. | 6. | 12. | .1019E+07 | .9352E+00 | 1089034. | .000334 | -3.47670 | 28.45122 | 6.00796 |
| 419 | 3. | 6. | 8. | .1095E+06 | .3208E+00 | 341288. | .000402 | -3.39555 | 27.48267 | 5.03941 |
| 487 | 3. | 6. | 12. | .1155E+06 | .2264E+00 | 510210. | .000377 | -3.42367 | 27.50584 | 5.06258 |
| 471 | 3. | 9. | 8. | .1185E+06 | .7254E+00 | 163350. | .000453 | -3.34402 | 27.51697 | 5.07372 |
| 455 | 4. | 6. | 8. | .1449E+06 | .9820E+00 | 147563. | .000460 | -3.33691 | 27.60432 | 5.16107 |
| 453 | 4. | 6. | 8. | .1359E+06 | .4430E+00 | 306764. | .000409 | -3.38809 | 27.57647 | 5.13322 |
| 425 | 4. | 6. | 12. | .7575E+06 | .1042E+01 | 726904. | .000356 | -3.44843 | 28.32264 | 5.87938 |
| 417 | 4. | 9. | 8. | .2520E+06 | .8012E+00 | 314521. | .000408 | -3.38984 | 27.84465 | 5.40140 |
| 477 | 4. | 9. | 12. | .1649E+07 | .1429E+01 | 1153995. | .000331 | -3.48075 | 28.66034 | 6.21709 |
| 469 | 5. | 6. | 8. | .8400E+06 | .7164E+00 | 1172532. | .000330 | -3.48186 | 28.36753 | 5.92428 |
| 445 | 5. | 6. | 12. | .1052E+07 | .6511E+00 | 1615064. | .000313 | -3.50426 | 28.46506 | 6.02181 |
| 303 | 4. | 6. | 8. | .1200E+06 | .7707E+00 | 155698. | .000456 | -3.34067 | 27.52244 | 5.07918 |
| 323 | 4. | 6. | 12. | .1200E+06 | .1071E+01 | 112036. | .000481 | -3.31765 | 27.52244 | 5.07918 |
| 253 | 4. | 6. | 16. | .6765E+06 | .1950E+01 | 346878. | .000401 | -3.39669 | 28.27352 | 5.83027 |
| 321 | 4. | 9. | 8. | .1200E+06 | .1248E+01 | 96156. | .000493 | -3.30696 | 27.52244 | 5.07918 |
| 267 | 4. | 9. | 12. | .1620E+06 | .1538E+01 | 105324. | .000486 | -3.31333 | 27.65277 | 5.20952 |
| 309 | 4. | 9. | 16. | .1535E+07 | .4167E+01 | 368219. | .000397 | -3.40086 | 28.62922 | 6.18597 |
| 259 | 5. | 6. | 8. | .1365E+06 | .6848E+00 | 199322. | .000439 | -3.35794 | 27.57839 | 5.13513 |
| 307 | 5. | 6. | 12. | .8775E+06 | .1576E+01 | 556653. | .000372 | -3.42976 | 28.38650 | 5.94325 |
| 305 | 5. | 6. | 12. | .1890E+06 | .6615E+00 | 285720. | .000414 | -3.38312 | 27.71972 | 5.27646 |
| 327 | 5. | 6. | 16. | .1014E+07 | .1700E+01 | 596383. | .000368 | -3.43459 | 28.44929 | 6.00604 |
| 313 | 5. | 9. | 8. | .6615E+06 | .1551E+01 | 426450. | .000388 | -3.41113 | 28.26378 | 5.82053 |
| 331 | 5. | 9. | 12. | .8355E+06 | .8997E+00 | 928601. | .000342 | -3.46555 | 28.36520 | 5.92195 |
| 325 | 6. | 6. | 8. | .1530E+06 | .4016E+00 | 380968. | .000395 | -3.40324 | 27.62794 | 5.18469 |
| 257 | 6. | 6. | 12. | .1070E+07 | .1150E+01 | 929806. | .000342 | -3.46564 | 28.47243 | 6.02918 |
| 263 | 6. | 9. | 8. | .7680E+06 | .8489E+00 | 904676. | .000344 | -3.46373 | 28.32862 | 5.88536 |
| 271 | 6. | 9. | 8. | .1058E+07 | .1384E+01 | 764359. | .000353 | -3.45194 | 28.46754 | 6.02428 |
| 311 | 6. | 9. | 12. | .1005E+07 | .8740E+00 | 1149881. | .000331 | -3.48050 | 28.44542 | 6.00217 |

REGRESSION LINE IS:
A0 6.876
A1 -6.214
R-SQUARE .599

In the example DAMOD-4 output (Table 3.5), there are several columns of information which are defined as follows for each column heading:

NSEC = AASHTO Section Number.

D1, D2, D3 = Layer thickness (inches) for surface, base and subbase.

TRSUM = Actual cumulative number of single axle applications sustained.

DAMSUM = Total damage for section computed using initial $a_0$, $a_1$ and $a_2$ values.

STREF = Effective fall stress or strain for section.

TRPRIM = Allowable load applications corresponding to effective fall stress or strain.

X = Log (base 10) of STREF (This represents the independent variable in the regression analysis).

YPRIM = Log (base 10) of TRSUM (This represents the dependent variable in the regression analysis).

Y = YPRIM minus the fall seasonal effect.

To get the best combination of $a_0$, $a_1$ and $a_2$, it is necessary to try different $a_2$ values with the objective of finding the combination that provides the highest coefficient of determination ($r^2$). Table 3.6 illustrates how the $a_2$ value of -3.97 and the corresponding $a_0$ and $a_1$ values of 6.89 and -6.21 (respectively) provided the maximum $r^2$. Therefore, they represent the best set of coefficients to use in the single axle damage model.

Table 3.6. Example selection of optimum combination of $a_0$, $a_1$ and $a_2$ for single axle damage model.

| Optimum Coefficients | | | Coefficient of Determination ($r^2$) |
| --- | --- | --- | --- |
| $a_2$ | $a_1$ | $a_0$ | |
| -3.50 | -6.46 | 3.33 | 0.588 |
| -3.70 | -6.35 | 4.85 | 0.597 |
| -3.90 | -6.23 | 6.40 | 0.597 |
| -3.95 | -6.21 | 6.78 | 0.597 |
| -3.97 | -6.21 | 6.89 | 0.599 |
| -4.00 | -6.19 | 7.13 | 0.597 |
| -4.10 | -6.15 | 7.85 | 0.596 |
| -4.30 | -6.06 | 9.34 | 0.587 |

The DAMOD-4 analysis for single axle loads was performed considering five different mechanistic responses (including asphalt concrete tensile strain). The results are summarized in Table 3.7. Figure 3.7 provides a graph illustrating how well the tensile strain model fits the Road Test data. It should be recognized, however, that this and the other relationships were all considered initial or preliminary single axle damage models. Although they are certainly valid and could be used for design or pavement performance prediction, additional equations (described next) were developed which may be more suitable.

While attempting to develop a single axle damage model based on vertical strain at the top of the roadbed soil, the analysis indicated an impractical and undue correlation with vertical strains sustained during the winter (i.e., the higher the strain during winter, the more load applications that could be sustained throughout). The strong degree of correlation was perhaps due to the near order-of-magnitude difference between vertical strains during the winter and those during the rest of the seasons. It may also have been due to the fact that the underlying materials were assigned modulus values based on engineering judgment of the properties during the winter rather than on the deflection based materials characterization technique used for the other seasons. Whatever the explanation, it was reasoned that if pavement damage during the winter was indeed insignificant, then a suitable damage model could be developed by not considering the frozen-winter seasons in the DAMOD-4 analysis. When this analysis was performed, the results for the vertical strain model were so remarkably improved that similar analyses were carried out to develop models for the other four mechanistic response variables. The results are summarized in Table 3.8. Graphs illustrating the relative precision for the asphalt concrete tensile strain and roadbed soil vertical strain models are presented in Figures 3.8 and 3.9, respectively. Table 3.9 presents the DAMOD-4 program output for the asphalt concrete tensile strain model without the frozen-winter effects.

A test of these models was made to determine if the increase in damage that results in each section when the frozen-winters are included was indeed insignificant. The outcome of this test for the asphalt

Table 3.7. Initial single axle damage models resulting from DAMOD-4 computer analysis.

Form of Damage Model

$$\log(N_f) = a_0 + a_1 * \log(R) + a_2 * \log(E_{AC})$$

| Mechanistic Response Considered | Symbol (R) | Optimum Coefficients | | | Coefficient of Determination ($r^2$) |
|---|---|---|---|---|---|
| | | $a_0$ | $a_1$ | $a_2$ | |
| Asphalt Concrete Tensile Strain | $\varepsilon_{AC}$ | 6.89 | -6.21 | -3.97 | 0.599 |
| Asphalt Concrete Tensile Stress | $\sigma_{AC}$ | 4.68 | -6.40 | 2.80 | 0.615 |
| Asphalt Concrete Shear Strain | $\gamma_{AC}$ | 8.96 | -6.43 | -4.20 | 0.584 |
| Asphalt Concrete Shear Stress | $\tau_{AC}$ | 6.69 | -6.28 | 2.10 | 0.562 |
| Vertical Strain on Roadbed Soil | $\varepsilon_{RS}$ | (Model not possible) | | | - |

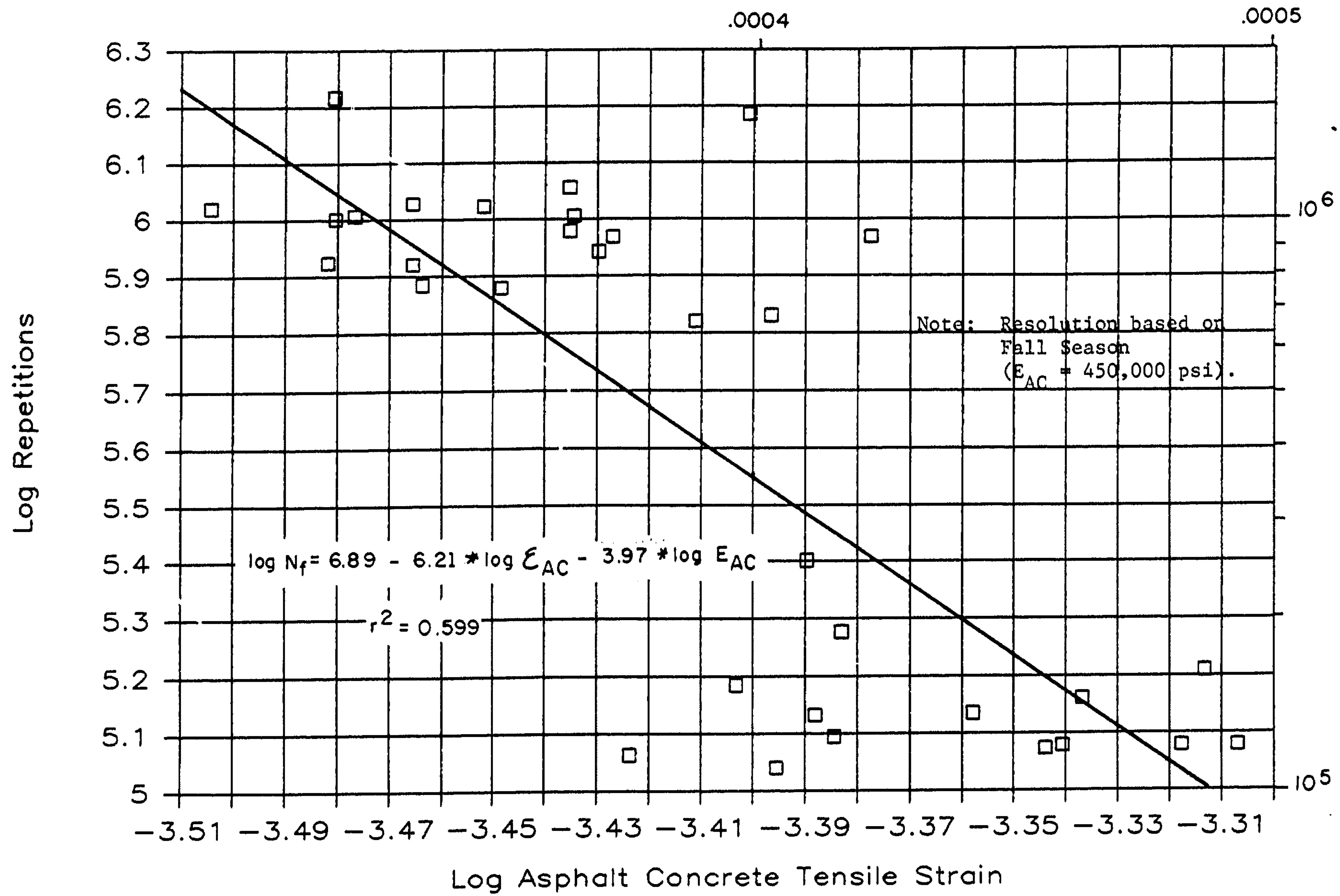



Figure 3.7. Illustration of single axle damage model based on asphalt concrete tensile strain.

Table 3.8. Single axle damage models resulting from DAMOD-4 computer analysis on data without frozen-winter effects.

<u>Form of Damage Model</u>

$$\log(N_f) = a_0 + a_1*\log(R) + a_2*\log(E_{AC})$$

| Mechanistic Response Considered | Symbol (R) | Optimum Coefficients $a_0$ | $a_1$ | $a_2$ | Coefficient of Determination ($r^2$) |
|---|---|---|---|---|---|
| Asphalt Concrete Tensile Strain | $\varepsilon_{AC}$ | 3.25 | -7.50 | -4.10 | 0.834 |
| Asphalt Concrete Tensile Stress | $\sigma_{AC}$ | 2.69 | -7.47 | 3.60 | 0.841 |
| Asphalt Concrete Shear Strain | $\gamma_{AC}$ | 6.61 | -7.72 | -4.50 | 0.829 |
| Asphalt Concrete Shear Stress | $\tau_{AC}$ | 3.85 | -7.62 | 3.10 | 0.819 |
| Vertical Strain on Roadbed Soil | $\varepsilon_{RS}$ | -7.75 | -4.28 | - | 0.723 |

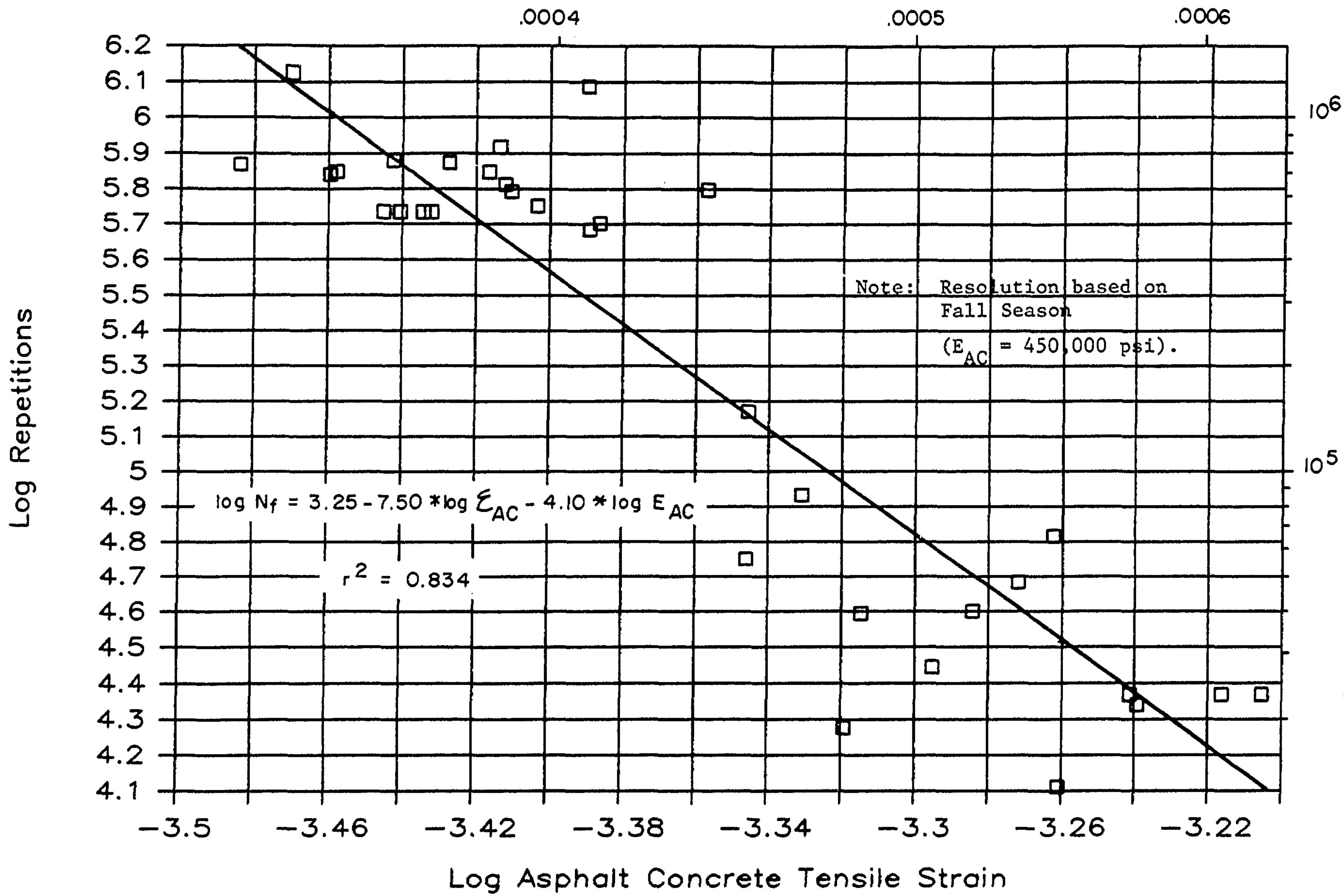



Figure 3.8. Illustration of single axle damage model based on asphalt concrete tensile strain (frozen winter effects not included).

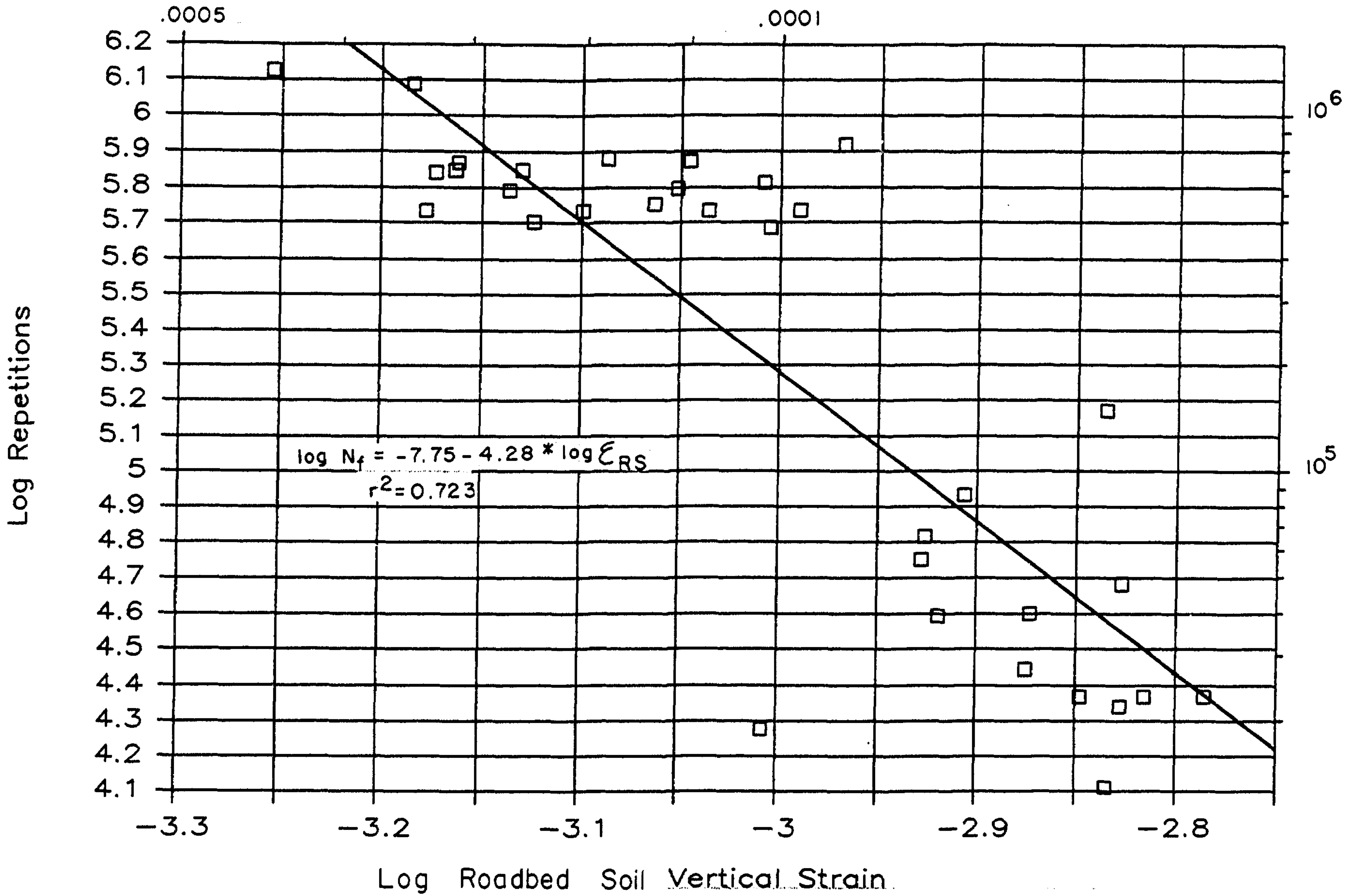



Figure 3.9. Illustration of single axle damage model based on roadbed soil vertical strain (frozen winter effects not included).

Table 3.9. DAMOD-4 output for single axle model with frozen-winter effects excluded.

CRITICAL RESPONSE FOR DAMAGE MODEL: AC TENSILE STRAIN
TRIAL NO. 5

A0 3.250
A1 -7.500
A2 -4.100
SEASONAL EFFECTS:
SPRING -23.9901600
SUMMER -21.9830000
FALL -23.1781700
WINTER -25.5448400

| NSEC | D1 | D2 | D3 | TRSUM | DAMSUM | TRPRIM | STREF | X | Y | YPRIM |
|---|---|---|---|---|---|---|---|---|---|---|
| 111 | 2. | 6. | 8. | .6270E+06 | .3515E+01 | 178383. | .000439 | -3.35727 | 28.97544 | 5.79727 * |
| 155 | 3. | 6. | 8. | .6510E+06 | .1414E+01 | 460542. | .000387 | -3.41219 | 28.99175 | 5.81358 * |
| 623 | 3. | 6. | 8. | .2790E+05 | .4566E+00 | 61108. | .000507 | -3.29524 | 27.62378 | 4.44560 * |
| 601 | 3. | 6. | 12. | .6204E+06 | .1386E+01 | 447746. | .000389 | -3.41056 | 28.97084 | 5.79267 * |
| 577 | 4. | 6. | 8. | .8289E+06 | .1753E+01 | 472779. | .000386 | -3.41371 | 29.09667 | 5.91850 * |
| 625 | 4. | 6. | 12. | .7074E+06 | .6981E+00 | 1013344. | .000348 | -3.45786 | 29.02784 | 5.84967 * |
| 419 | 3. | 6. | 8. | .1290E+05 | .3810E+00 | 33862. | .000548 | -3.26105 | 27.28876 | 4.11059 * |
| 487 | 3. | 6. | 12. | .1890E+05 | .2045E+00 | 92400. | .000480 | -3.31918 | 27.45463 | 4.27646 * |
| 471 | 3. | 9. | 8. | .2190E+05 | .9426E+00 | 23234. | .000576 | -3.23924 | 27.51862 | 4.34044 * |
| 455 | 4. | 6. | 8. | .4830E+05 | .1181E+01 | 40885. | .000535 | -3.27197 | 27.86212 | 4.68395 * |
| 453 | 4. | 6. | 8. | .3930E+05 | .4592E+00 | 85575. | .000484 | -3.31474 | 27.77256 | 4.59439 * |
| 425 | 4. | 6. | 12. | .5438E+06 | .8349E+00 | 651276. | .000370 | -3.43226 | 28.91357 | 5.73540 * |
| 417 | 4. | 9. | 8. | .1488E+06 | .1018E+01 | 146168. | .000451 | -3.34574 | 28.35077 | 5.17260 * |
| 477 | 4. | 9. | 12. | .1337E+07 | .1071E+01 | 1248594. | .000339 | -3.46995 | 29.30443 | 6.12626 * |
| 469 | 5. | 6. | 8. | .5438E+06 | .6687E+00 | 813189. | .000359 | -3.44512 | 28.91357 | 5.73540 * |
| 445 | 5. | 6. | 12. | .7404E+06 | .4657E+00 | 1589881. | .000328 | -3.48394 | 29.04764 | 5.86947 * |
| 303 | 4. | 6. | 8. | .2340E+05 | .9705E+00 | 24110. | .000574 | -3.24138 | 27.54739 | 4.36922 * |
| 323 | 4. | 6. | 12. | .2340E+05 | .1495E+01 | 15649. | .000608 | -3.21636 | 27.54739 | 4.36922 * |
| 253 | 4. | 6. | 16. | .5069E+06 | .1712E+01 | 296140. | .000411 | -3.38662 | 28.88305 | 5.70488 * |
| 321 | 4. | 9. | 8. | .2340E+05 | .1803E+01 | 12976. | .000623 | -3.20551 | 27.54739 | 4.36922 * |
| 267 | 4. | 9. | 12. | .6540E+05 | .1881E+01 | 34763. | .000546 | -3.26257 | 27.99375 | 4.81558 * |
| 309 | 4. | 9. | 16. | .1223E+07 | .3900E+01 | 313674. | .000407 | -3.38995 | 29.26574 | 6.08757 * |
| 259 | 5. | 6. | 8. | .3990E+05 | .7885E+00 | 50605. | .000520 | -3.28431 | 27.77914 | 4.60097 * |
| 307 | 5. | 6. | 12. | .5664E+06 | .1430E+01 | 396003. | .000395 | -3.40345 | 28.93129 | 5.75312 * |
| 305 | 5. | 6. | 12. | .8580E+05 | .7583E+00 | 113144. | .000467 | -3.33091 | 28.11166 | 4.93349 * |
| 327 | 5. | 6. | 16. | .7029E+06 | .1417E+01 | 496042. | .000383 | -3.41649 | 29.02506 | 5.84689 * |
| 313 | 5. | 9. | 8. | .4853E+06 | .1564E+01 | 310269. | .000408 | -3.39932 | 28.86414 | 5.68597 * |
| 331 | 5. | 9. | 12. | .5438E+06 | .7229E+00 | 752135. | .000363 | -3.44060 | 28.91357 | 5.73540 * |
| 325 | 6. | 6. | 8. | .5640E+05 | .3833E+00 | 147148. | .000451 | -3.34612 | 27.92945 | 4.75128 * |
| 257 | 6. | 6. | 12. | .7584E+06 | .9765E+00 | 776651. | .000361 | -3.44245 | 29.05807 | 5.87990 * |
| 263 | 6. | 9. | 8. | .5438E+06 | .8051E+00 | 675361. | .000368 | -3.43436 | 28.91357 | 5.73540 * |
| 271 | 6. | 9. | 8. | .7464E+06 | .1247E+01 | 598434. | .000374 | -3.42736 | 29.05114 | 5.87297 * |
| 311 | 6. | 9. | 12. | .6939E+06 | .6542E+00 | 1044727. | .000347 | -3.45962 | 29.01947 | 5.84130 * |

REGRESSION LINE IS:
A0 3.248
A1 -7.498
R-SQUARE .934

concrete tensile strain model is depicted in Figure 3.10. Since none of the points are significantly above the line of equality, the increase in damage due to load applications during the frozen-winter season is for all intents and purposes, negligible.

Task 9 - Develop Tandem Axle Damage Models

The approach to developing the tandem axle damage models was almost identical to that for the single axle models developed in Task 8. The form of the model is the same, the same five mechanistic response variables were considered and, for purposes of consistency, load applications during the frozen winter season were not considered. The principal difference in the analyses was in the recognition that damage due to the steering axles had to be assessed using the appropriate single axle damage model. The necessary changes were incorporated into the DAMOD-4 program to produce DAMOD-5. The flow diagram for the DAMOD-5 program is basically the same as for DAMOD-4 (see Figure 3.6). The differences are in steps 1, 3, 4 and 5.

In step 1, the user must enter the fixed $a_0$, $a_1$ and $a_2$ values from the single axle model along with the trial $a_2$ value and initial estimates of $a_0$ and $a_1$ for the tandem axle model. In step 3, the allowable load repetitions for the steering and tandem axle loads are calculated using the appropriate $a_0$, $a_1$ and $a_2$ values. In step 4, total damage is calculated with particular attention to the load configuration (steering or tandem). In step 5, the effective stress or strain is calculated using a formula derived below.

The applicable damage equation for the case where both tandem trailing and single steering axle loads are being applied is as follows:

$$D = \frac{\sum_{j=1}^{m} (n_S)_j}{(N_f)_{Seff}} + \frac{\sum_{j=1}^{m} (n_T)_j}{(N_f)_{Teff}} \qquad (3.9)$$

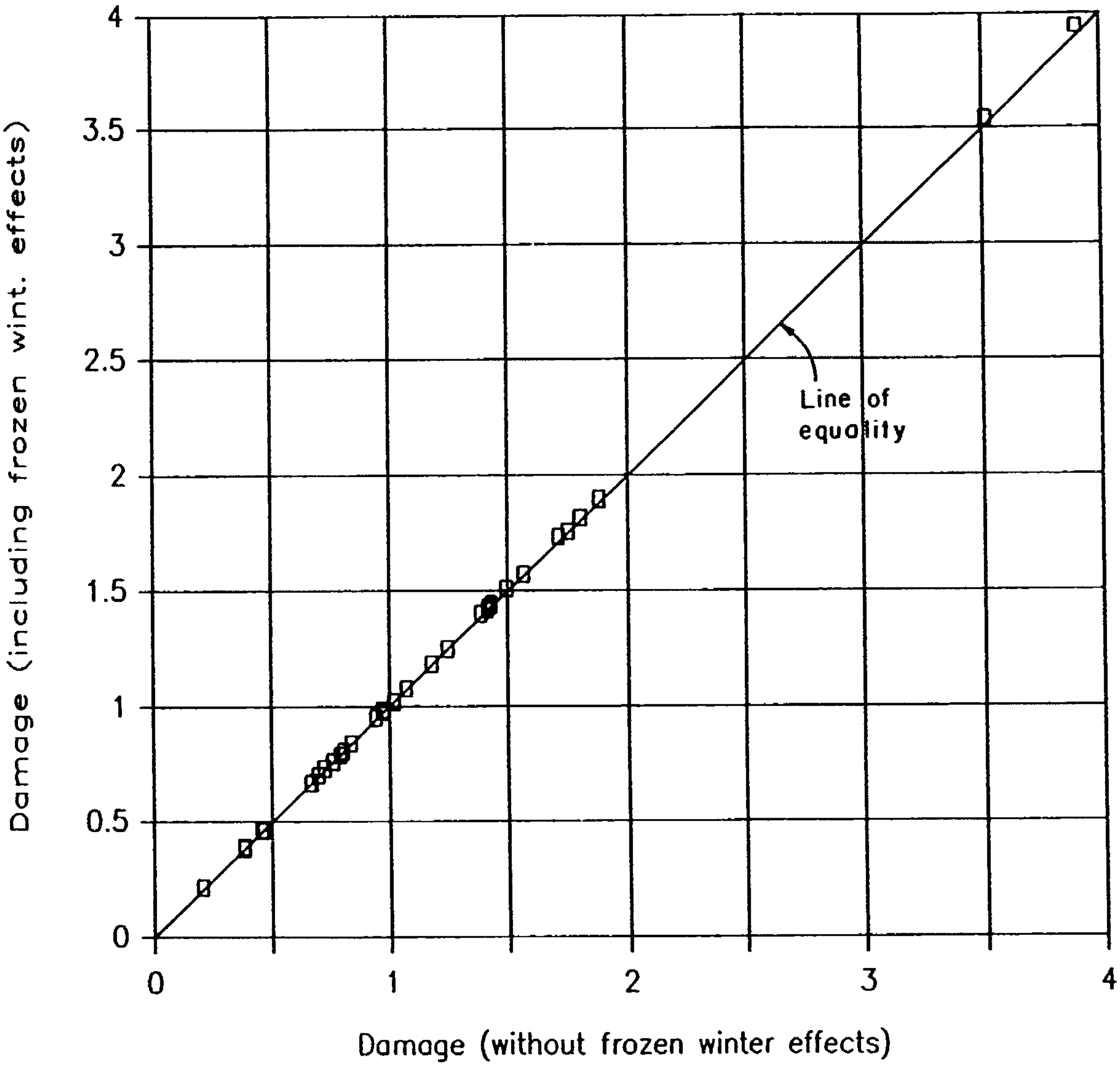



Figure 3.10. Graph illustrating the increase in pavement damage associated with applying the single axle AC tensile strain model (developed without frozen winter effects) using data with frozen winter effects.

In this case, $(N_f)_{Seff}$ and $(N_f)_{Teff}$ are, respectively, the predicted allowable load applications (corresponding to the effective stress or strain) from the single and tandem axle damage models. Also, $(n_S)_j$ and $(n_T)_j$ represent, respectively, the number of applications of single and tandem axle loads during the $j^{th}$ season of a given section.

The important point to recognize in solving for an effective stress or strain for a given section is that the value for the effective stress or strain must be the same in both the $(N_f)_{Seff}$ and $(N_f)_{Teff}$ equations. Consequently, Equation 3.7 can be rearranged to solve for the effective stress or strain, $R_{eff}$, as follows:

$$R_{eff} = \left[ \frac{\sum_{j=1}^{m} (n_T)_j}{\left[ D - \frac{\sum_{j=1}^{m} (n_S)_j}{(N_f)_{Seff}} \right]} * (10)^{-a_{0T}} * (E_{AC})^{-a_{2T}} \right]^{1/a_{1T}} \qquad (3.10)$$

Note that the "T" on the $a_0$, $a_1$ and $a_2$ coefficients is added to indicate that they are part of the tandem axle relationship. Note also that $R_{eff}$ appears on both sides of the equation as it is part of the equation that solves for $(N_f)_{Seff}$. Consequently, to solve for $R_{eff}$, it is necessary to assume a value, calculate a new value using Equation 3.10 and iterate until the new value is equivalent to the assumed value.

Once the effective stress or strain value is determined for all tandem axle sections, then, as in the single axle model, a regression analysis is performed to generate new $a_{0T}$ and $a_{1T}$ coefficients for the tandem axle model. If these new values are not equivalent to the assumed values, the process must be re-executed using the new coefficients as initial estimates. When the calculated $a_{0T}$ and $a_{1T}$ values are equivalent to the initial estimates, convergence is reached and the values of the two coefficients represent the best combination of $a_{0T}$ and $a_{1T}$ for trial $a_{2T}$. Table 3.10 provides example output from the DAMOD-5 program for the asphalt concrete tensile strain model. All the columns are as previously described except that TRSUM(1) represents the cumulative number of steering axle applications and TRSUM(2) represents the cumulative number of tandem axle repetitions.

As in the case of the single axle damage model, it is then necessary to try different $a_{2T}$ values until the set of coefficients which produces the highest $r^2$ is determined. The results of the DAMOD-5 analysis for all five mechanistic response variables considered are presented in Table 3.11. (Recall that these values are all based on data in which the frozen-winter effects were removed). Figures 3.11 and 3.12 illustrate the relative precision of the asphalt concrete tensile strain and roadbed soil vertical strain models.

RECOMMENDED MODELS

Based on the results of the analyses, it is recommended that the single and tandem axle damage models that are based on asphalt concrete tensile strain without frozen-winter effects be used both for asphalt concrete pavement design and for examining the relative effects of different loads, load configurations and tire pressures on pavements with asphalt concrete thicknesses greater than 2 inches. Although the predictive accuracy of all the models based on a mechanistic response in the asphalt concrete surface was very high, the single and tandem axle tensile strain models have the highest combined precision. Another reason for using the tensile strain based models is that most of the experience to date with asphalt concrete damage models has been with tensile strain.

The roadbed soil vertical strain models are recommended only for cases where surface treatments or thin asphalt concrete surfaced pavements are being designed or evaluated. (This is necessary because of the likelihood of the predicted strains in the bottom of a thin asphalt

Table 3.10. Example DAMOD-5 output for tandem axle model.

CRITICAL RESPONSE FOR DAMAGE MODEL: AC TENSILE STRAIN
TRIAL NO. 8

| | SINGLE | TANDEM |
|---|---|---|
| COEFFICIENTS | | |
| A0 | 3.250 | .821 |
| A1 | -7.500 | -6.176 |
| A2 | -4.100 | -3.000 |
| SEASONAL EFFECTS | | |
| SPRING | -23.9901600 | -17.5537800 |
| SUMMER | -21.9830800 | -16.0851800 |
| FALL | -23.1781700 | -16.9596400 |
| WINTER | -25.5448400 | -18.6913500 |

| NSEC | D1 | D2 | D3 | TRSUM(1) | TRSUM(2) | DAMSUM | STREF | X | Y | YPRIM | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 112 | 2. | 6. | 8. | 183450. | 366900. | .5560E+01 | .000398 | -3.39996 | 22.52419 | 5.56455 | * |
| 156 | 3. | 6. | 8. | 183450. | 366900. | .1905E+01 | .000336 | -3.47403 | 22.52419 | 5.56455 | * |
| 624 | 3. | 6. | 8. | 36300. | 72600. | .1842E+01 | .000432 | -3.36446 | 21.82057 | 4.86094 | * |
| 602 | 3. | 6. | 12. | 181250. | 362500. | .2276E+01 | .000346 | -3.46087 | 22.51894 | 5.55931 | * |
| 578 | 4. | 6. | 8. | 254300. | 508600. | .2145E+01 | .000325 | -3.48842 | 22.66601 | 5.70638 | * |
| 420 | 3. | 6. | 8. | 5800. | 11600. | .4612E+00 | .000464 | -3.33355 | 21.02409 | 4.06446 | * |
| 488 | 3. | 6. | 12. | 172450. | 344900. | .2659E+01 | .000358 | -3.44666 | 22.49733 | 5.53769 | * |
| 472 | 3. | 9. | 8. | 10450. | 20900. | .1589E+01 | .000514 | -3.28907 | 21.27978 | 4.32015 | * |
| 456 | 4. | 6. | 8. | 14250. | 28500. | .7098E+00 | .000431 | -3.36574 | 21.41448 | 4.45484 | * |
| 454 | 4. | 6. | 8. | 43400. | 86800. | .1449E+01 | .000404 | -3.39331 | 21.89816 | 4.93852 | * |
| 426 | 4. | 6. | 12. | 58800. | 117600. | .7200E+00 | .000345 | -3.46262 | 22.03004 | 5.07041 | * |
| 418 | 4. | 9. | 8. | 29300. | 58600. | .1266E+01 | .000421 | -3.37547 | 21.72754 | 4.76790 | * |
| 470 | 5. | 6. | 8. | 154300. | 308600. | .1269E+01 | .000323 | -3.49019 | 22.44903 | 5.48940 | * |
| 446 | 5. | 6. | 12. | 280500. | 561000. | .9822E+00 | .000282 | -3.54942 | 22.70860 | 5.74896 | * |
| 304 | 4. | 6. | 8. | 24800. | 49600. | .8747E+00 | .000408 | -3.38951 | 21.65512 | 4.69548 | * |
| 324 | 4. | 6. | 12. | 11950. | 23900. | .5116E+00 | .000421 | -3.37613 | 21.33804 | 4.37840 | * |
| 254 | 4. | 6. | 16. | 76300. | 152600. | .6385E+00 | .000324 | -3.48898 | 22.14319 | 5.18355 | * |
| 322 | 4. | 9. | 8. | 27300. | 54600. | .8607E+00 | .000401 | -3.39728 | 21.69683 | 4.73719 | * |
| 268 | 4. | 9. | 12. | 84300. | 168600. | .1385E+01 | .000361 | -3.44227 | 22.18649 | 5.22686 | * |
| 260 | 5. | 6. | 8. | 17800. | 35600. | .3563E+00 | .000373 | -3.42863 | 21.51109 | 4.55145 | * |
| 308 | 5. | 6. | 12. | 181250. | 362500. | .1211E+01 | .000313 | -3.50460 | 22.51894 | 5.55931 | * |
| 306 | 5. | 6. | 12. | 196800. | 393600. | .1505E+01 | .000320 | -3.49522 | 22.55469 | 5.59506 | * |
| 328 | 5. | 6. | 16. | 183800. | 367600. | .9956E+00 | .000303 | -3.51913 | 22.52501 | 5.56538 | * |
| 314 | 5. | 9. | 8. | 195500. | 391000. | .1555E+01 | .000322 | -3.49250 | 22.55181 | 5.59218 | * |
| 332 | 5. | 9. | 12. | 102800. | 205600. | .5623E+00 | .000303 | -3.51846 | 22.27266 | 5.31302 | * |
| 326 | 6. | 6. | 8. | 27800. | 55600. | .2827E+00 | .000335 | -3.47548 | 21.70471 | 4.74507 | * |
| 272 | 6. | 9. | 8. | 207500. | 415000. | .8760E+00 | .000291 | -3.53644 | 22.57768 | 5.61805 | * |

REGRESSION LINE IS: A0 = .824, A1 =-6.176, R-SQUARE = .676

Table 3.11. Tandem axle damage models resulting from DAMOD-5 computer analysis on data without frozen-winter effects.

Form of Damage Model

$$\log(N_f) = a_0 + a_1 * \log(R) + a_2 * \log(E_{AC})$$

| Mechanistic Response Considered | Symbol (R) | Optimum Coefficients $a_0$ | $a_1$ | $a_2$ | Coefficient of Determination ($r^2$) |
|---|---|---|---|---|---|
| Asphalt Concrete Tensile Strain | $\varepsilon_{AC}$ | 0.82 | -6.18 | -3.0 | 0.676 |
| Asphalt Concrete Tensile Stress | $\sigma_{AC}$ | 0.91 | -5.51 | 3.0 | 0.654 |
| Asphalt Concrete Shear Strain | $\gamma_{AC}$ | 5.19 | -5.30 | -3.0 | 0.580 |
| Asphalt Concrete Shear Stress | $\tau_{AC}$ | 4.75 | -5.05 | 1.9 | 0.578 |
| Vertical Strain on Roadbed Soil | $\varepsilon_{RS}$ | -5.27 | -3.42 | - | 0.649 |

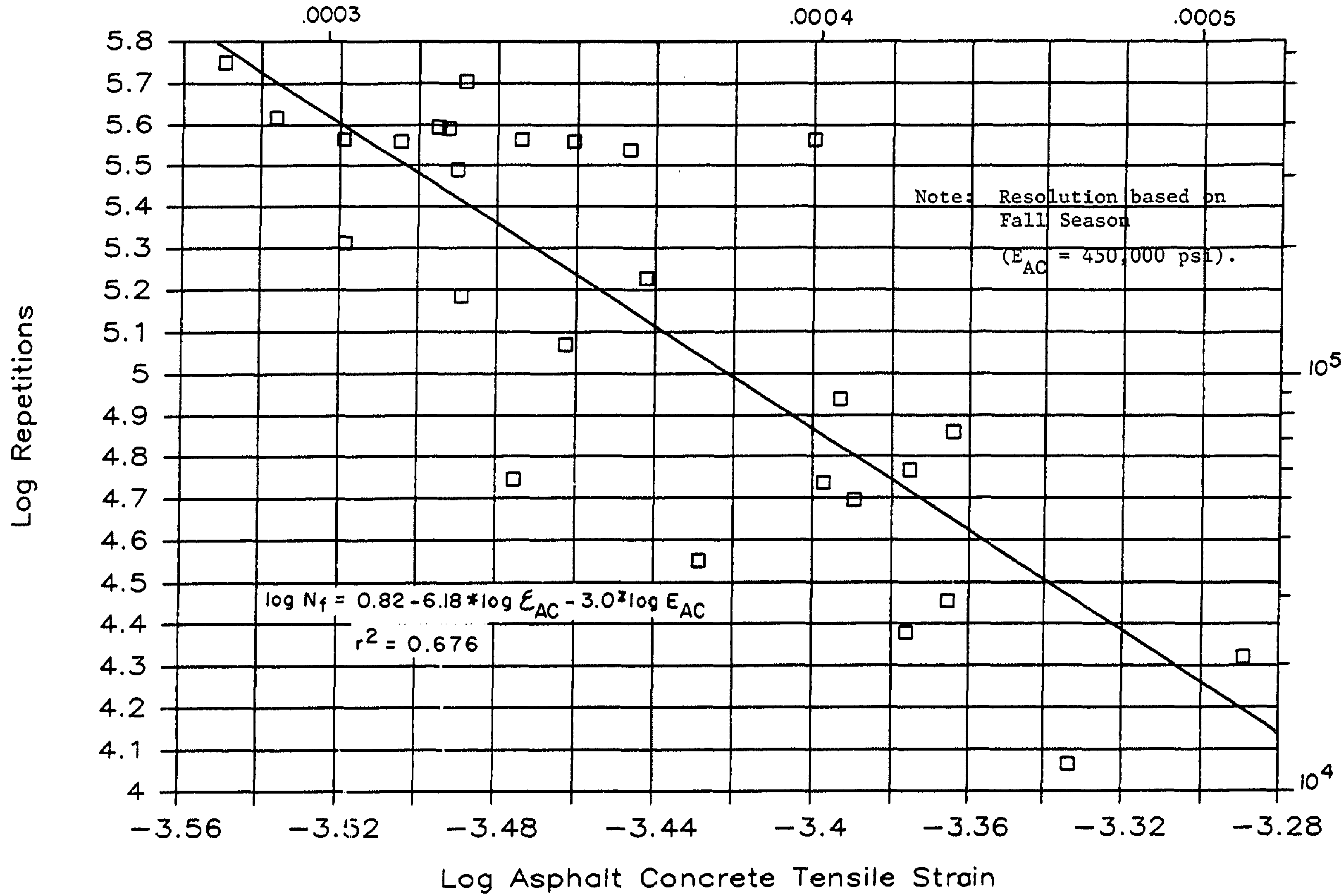



Figure 3.11. Illustration of tandem axle damage model based on asphalt concrete tensile strain (frozen winter effects not included).

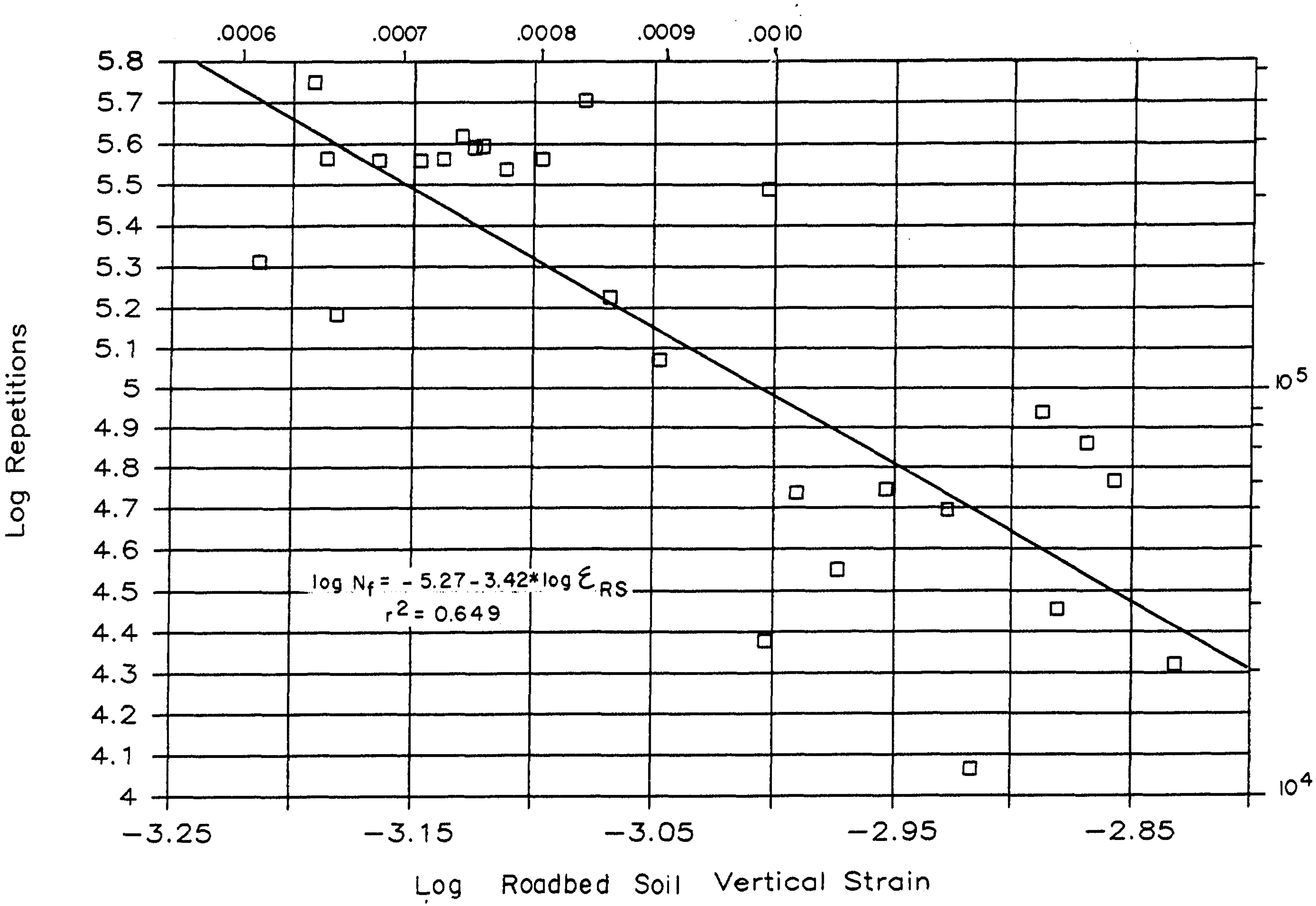



Figure 3.12. Illustration of tandem axle damage model based on roadbed soil vertical strain (frozen winter effects not included).

concrete being compressive rather than tensile.) Although the roadbed soil vertical strain models have a somewhat lower level of precision, they still explain a high percentage of the variability observed in the AASHO Road Test Data.

# CHAPTER 4. EQUIVALENCE FACTOR DEVELOPMENT

A new set of 18-kip single axle equivalence factors were developed on this project using the damage models described in Chapter 3. The new factors were mechanistically developed and are intended to eventually replace the AASHTO load equivalence factors currently used by ADOT. One significant improvement in this new set of equivalence factors is that they were developed considering the effects of tire pressure. The resulting factors should, therefore, allow more accurate estimates of equivalent loads accounting for the higher tire pressures which have been observed on Arizona highways as described in Chapter 5 of this report.

## VARIABLES USED IN EQUIVALENCE FACTOR DEVELOPMENT

The equivalence factors are dependent on a number of different parameters. These include the thicknesses and moduli of all pavement layers, tire pressure, axle type and load. Several of the parameters have more influence than others. The parameters which have relatively little effect on the equivalence factors were fixed in the development. The minimum performance level was fixed at a terminal serviceability of 2.5. The parameters which are varied in the analysis and their associated levels are as follows:

1. Load (lb): 4000, 10000, 18000, 30000, 50000
2. Tire Pressure (psi): 75, 110, 145
3. Modulus of Roadbed Soil (psi): 4000, 12000, 20000
4. Subbase/Base Thickness (in): 4/4, 6/8, 8/12
5. AC Thickness (in): 0, 3, 6
6. Axle Type: Single axle single tire, single axle dual tire, tandem axle, and tridem axle.

Moduli for base and subbase layers were assigned fixed values depending on the roadbed soil modulus:

| Roadbed Soil Modulus (psi) | Subbase Modulus (psi) | Base Modulus (psi) |
|---|---|---|
| 4,000 | 10,000 | 24,000 |
| 12,000 | 30,000 | 60,000 |
| 20,000 | 40,000 | 80,000 |

An equivalence factor was developed for all combinations of each of these levels using the new damage models.

USE OF DAMAGE MODELS TO DEVELOP EQUIVALENCE FACTORS

Given the damage models described in Chapter 3, the technique for generating 18-kip single axle equivalence factors for a variety of conditions is relatively simple. An equivalence factor is a ratio of the relative damage between a given loading condition (x/c/p), and a standard 18-kip single axle load. (Note: "x" refers to the load magnitude, "c" to the load configuration and "p" to the tire pressure.)

The equivalence factor for load (x/c/p), therefore, may be calculated as the ratio of the allowable 18-kip single axle load applications to the allowable applications for load (x/c/p):

$$e_{x/c/p} = \frac{(N_f)_{18/1/75}}{(N_f)_{x/c/p}}$$

$(N_f)_{18/1/75}$ is calculated for the selected structural and soil support conditions using the single axle damage model with a standard 75-psi tire pressure and 18-kip single axle as the load. $(N_f)_{x/c/p}$ is calculated (for the same structural and soil support conditions) using the appropriate single or tandem axle damage model along with the load magnitude (x) and tire pressure (p) corresponding to load (x/c/p). Two sets of damage models were used in the development. For 3 and 6 inch surface thicknesses, the set of models having tensile strain at the bottom of the asphalt layer as the response parameter was used. For thin surface treatments, the models having vertical strain on the subgrade as response parameter were used. Figure 4.1 illustrates the equivalence factor development process. The following example is provided to demonstrate the technique.

Suppose we have a pavement structure consisting of 3 inches of asphalt concrete, 6 inches of base and 8 inches of subbase in a weak roadbed soil environment ($E_{RS}$ = 4000 psi). Suppose also that we want to calculate the equivalence factor for a 30-kip tandem axle having a 110 psi tire pressure. Assuming reasonable subbase, base and asphalt concrete moduli of 8000 psi, 12000 psi and 450000 psi, respectively, the critical asphalt concrete tensile strains that would be calculated using an elastic layer theory based computer program (e.g., ELSYM5) are $5.111 \times 10^{-4}$ for the standard 18-kip single axle and $5.179 \times 10^{-4}$ for the 30-kip tandem axle. $(N_f)_{18/1/75}$ determined using the single axle damage model is 57,284 and $(N_f)_{30/2/110}$ from the tandem axle model is 14,666. Thus, the tandem axle equivalence factor for these conditions is:

$$e_{30/2/110} = 57284/14666 = 3.91$$

EQUIVALENCE FACTORS FOR TRIDEM AXLES

Tridem or triple axles refer to a series of three axles in a vehicle designed to better distribute load to the pavement. By AASHTO definition, a triple axle load is "the total load transmitted to the road by three consecutive axles whose centers may be included between parallel vertical planes spaced more than 40 inches and not more than 96 inches apart, extending across the full width of the vehicle." Since more efficiency and less pavement damage is associated with tridem axles, there is an obvious need to estimate their equivalence factors.

Unfortunately, since tridem axle loads were not considered in the AASHO Road Test experiment, it was not possible to develop a damage model based on tridem axle loads. Nevertheless, the mechanistic nature of the damage models used to generate the single and tandem axle load equivalence factors made it essential that some compatible set of load equivalence factors be established for tridem axle loads. Five different options were

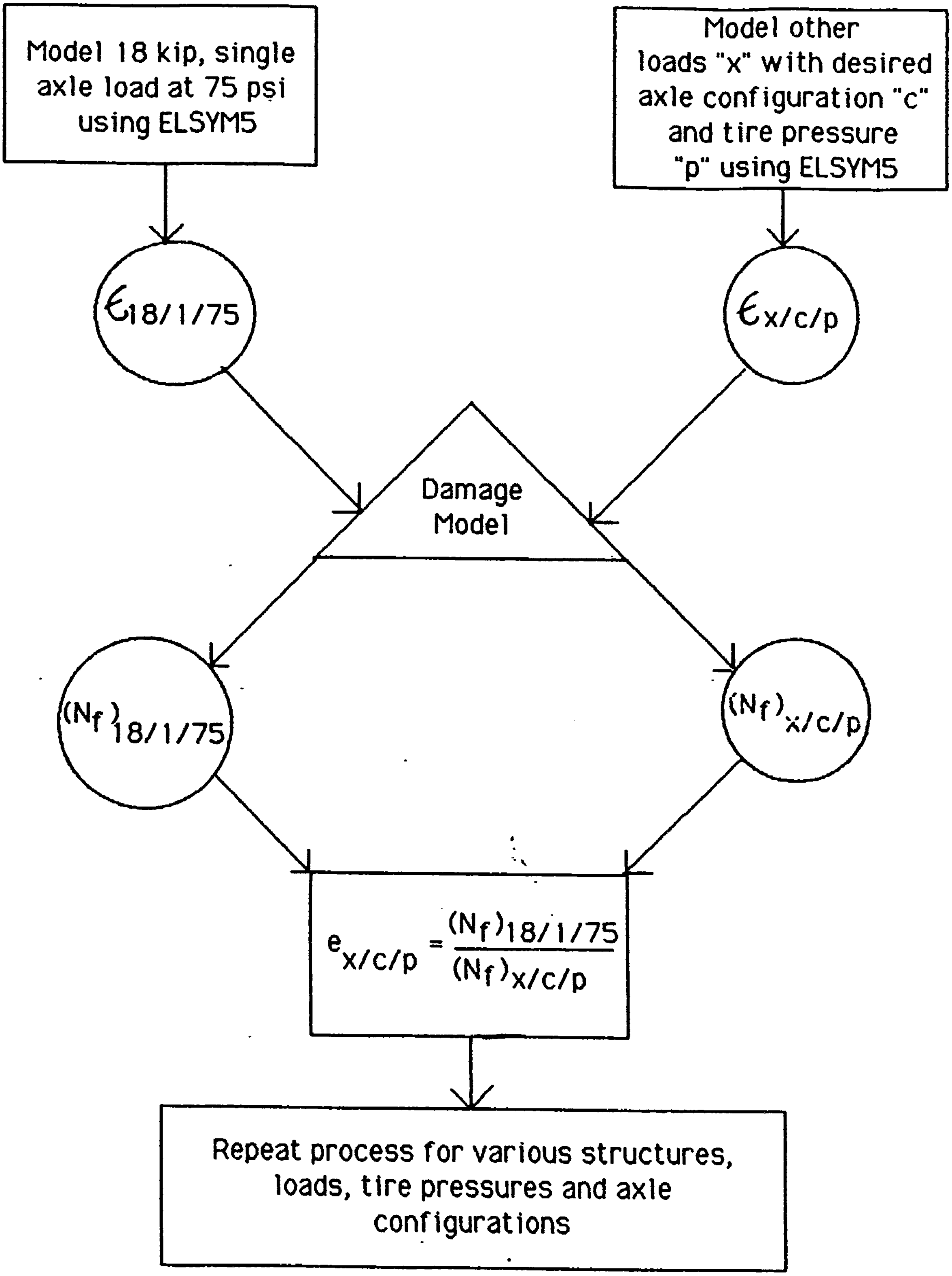



Figure 4.1. Illustration of equivalence factor development process.

identified to determine the factors. All options depend on some extrapolation of the single and tandem axle load equivalence factors:

Option 1: Use tandem axle equivalence factors for tridem axle loads. Of all the options, this was the least attractive because it is too conservative in that it does not give any benefit to having another axle to distribute the load to.

Option 2: Determine the tandem axle load equivalence factor for two-thirds the tridem axle load and increase by 50 percent to account for the third axle:

$$e_{x/3/p} = 1.5 * e_{x/2/p}$$

As an example, for a roadbed soil modulus of 4000 psi and a pavement structure consisting of an 8-inch/8000 psi subbase, 6-inch/12000 psi base and a 3-inch/450000 psi asphalt concrete surface, the equivalence factor for a 30-kip tridem axle load with 75 psi tire pressure, $e_{30/3/75}$, would be 1.5 times the equivalence factor for two-thirds the tandem axle load (20-kips):

$$e_{30/3/75} = 1.5 * e_{20/2/75} = 1.5 * (0.309) = 0.464$$

Option 3: Determine the single and tandem axle load equivalence factors for one-third and two-thirds the load, respectively, then add the two together:

$$e_{x/3/p} = e_{.333x/1/p} + e_{.666x/2/p}$$

Using the 30-kip tridem axle load as an example:

$$e_{30/3/75} = e_{10/1/75} + e_{20/2/75} = 0.064 + 0.309 = 0.373$$

Option 4: Determine the ratio of the tandem axle to the single axle load equivalence factor and assume that the ratio is the same as the ratio of the tridem axle to the tandem axle load equivalence factor:

$$e_{x/3/p} = e_{x/2/p} * \frac{e_{x/2/p}}{e_{x/1/p}}$$

Again using the 30-kip tridem axle as an example:

$$e_{30/3/75} = e_{30/2/75} * \frac{e30/2/75}{e30/1/75} = 1.592 * \frac{1.592}{17.00} = 0.149$$

<u>Option 5</u>: Determine the ratio of the actual tandem axle equivalence factor to the expected tandem axle equivalence factor obtained from two single axles having half the tandem axle load. Then, multiply this ratio by the expected tridem axle load equivalence factor obtained from 1.5 tandem axles having two-thirds the load:

$$e_{x/3/p} = \frac{e_{x/2/p}}{(2*e_{.5x/1/p})} * (1.5*e_{.666x/2/p})$$

The solution for the 30-kip tridem axle load would, in this case, be:

$$e_{30/3/75} = \frac{e_{30/2/75}}{(2*e_{15/1/75})} * (1.5*e_{20/2/75})$$

$$= \frac{1.592}{(2*0.380)} * (1.5 * 0.309)$$

$$= 0.972$$

Table 4.1 provides a summary of the equivalence factor calculations for these five options using five different loads. Figure 4.2 provides a plot of equivalence factor versus load for the five options.

Based on an examination of these results, Option 5 was selected as the best model for estimating tridem axle load equivalence factors for Arizona. Although the extrapolation technique is relatively complex, the results appear to be more reasonable than any of the other options. In fact, options 2 and 3 could not really be considered since, as the results indicated, the technique of simply separating a tridem into a tandem and a

Table 4.1. 18-kip single axle equivalence factors for five different tridem axle load equivalence factor options. (3-inch/450000 psi asphalt concrete, 6-inch/12000 psi base, 8-inch/8000 psi subbase, 4000 psi roadbed soil assumed).

| Axle Load (Kips) | Damage Model Based Equivalence Factors | | Equivalence Factors for Various Tridem Axle Options | | | | |
|---|---|---|---|---|---|---|---|
| | Dual-Single | Dual-Tandem | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 |
| 4 | 0.00050 | 0.00020 | 0.00020 | ----- | ----- | 0.00008 | ---- |
| 10 | 0.06442 | 0.01766 | 0.01766 | 0.0024 | 0.0019 | 0.00484 | 0.01695 |
| 18 | 1.000 | 0.2189 | 0.2189 | 0.0597 | 0.0423 | 0.0479 | 0.2068 |
| 30 | 17.00 | 1.592 | 1.592 | 0.464 | 0.373 | 0.149 | 0.972 |
| 50 | 229.8 | 12.74 | 12.74 | 3.44 | 2.92 | 0.706 | 5.022 |

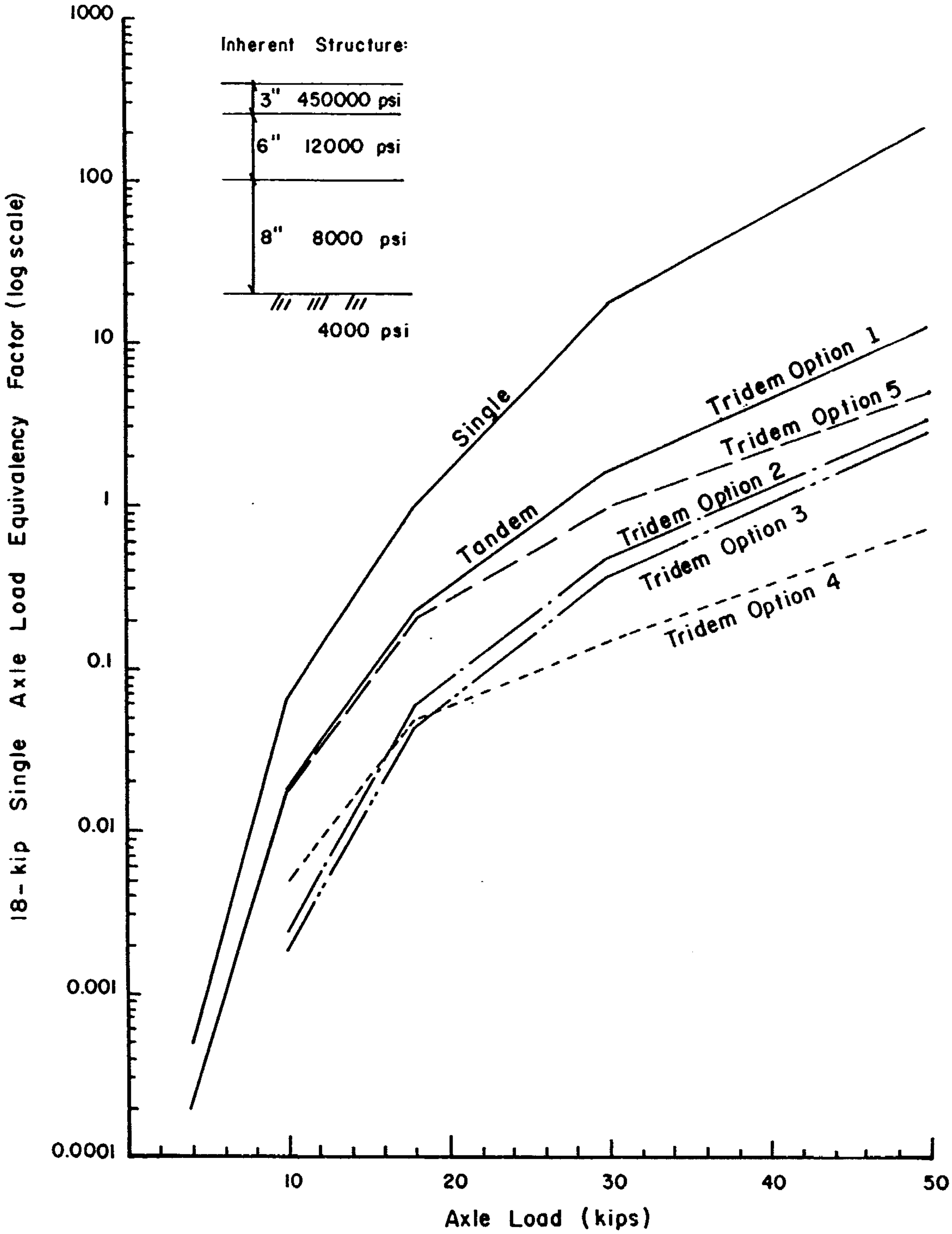



Figure 4.2. Plot of 18-kip single axle load equivalence factor versus axle load illustrating five tridem axle equivalence factor options.

half or one tandem and one single is not accurate, since equivalence factors are an exponential function of load magnitude. Assuming this logic was correct, option 4 was eliminated since it had tridem axle load equivalency factors less than those for options 2 and 3.

## USE OF EQUIVALENCE FACTORS IN 18KESAL PREDICTION PROGRAMS

Tables of ARE equivalence factors were developed as described above and are presented in Appendix F. The ARE factors were incorporated into the 18KESAL prediction programs (described in Chapter 7) using Lagrange multivariate interpolation algorithms (Ref 22). Through the use of interpolation, it is possible to estimate the equivalence factors on a continuous scale for several of the variable parameters that were analyzed at discrete points. The interpolation algorithms have load, tire pressure and roadbed soil modulus as variable parameters within the equations. This allows these to be varied on a continuous scale to predict equivalence factors. The equations are therefore expressed as:

$$e_f = f(\text{Load, Tire pressure, Roadbed soil modulus})$$

Separate algorithms are used for all combinations of the remaining variables. This includes three levels of base thickness, three levels of AC thickness and four different axle types for a 3x3x4 factorial or thirty-six sets.

The equivalence factor prediction algorithms are used in the 18KESAL estimation programs to generate equivalence factors for each input axle load. The proper interpolation array will be chosen by user input of layer thicknesses and by axle type. The program query for the layer thickness offers general terms such as thin, medium and thick with a range of thickness values listed which distinguish between the general categories. The ranges for the thickness categories are as follows:

Surface Thickness

| | | |
|---|---|---|
| Thin | - < 2 in | - assign 0 in |
| Medium | - 2 - 5 in | - assign 3 in |
| Thick | - > 5 in | - assign 6 in |

Total Base/Subbase Thickness

| | | |
|---|---|---|
| Thin | - < 10" overall | - assign 4"/4" |
| Medium | - 10" - 17" overall | - assign 6"/8" |
| Thick | - > 17" overall | - assign 8"/12" |

Values for the variables tire pressure and roadbed soil modulus used in the equations are user inputs. They can be input using general ranges as with the thicknesses or, if the user desires, he can input the actual values if they are known. The ranges presented for roadbed soil modulus are as follows:

| | | |
|---|---|---|
| Low | - < 8000 psi | - assign 4000 |
| Medium | - 8000 - 16000 psi | - assign 12000 |
| High | - > 16000 psi | - assign 20000 |

The user also has the option of entering the value exactly instead of using the general ranges. A default value of 12000 psi should be specified if the user has no information to base a decision on.

Tire pressure is presented as follows:

Standard AASHO Road Test Pressures (75 psi)
ARE Inc Measurements of Existing Field Pressures (110 psi)
High Pressure (145 psi)

Again, the user has the option of entering an exact value of tire pressure instead of using the three general ranges provided. A default value of 110 psi should be assigned if no value is known.

# CHAPTER 5. FIELD STUDIES

This chapter presents the activities and accomplishments of field work performed by ARE Inc for the Arizona Department of Transportation. The object of these studies was to collect data on the operating tire pressures of trucks operating in Arizona and perform condition surveys on several test sections in eastern Arizona which were part of the SODA (Structural Overlay Design for Arizona (Ref 11)) program.

## TRUCK TIRE PRESSURES

Truck tire pressures were inventoried at three Arizona Port-of-Entry (P.O.E.) weight stations: San Simon, Duncan, and Sanders. Only a few trucks were recorded in Duncan; therefore, extra measurements were taken at San Simon. Pressure data from 350 trucks were recorded over 4 days of measurements from September 19-24, 1985.

### Pressure Measurements

The field crew began checking tire pressures on trucks as they were stopped on the weigh station scales. The trucks had just come off the highway, so the tires were at operating temperature and pressure. The test procedure was to check the pressures of three tires on each truck: one front steering tire, one drive tire on the tractor and one of the rear tires on the trailer or trailers. Information noted on each truck was; configuration, tire size and type, tire pressure, and ambient temperature in both the sun and shade at intervals throughout the day.

The cooperation of the truck drivers was better than expected. Only one driver refused to participate in the study. The data collection procedure was changed so pressures were measured in the parking area. The drivers were asked for permission to check their tires as they went in to have their papers checked. The work was completed by the time they returned so there was no time loss or inconvenience caused by the data collection efforts.

## Pressure Data Analysis

The tire pressure data was reduced and analyzed. Table 5.1 summarizes the radial tire pressure information collected at all three truck stations. The tire pressures are subdivided by their location on the truck: front (steering axle), middle (drive axle), and rear (trailer axle).

The most common tire size observed was the 11R24.5 constituting over 50 percent of all the front tire measurements. Three other tire sizes (11R22.5, 275/80R24.5, and 285/75R24.5) in conjunction with the 11R24.5's constituted almost 90 percent of the front tire observations. As might be expected, the measured standard deviation is lowest for front tires because truckers check front tire pressure more often to insure optimum ride and handling of the truck. Many of the truckers do not own the trailer they haul; consequently, trailer tire pressures vary (higher standard deviation) more than tractor tire pressures.

Table 5.2 includes all types of tires measured but separates bias ply from radials. For three truck axle locations (front, middle, and rear), the number of observations, the mean tire pressure, and the standard deviation are calculated. In addition, intervals are calculated that indicate a range of tire pressures between which 99, 95 and 90 percent of the tire population should statistically fall.

## Conclusions on Truck Tire Pressures

The following conclusions can be drawn from the analysis of the pressure data collected on this project:

1. The number of bias ply tires as compared to the number of radial tires (tractor = 5.1%, trailer = 17.2%) is small enough that we could consider only radials in the equivalence factor analysis.

2. Tire pressures on the steering axle exhibit a lower standard deviation than do tires on the middle or rear (trailer) axles.

Table 5.1. Tire pressure breakdown by tire type.

**FRONT RADIALS**

| TIRE TYPE | OBS. | MEAN | ST.DEV. |
|---|---|---|---|
| 10.00R20 | 3 | 100.0 | 6.9 |
| 10.00R22 | 4 | 98.3 | 9.5 |
| 10.00R24.5 | 1 | 122.0 | 0.0 |
| 11/80R22.5 | 2 | 106.0 | 5.7 |
| 11R22.5 | 33 | 104.4 | 8.3 |
| 11R24.5 | 189 | 106.5 | 9.9 |
| 275/80R22.5 | 9 | 107.4 | 5.2 |
| 275/80R24.5 | 35 | 107.3 | 9.2 |
| 275/85R22.5 | 1 | 86.0 | 0.0 |
| 275/85R24.5 | 1 | 112.0 | 0.0 |
| 275/95R24.5 | 1 | 108.0 | 0.0 |
| 280/75R24.5 | 1 | 108.0 | 0.0 |
| 285/75R24.5 | 37 | 103.9 | 10.8 |
| 285/80R22.5 | 1 | 100.0 | 0.0 |
| 285/80R24.5 | 1 | 110.0 | 0.0 |
| 295/75R22.5 | 9 | 106.0 | 4.0 |
| 9R22.5 | 1 | 95.0 | 0.0 |

**MIDDLE RADIALS**

| TIRE TYPE | OBS. | MEAN | ST.DEV. |
|---|---|---|---|
| 10.00R20 | 3 | 98.3 | 12.6 |
| 10.00R22 | 4 | 102.0 | 15.6 |
| 10.00R24.5 | 1 | 122.0 | 0.0 |
| 11/80R22.5 | 2 | 106.0 | 2.8 |
| 11R22.5 | 33 | 100.5 | 7.2 |
| 11R24.5 | 180 | 103.5 | 11.2 |
| 275/80R22.5 | 9 | 103.1 | 8.4 |
| 275/80R24.5 | 33 | 102.4 | 10.0 |
| 275/85R22.5 | 1 | 98.0 | 0.0 |
| 275/85R24.5 | 1 | 102.0 | 0.0 |
| 275/95R24.5 | 1 | 88.0 | 0.0 |
| 280/75R24.5 | 1 | 92.0 | 0.0 |
| 285/75R24.2 | 1 | 102.0 | 0.0 |
| 285/75R24.5 | 36 | 99.1 | 10.9 |
| 285/80R22.5 | 1 | 102.0 | 0.0 |
| 285/80R24.5 | 1 | 110.0 | 0.0 |
| 295/75R22.5 | 9 | 103.8 | 4.9 |
| 9R22.5 | 1 | 75.0 | 0.0 |

**REAR RADIALS**

| TIRE TYPE | OBS. | MEAN | ST.DEV. |
|---|---|---|---|
| 10.00R17.5HC | 1 | 116.0 | 0.0 |
| 10.00R20 | 3 | 97.3 | 15.5 |
| 10.00R22 | 5 | 95.8 | 12.2 |
| 10.00R22.5 | 2 | 97.5 | 3.5 |
| 10.00R24.5 | 1 | 118.0 | 0.0 |
| 10/70R22.5 | 1 | 102.0 | 0.0 |
| 10R22.5 | 2 | 96.0 | 8.5 |
| 11/80R22.5 | 2 | 105.0 | 1.4 |
| 11/80R24.5 | 3 | 107.7 | 0.6 |
| 11R17.5 | 1 | 112.0 | 0.0 |
| 11R22.5 | 40 | 102.1 | 11.2 |
| 11R24.5 | 137 | 102.2 | 11.6 |
| 255/70R22.5 | 4 | 105.5 | 4.9 |
| 275/80R22.5 | 7 | 100.1 | 8.8 |
| 275/80R24.5 | 24 | 102.5 | 11.7 |
| 280/75R24.5 | 1 | 66.0 | 0.0 |
| 285/75R24.2 | 1 | 100.0 | 0.0 |
| 285/75R24.5 | 32 | 99.8 | 11.8 |
| 285/80R22.5 | 1 | 103.0 | 0.0 |
| 295/75R22.5 | 5 | 97.6 | 12.0 |
| 8.25R20 | 1 | 98.0 | 0.0 |
| 9.00R20 | 1 | 110.0 | 0.0 |
| 9R17.5 | 1 | 114.0 | 0.0 |
| 9R22.5 | 3 | 103.3 | 10.8 |

Table 5.2. Statistical breakdown of Arizona tire pressure data.

| TIRE TYPE | TRUCK AXLE | % * USED | OBS. | SAMPLE MEAN | STAND. DEV. | 99% OBS. LOW | 99% OBS. HIGH | 95% OBS. LOW | 95% OBS. HIGH | 90% OBS. LOW | 90% OBS. HIGH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BIAS PLY | FRONT | 100% | 18 | 90.6 | 7.9 | 70.2 | 111.0 | 75.1 | 106.1 | 77.6 | 103.6 |
| | | 95% | 17 | 89.8 | 7.2 | 71.3 | 108.3 | 75.8 | 103.9 | 78.0 | 101.6 |
| | MIDDLE | 100% | 17 | 86.4 | 7.7 | 66.5 | 106.2 | 71.3 | 101.4 | 73.7 | 99.0 |
| | | 95% | 16 | 85.5 | 6.8 | 67.9 | 103.1 | 72.1 | 98.9 | 74.3 | 96.7 |
| | REAR | 100% | 58 | 88.1 | 12.5 | 55.8 | 120.4 | 63.5 | 112.6 | 67.5 | 108.7 |
| | | 95% | 55 | 87.4 | 10.9 | 59.4 | 115.4 | 66.2 | 108.7 | 69.6 | 105.3 |
| RADIAL | FRONT | 100% | 329 | 105.9 | 9.5 | 81.2 | 130.5 | 87.2 | 124.6 | 90.2 | 121.6 |
| | | 95% | 313 | 105.8 | 7.8 | 85.7 | 126.0 | 90.5 | 121.2 | 93.0 | 118.7 |
| | MIDDLE | 100% | 318 | 102.4 | 10.6 | 75.1 | 129.7 | 81.6 | 123.2 | 85.0 | 119.8 |
| | | 95% | 302 | 102.7 | 8.6 | 80.5 | 125.0 | 85.8 | 119.6 | 88.5 | 116.9 |
| | REAR | 100% | 279 | 101.8 | 11.4 | 72.4 | 131.1 | 79.5 | 124.0 | 83.1 | 120.5 |
| | | 95% | 265 | 102.6 | 9.5 | 78.2 | 127.1 | 84.1 | 121.2 | 87.0 | 118.2 |

* Indicates the percentage of observations in the analysis.
100% - all observations were included
95% - 5% of the observations furthest from the mean were dropped as outliers for this analysis.

This indicates that the front axle may be more representative of the tire pressure favored by truckers.

3. Average radial tire pressure for the front, middle and rear axles are 105.9, 102.4, and 101.8 psi, respectively.

4. This data cannot prove or disprove that tire pressures are significantly higher when temperatures in the sun are greater than 100°F. On the days when tire pressure measurements were recorded, the temperature fluctuated because of partly cloudy conditions. The sun was never out long enough to substantially heat the pavement for a prolonged period of time.

The apparent increase in truck tire pressures since the AASHO Road Test has led us to investigate their effects on pavement stresses and strains and on pavement life. These investigations are discussed in detail in the next chapter entitled "Special Studies".

SODA SECTION SURVEY

A survey of 13 Structural Overlay Design for Arizona (SODA) design sections was performed in conjunction with the tire pressure data collection effort. The survey method used on the SODA section was the method developed by ARE Inc for its Pavement Management System (Ref 30). At each SODA section, a 100-foot representative sample was selected. The crew would first drive through the section (several are more than 10 miles long) noting the types of distresses and any significant pavement changes. They would then return to an area representative of the entire length. Using the nearest milepost as a starting point, they rated the right drive lane for approximately 100 feet in the direction of increasing mileposts. After finishing the surveys and taking site photos, the crew proceeded on to the next section.

The data was recorded using the ARE Inc rating procedure and is summarized in Table 5.3. In addition to the condition data, each section was photographed to further document section condition.

The validity of the damage models and equivalent load estimation procedure developed for Arizona on this project was established by comparing results from the condition survey with expected results from both the original and new design load computation procedures. Chapter 8 contains the 18KESAL estimates for the SODA sections. Table 8.1 compares various methods of design 18KESAL calculations for each section. The condition scores determined from the survey discussed in this section are also shown in Table 8.1. A comparison is made in Chapter 8 between current section condition and the 18KESAL values calculated with AASHTO and ARE Inc equivalence factors. The results of these investigations were applied in recommendations on changes to Arizona's current design procedures.

Table 5.3. SODA section condition rating deductions and condition score.

| SECTION | SURFACE TYPE | TRANS. CRACK | | | LONG. CRACK | | ALLI. CRACK | | | RUTS | | EDGE DETER. | | BLOCK CRACK | | PAT. | | RIDE | BMP, HMP | | SURF. DEF. | TOT DEDUCT | COND SCORE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SLIGHT | MODER | EXTR. | SL/MD | EXTR. | SLIGHT | MODER | EXTR. | SL/MD | EXTR. | SL/MD | EXTR. | SL/MD | EXTR. | GOOD | POOR | 1-VG . . 5-VP | SL/MD | EXTR. | SEVER. EXTENT TYPE | | |
| 1 | F | | | | 4 | | 2 | | | 6 | | | | | | | | 0 | | | 3 | 15 | 85 |
| 2 | F | 0 | | | 4 | | | | | 6 | | | | 2 | | | | 0 | | | 5 | 17 | 83 |
| 3 | F | 0 | | | 4 | | 2 | | | 6 | 8 | | | | | | | 3 | | | 1 | 24 | 76 |
| 4 | F | | 5 | | 4 | | | 5 | | 6 | | | | | | | | 0 | | | 7 | 27 | 73 |
| 8 | F | | | | | | | | | 6 | | | | | | | | 0 | | | 7 | 13 | 87 |
| 9 | F | | | | | | | | | 6 | | | | | | | | 0 | | | 7 | 13 | 87 |
| 10 | F | | | | | | | | | | | | | | | | | 0 | | | | 0 | 100 |
| 11 | F | 2 | | | 4 | | | | | | | | | | | | | 3 | 2 | | 1 | 12 | 88 |
| 16 | F | 0 | | | 4 | | | | | 6 | | 5 | | | | | | 3 | | | 3 | 21 | 79 |
| 18 | F | | 5 | | | 15 | | | | | | | | 2 | | | | 0 | | | 7 | 29 | 76 |
| 19 | F | 0 | | | 4 | | | | | | | | | | | | | 0 | | | | 4 | 96 |
| 20 | F | 0 | | | 4 | | | | | | | | | | | 0 | | 3 | | | 7 | 14 | 86 |
| 21 | F | | | | | | | | | | | | | | | | | 0 | | | | 0 | 100 |

# CHAPTER 6. TIRE PRESSURE STUDIES

A major objective of the AASHO Road Test was to evaluate the effect that axle loads have on pavement performance under known conditions, i.e., pavement design, environment, and load repetitions. The road test results have provided quantitative information relative to the damaging effects of increased loads; however, no information was obtained regarding the influence of tire pressure on pavement performance. A major objective of this project, in addition to evaluating load effects, was to study the effect of increased tire pressure on pavement deterioration.

This section covers research performed by three organizations on the effects of increased tire pressure on pavement life. The first study is a computer simulation performed by ARE Inc as a part of this project. The second research was by the Center for Transportation Research (CTR) at the University of Texas on a project for the Texas Highway Department. Both studies were conducted simultaneously but independently using different computer programs. The third study was performed by the Texas Transportation Institute (TTI) at Texas A&M University. The results from these independent studies indicate the same conclusion: increased tire pressures do have a pronounced effect on pavement response and pavement life. The details of these research efforts and the results obtained are presented in the following sections.

## ARE INC TIRE PRESSURE STUDY

In this study, the effects of tire pressure on pavements were examined using a mechanistic approach. An elastic layer theory program, ELSYM5 (Ref 20), was used to model an average pavement structure. The following pavement cross section was considered in the analysis:

| Layer | Elastic Modulus (psi) | Poissons Ratio | Thickness (in) |
|---|---|---|---|
| 1 | 300000 | .30 | 3 |
| 2 | 20000 | .35 | 6 |
| 3 | 12000 | .40 | 8 |
| 4 | 3000 | .45 | |

Runs were made simulating axle loads of 18 and 28 kips. Each set of runs consisted of tire pressures ranging from 70 to 160 psi varying at 10 psi increments.

The results are shown as plots of several important pavement response parameters versus tire pressure. Figure 6.1 shows a plot of the principal horizontal tensile and shear strains at the bottom of the asphalt layer and vertical compressive strain at the subgrade level versus tire pressure for the 18-kip axle load. This plot indicates that horizontal tensile strain and shear strain increase as tire pressure increases while vertical strain on the roadbed soil remains fairly constant. The implication is that tire pressure increases may affect the surface layer in terms of reduced fatigue life or increased roughness but that there is very little effect in terms of pavement damage attributable to vertical strain on the roadbed soil.

By superimposing the range which contains 90 percent of the field measured tire pressures for radial steering axle tires (from Chapter 5) on the principal strain versus tire pressure plot as shown in Figure 6.2, about a 12 percent increase in principal strain is observed.

From field measurements discussed in Chapter 5;

Mean Radial Tire Pressure (steering axle) = 105.9 psi

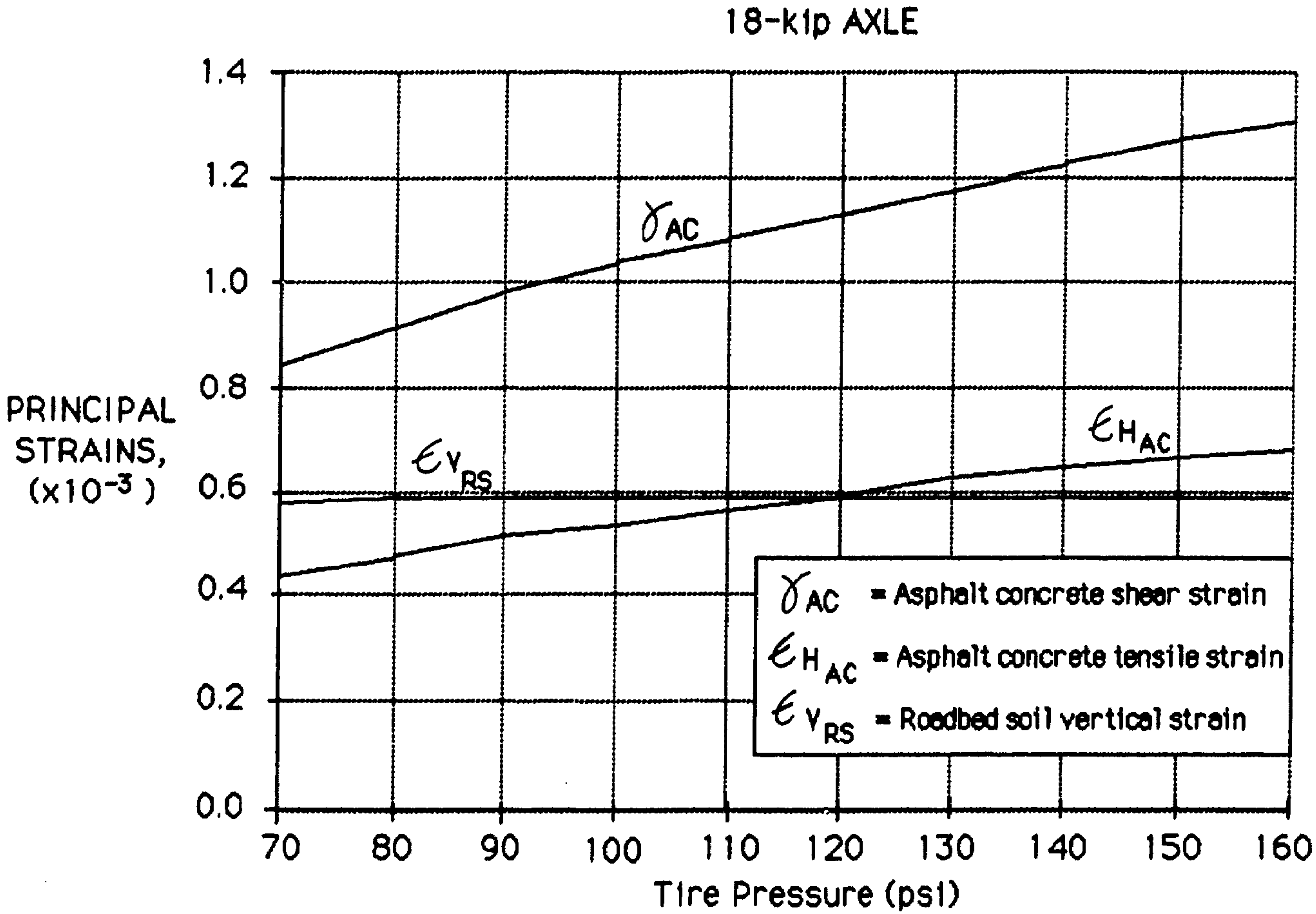



Figure 6.1. Plot of principal strain in the pavement structure versus tire pressure from ARE Inc study.

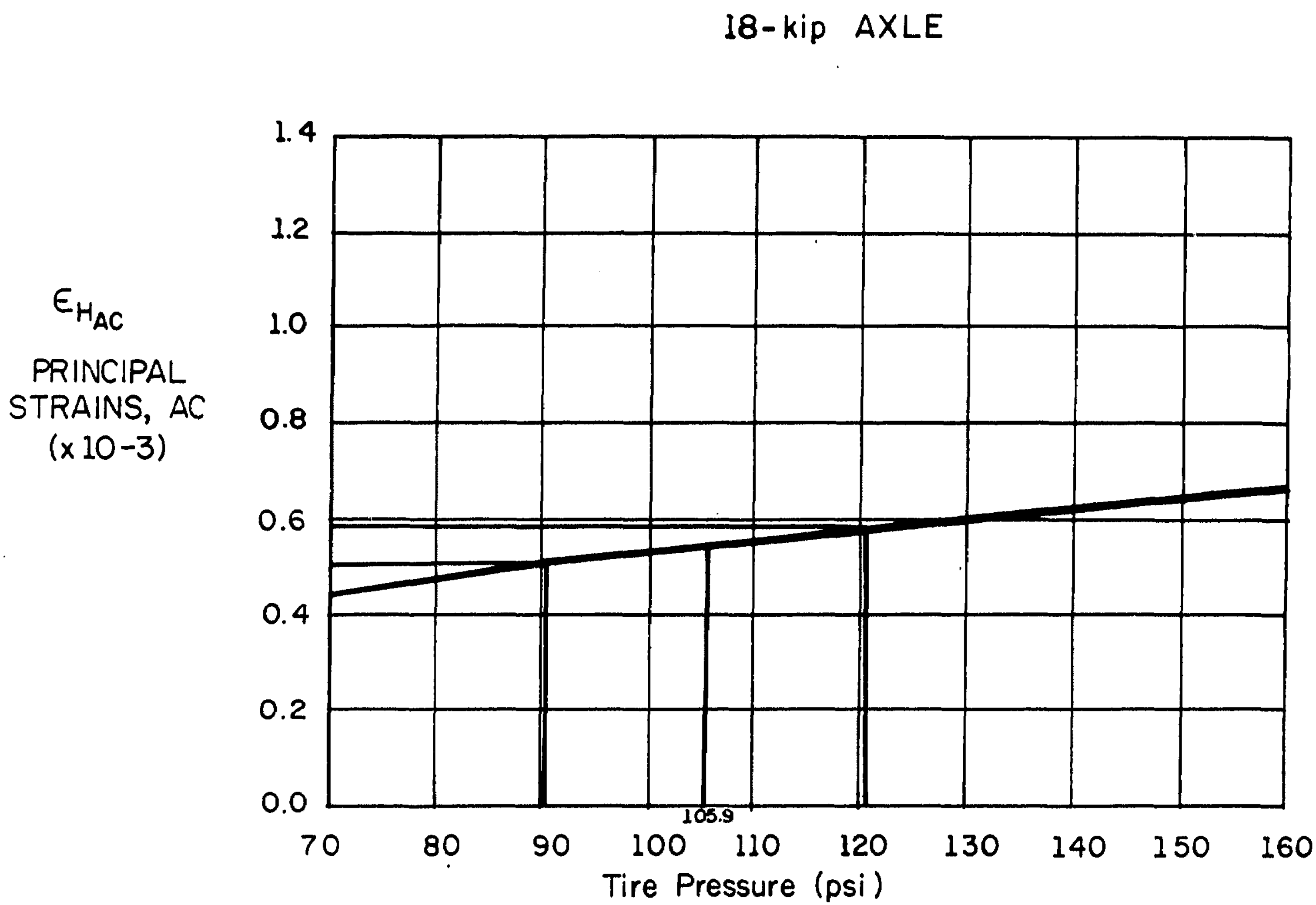



Figure 6.2. Plot of principal strain versus tire pressure.

Interval containing 90 percent of all observations = 90.2 psi to 121.6 psi corresponding to strains of $0.51 \times 10^{-3}$ in/in to $0.59 \times 10^{-3}$ in/in.

To examine the effect of these strain differences on pavement life, we can use a fatigue or damage model. The fatigue equation for less than 10 percent cracking developed by Finn, et al. in NCHRP Project 1-10B (Ref. 17) is as follows:

$$\log (N_f) = 15.947 - 3.291*\log(\varepsilon_{AC}/10^{-6}) - 0.854*\log(E/10^3) \qquad (6.1)$$

therefore, at 90.2 psi, strain = $0.51 \times 10^{-3}$, and assuming E = 300,000 psi, then, $N_f$ = 83,350 load repetitions. At 121.6 psi, strain = $.59 \times 10^{-3}$, so $N_f$ = 51,601 load repetitions.

The new ARE Inc/Arizona DOT roughness and tensile strain based damage model (see Figure 3.8):

$$\log (N_f)[\text{for } p_t=2.5] = 3.25 - 7.50*\log (\varepsilon_{AC}) - 4.10*\log(E_{AC}) \qquad (6.2)$$

produces the following results.

At 90.2 psi tire pressure, $N_f$ = 306,920 load applications.

At 121.6 psi, $N_f$ = 102,900 load applications.

These remaining life analyses indicate that for a 35 percent increase in tire pressure (from 90.2 psi to 121.6 psi) pavement life is reduced by 38 percent according to the Finn equation (equation 6.1) (Ref 17) and by 66 percent according to the ARE Inc/Arizona DOT equation (equation 6.2).

These analyses show a definite effect of tire pressure on pavement life. It must be understood, however, that this effect is based on equations relating pavement strain to pavement life and, thus, is only as accurate as the original damage or fatigue equations used in the derivation. The differences in the results are directly related to differences in the damage equations used. Some of the most apparent differences include:

- The NCHRP 1-10B equation is empirically derived whereas the ARE equation is mechanistically derived.

- Failure criteria for the NCHRP 1-10B equation is a fatigue cracking level of 10 percent while for the ARE equation, it is a serviceability level of 2.5.

- The ARE equation accounts for seasonal variations and the effects of steering axles, the NCHRP 1-10B equation does not.

Even with these differences, the resulting effects on pavement life must certainly be considered significant.

From these studies, it is clear that tire pressure should be considered in any new methodology to estimate equivalent single axle loads. Research performed by the CTR at the University of Texas and described in the next section also indicate this.

CTR Pressure Study

The Center for Transportation Research (CTR) of The University of Texas has performed studies (Ref 2, 3, 4, 5, 6, and 7) similar to the one described above. Besides using uniform loading models [e.g., ELSYM5 (Ref 20) and BISAR (Ref. 29)], a static, linear elastic, 3-D finite element program called TEXGAP-3D (Ref 6) was also used. This model allows the input of a non-uniform pressure distribution. The following discussion is taken from Reference 6.

The pavement structure factorial used in the analysis is as follows:

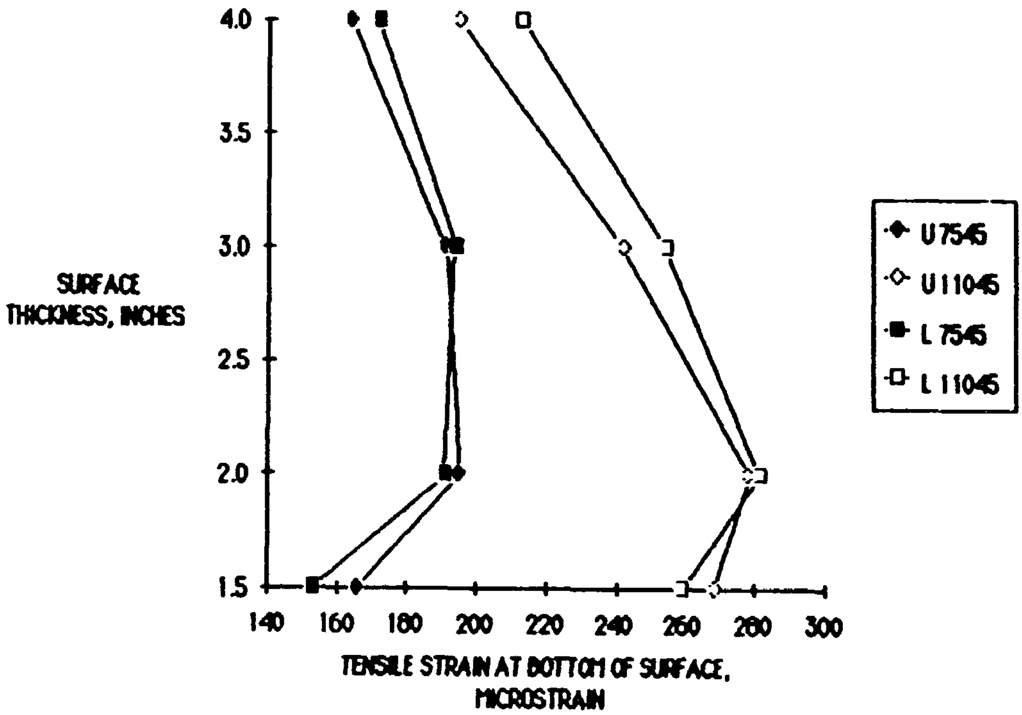
| Layer | Elastic Modulus (psi) | Poisson's Ratio | Thickness (in) |
|---|---|---|---|
| 1 | 400,000 | .35 | 1.5,2,3, and 4 |
| 2 | 60,000 | .4 | 8 |
| 3 | 6,000 | .45 | 169 |

There was no explanation given for the choice of 169 inches as roadbed soil thickness. However, inputting any thickness for roadbed soil will produce a simulation of bedrock below that.

The accuracy of the TEXGAP-3D model was compared to ELSYM5 for a uniform circular pressure model. Figure 6.3 shows a comparison between a uniform pressure modeling with TEXGAP-3D and the uniform circular pressure model of ELSYM5 for the tensile strain at bottom of the surface layer having various thicknesses. (Note the U designates uniform pressure model by TEXGAP-3D and L designates the same by ELSYM5). The two models produce relatively similar results; however, life cycle estimates from the strains would be influenced by the differences.

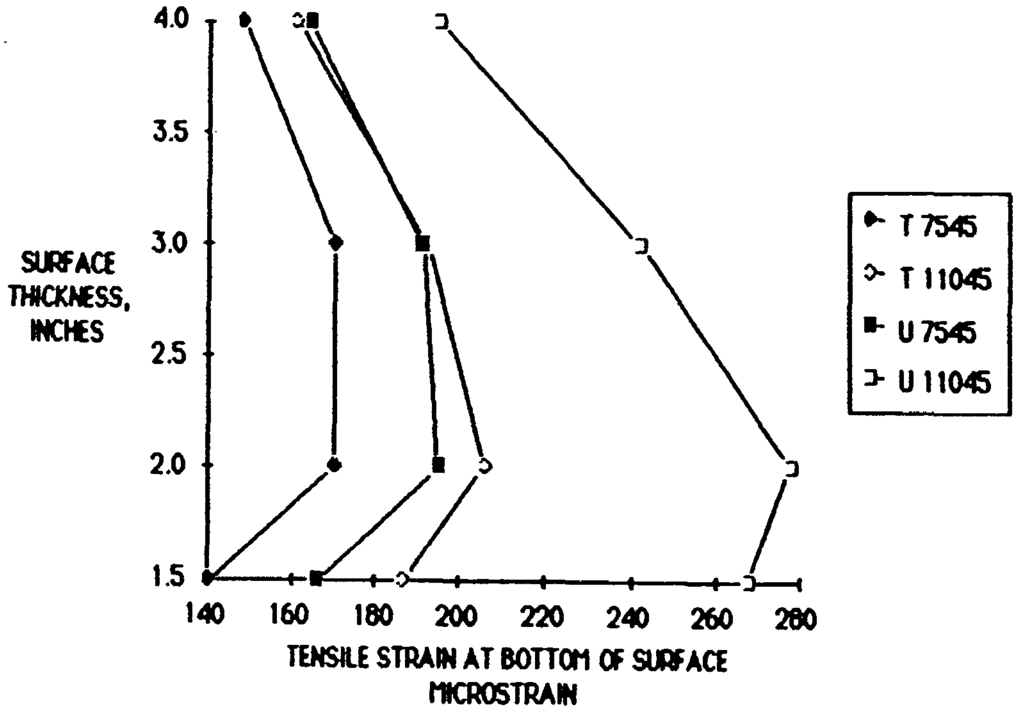
The curves of Figure 6.3 show a reduction of tensile strain for the thin (1.5 inch) surface layer. This effect is due to a phenomenon associated with thin surface layers subjected to distributed loads. For thicknesses greater than 2 to 3 inches, significant tension is generated at the bottom of the layer. However, as the thickness drops below 1.5 inches, the layer begins to behave more as if it were in the top fiber of a beam and go into compression. This seems like an ideal situation to design for; unfortunately, pavements don't just fail because of tension (cracking) in the asphalt concrete. For thinner and thinner surface layers, the burden of load carrying is shifted to the underlying weaker materials. If these materials are overstressed, other forms of pavement failure, particularly rutting, will control.

Figure 6.4 shows a comparison between the experimental nonuniform pressure model (T7545, T11045) and the uniform pressure model (U7545,




Note: U and L respectively represent the analysis obtained by using programs TEXGAP-3D and ELSYM5, and the values (7545, 11045) stand for a tire loaded at 4500 lbf with inflation pressures at 75 psi and 110 psi respectively.

Figure 6.3. Effect of pressure distribution model of critical tensile strain at the bottom of the surface (Ref. 6).




Note: T designates a treaded tire with a nonuniform (experimental) pressure model, and U designates a uniform pressure model. The values (7545, 11045) respectively represent a tire loaded at 4500 lbf with inflation pressures at 75 psi and 110 psi.

Figure 6.4. Effect of inflation pressure on the critical tensile strain at the bottom of the surface (Ref 6).

U11045) for the tensile strain at the bottom of the surface with various surface thicknesses. With an increase of the inflation pressure (for the same axle load), the uniform pressure model predicts a large increase in the tensile strain at the bottom of the surface layer, while the experimental (nonuniform) model yields a smaller increase in the surface tensile strain. The two models, however, produce similar relative effects. Therefore, use of either model consistently throughout any analysis would produce satisfactory results. Since it is not possible within the scope of this project to distinguish which model is more accurate with respect to actual effects on the highway, the uniform pressure model is chosen because it is easier to apply and more commonly used.

### TTI Pressure Study

The Texas Transportation Institute (TTI) of Texas A&M University performed a study entitled, "Effects of Higher Tire Pressure on Strain in Thin ACP" (Ref 12). The loads considered in the study were 4500 lb at tire pressures of 75 psi and 125 psi.

Two computer models used in the TTI study were the Tielking Tire Model and the ILLIPAVE Model. The Tielking Tire Model (TTM) was used to calculate tire contact boundary and interface pressure distribution for a specified tire deflection given inputs of material properties and shape of the tire. The pressure distribution data was one input for the ILLIPAVE computer program.

The ILLIPAVE program was selected by TTI to measure pavement response because it had a variety of material property inputs and because the tire pressure distribution could be entered in a number of ways. The ILLIPAVE output gave displacements of nodes, and stresses at the midpoint of desired elements.

Various pavement cross sections were analyzed by TTI to study the effect that pavement strength had on pavement performance. The factorial of pavement cross sections considered in the TTI study is shown below.

Surface:

Thickness: 1, 1.5, 2, and 4 inches

Elastic Moduli: 50, 100, 200, 400, and 800 ksi

Base:

Thickness: 8 inches

Elastic Moduli: 20, 40, and 60 ksi

Subgrade:

Thickness: semi-infinite

Elastic Moduli: f(deviator stress)

Figure 6.5 shows the effects of tire pressure on tensile strain for a pavement with a surface modulus of 400,000 psi. The increase in tire pressure produced increases in strain ranging from 20 to 30 percent for a 1-inch surface layer. The effect of increased tire pressure is lower for thicker surfaces. For example, the relative increase for a 4-inch surface is less than 10 percent.

To examine the effects of tire pressure, surface thickness, and moduli on fatigue cracking, an estimate was made of the additional fatigue damage produced by the increase in tire pressure from 75 to 125 psi. A fatigue equation developed from AASHO Road Test results was selected for use in the analysis (Ref 23).

The analysis indicated the importance of the interaction between surface modulus and thickness with respect to increased tire pressures and the corresponding effect on fatigue damage. The results showed thin pavements should be flexible to remain in compression in order to resist fatigue cracking. The TTI study indicated a relative sensitivity of thin, lower modulus surface materials to the effects of increased tire pressure and a relative insensitivity of thick, higher modulus materials to increased tire pressure (Ref 12).

## DYNAMIC LOADING RESEARCH

Dynamic highway loading as used in this section refers to the variations in static load of a tire as it moves over a rough surface. As

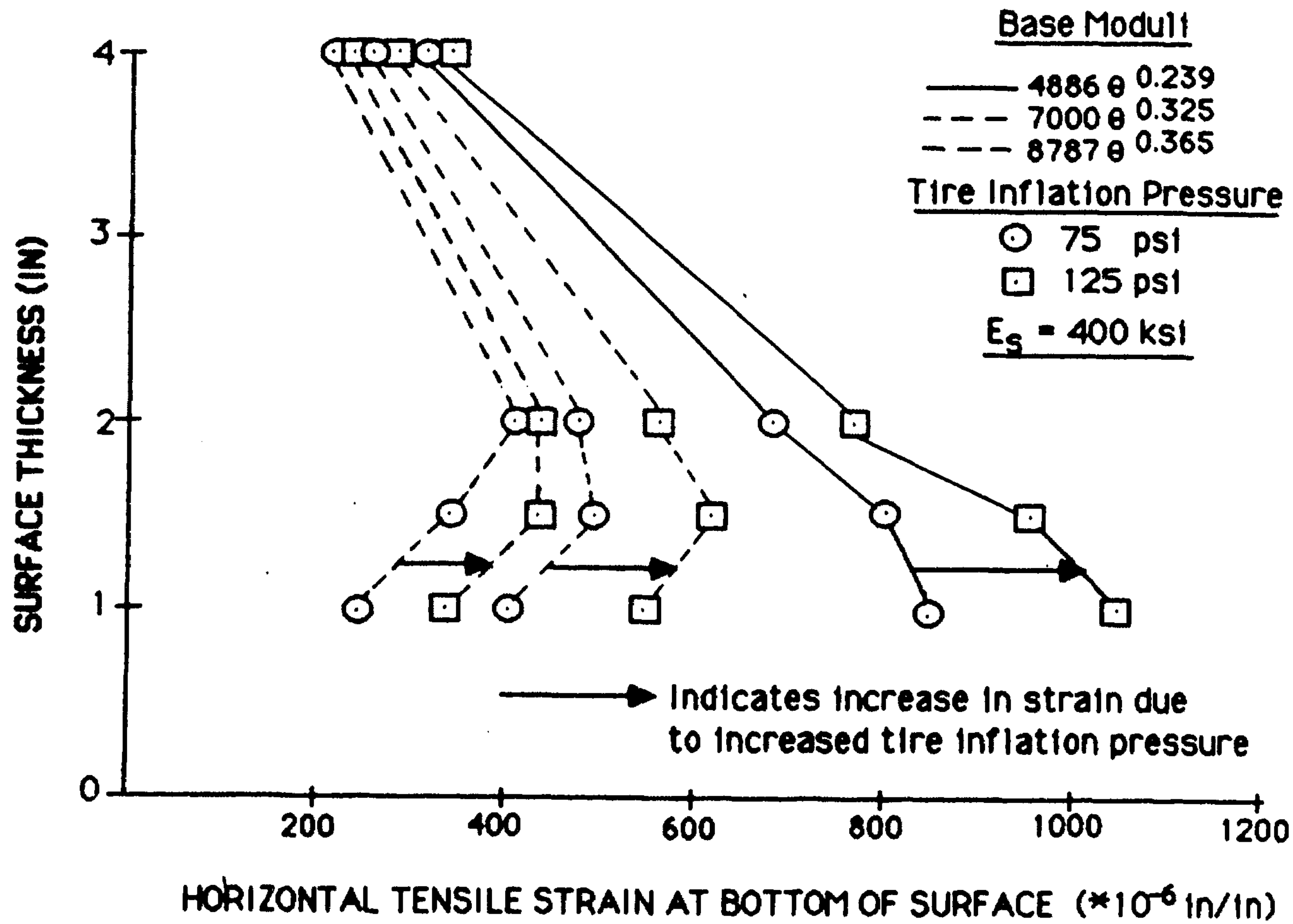



Figure 6.5. Effects of increased tire pressure on tensile strain for a surface modulus of 400 ksi (Ref 12).

# CHAPTER 7. COMPUTER PROGRAM DEVELOPMENT

One of the major objectives of this research project was to develop computer programs to predict 18-kip equivalent single axle loadings (18KESAL's) for Arizona highways. Three such programs were developed as a result of the research. A fourth program was developed to perform mechanistic pavement design using the damage models developed in this project (see Chapter 3). These programs are documented in detail in Volume 2 of this Final Report (Ref 1).

The first program is called FEDESAL. This program uses Arizona loadometer data to produce an average number of equivalent loads per 1000 vehicles based on the FHWA method. The other equivalent loads program, WIMESAL, reads weigh-in-motion (WIM) data and converts it to an estimate of the number of equivalent loads applied on a particular section of highway. The design traffic program, TRAF18K, uses the 18KESAL vehicle factors developed by FEDESAL and traffic volume and classification data from Arizona highway sections to estimate design traffic in terms of total 18KESAL applications over the expected design life. The last program, McPAD, takes design 18KESAL traffic generated by TRAF18K along with other design and material property information to generate pavement structural designs that are compatible with the new mechanistic load equivalence factors. For comparison purposes, McPAD also has the capability of generating structural designs that are based on the new AASHTO Guide for Design of Pavement Structures procedure.

All programs are written in a modular form with numerous comment statements to make them easy to follow or modify. The programs are written in Microsoft FORTRAN for use on an IBM PC (or compatible) microcomputer. Portions of the programs which might be changed in the future, such as the sets of equivalence factors used for computations, are stored in ASCII data files. This allows easy modification or updating using a simple editing program without having to recompile the FORTRAN code.

## PROGRAM FEDESAL OVERVIEW

Program FEDESAL calculates one-year and five-year running average 18KESAL vehicle factors. As a follow-up, program TRAF18K takes this information and produces "n" year accumulated 18KESAL's for a variety of road sections. Figure 7.1 shows the overall flow for these programs with Figure 7.2 defining the program and I/O (Input/Output) symbology. The traffic program, TRAF18K (program M in Figure 7.1), is an existing ADOT FORTRAN program which was modified to be compatible with the output from FEDESAL and to be user friendly. It is discussed in more detail later in this chapter.

The results of the FEDESAL vehicle factor program (program F in Figure 7.1) are 18-kip vehicle equivalence factors which are the average number of 18KESAL's per 1000 vehicles. These averages are calculated across two pavement surface types, three highway functional classes, and an option of either five or nine vehicle classifications. There is an option to use either the ARE Inc load equivalence factors or the AASHTO equivalence factors which, as described in Appendix G, have been extended to account for higher tire pressures. The available options for ARE equivalence factors are described in Chapter 4 - "Equivalence Factor Development" and in Volume 2 of this report (Ref 1). Another option allows the use of an axle load distribution shifting algorithm to predict the effect of changing the legal load limits on equivalent load estimates. There is also an option to obtain the 18KESAL estimates based on only the current year data or to determine a five-year moving average using five years of historical 18KESAL data. One additional option allows a check on the FHWA loadometer data to assist in locating input errors. An example output using ARE Inc equivalence factors is shown in Figure 7.3.

Program FEDESAL in Figure 7.1 is to be used as a tool for central office personnel. They will get access to the current year's FHWA weight data and transfer it from the mainframe to the microcomputer or enter it directly into the microcomputer. Then, using either set of 18-kip axle equivalence factors, it will produce statewide 18KESAL vehicle factors.

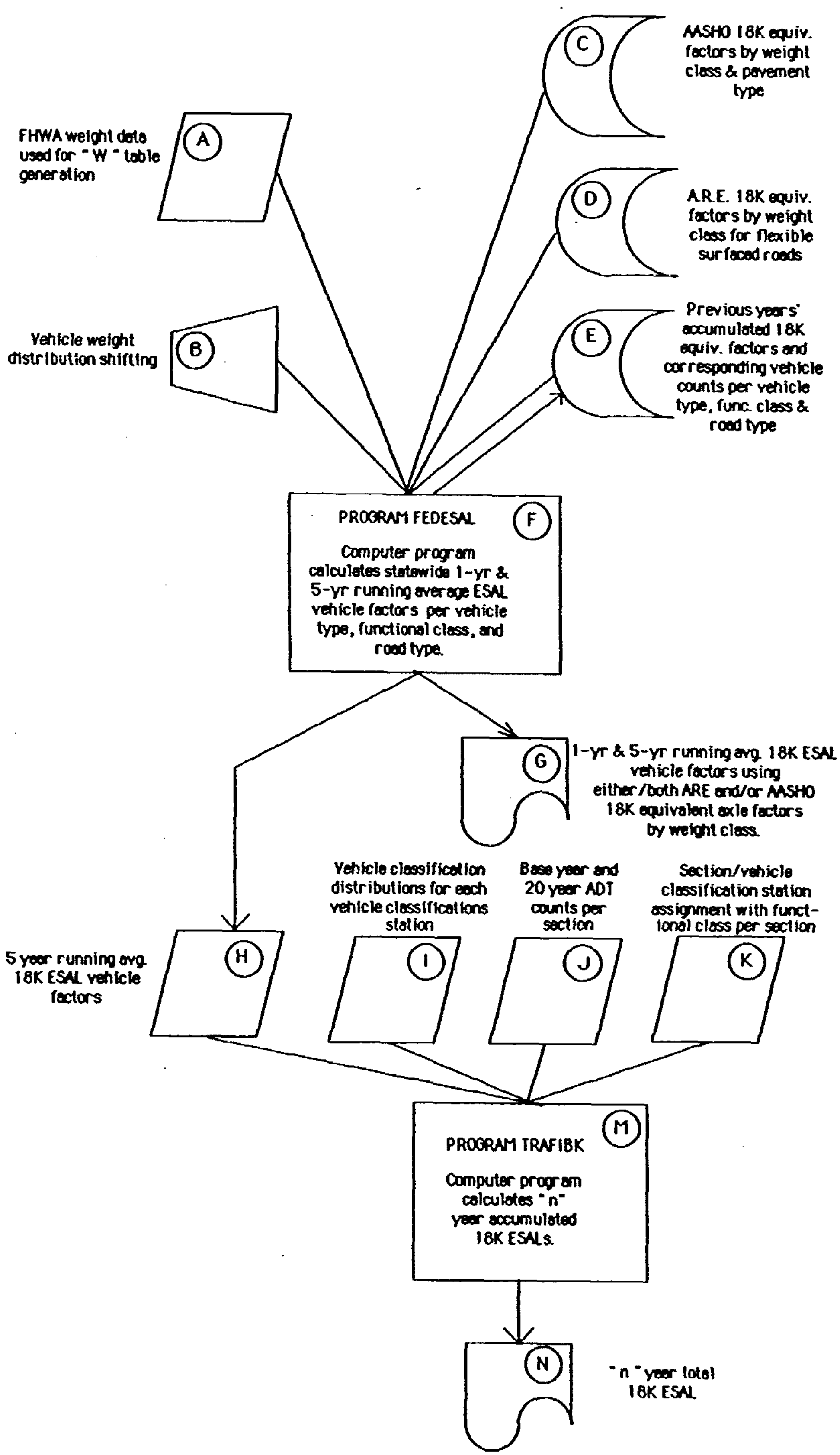



Figure 7.1. Microcomputer program(s) flow.

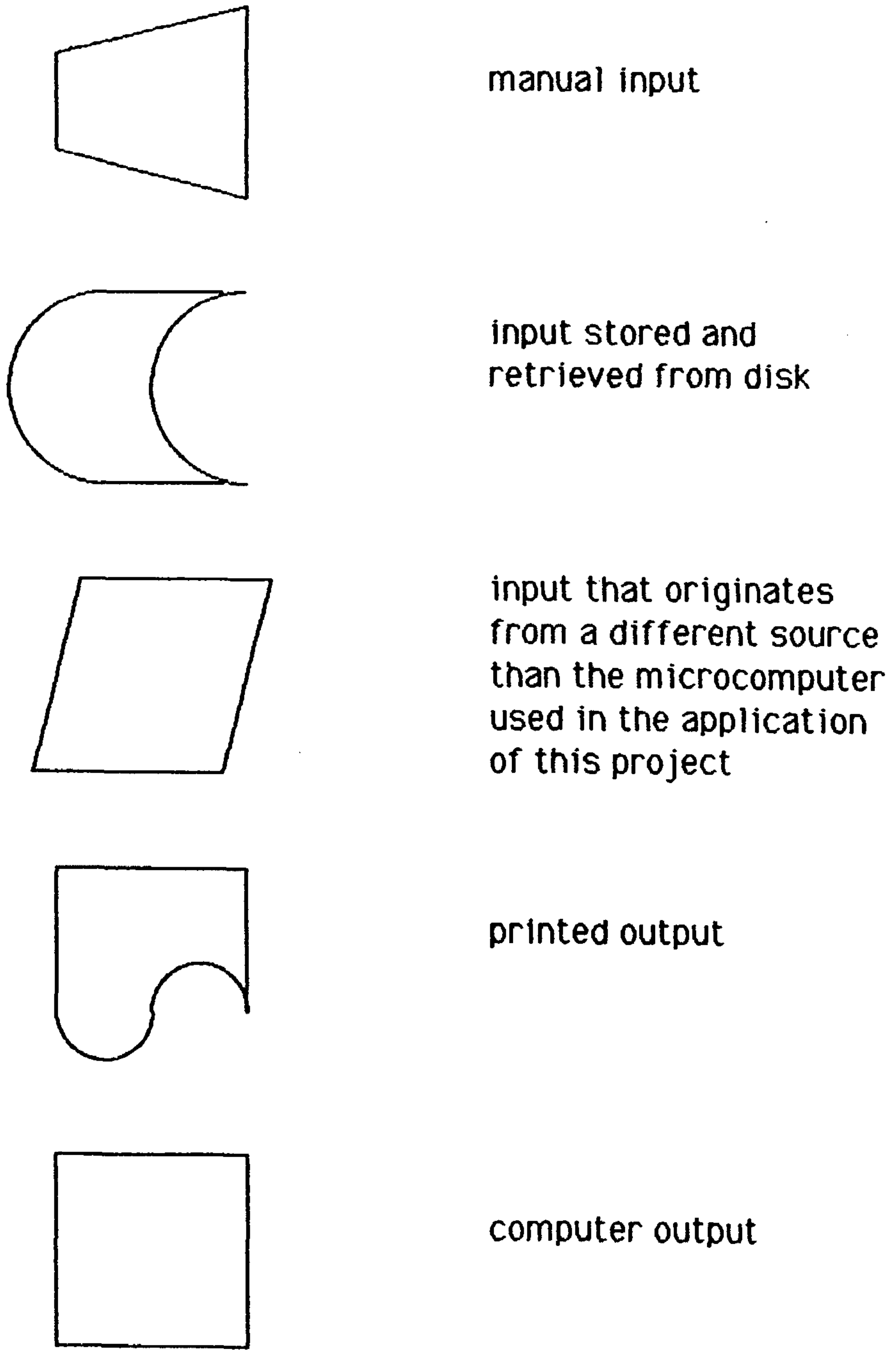



Figure 7.2. Input/output symbology defining the origin of input and type of output.

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AVERAGE 18 KIP EQUIVALENT SINGLE
AXLE LOADS PER 1000 VEHICLES
USING FHWA TRUCK WEIGHT DATA

COMMENTS: ARE Inc Equivalence Factors Used
Rigid Factors not Calculated
Example Run for Final Report

Station Location: Interstate

Road Characteristics Used to Compute ARE Inc Factors

| | |
|---|---|
| Surface Thickness: | Medium = 1 - 5 in. |
| Base/Subbase Thickness: | Medium = 10 - 17 in. overall |
| Roadbed Soil Modulus: | 12000.0 psi |
| Tire Pressure: | 105.0 psi |

| VEHICLE CLASS | TOTAL VEHICLE COUNTS | CURRENT 18 KIP ESAL PER 1000 VEHICLES | | FIVE-YEAR AVERAGE 18 KIP ESAL PER 1000 VEHICLES | |
|---|---|---|---|---|---|
| | | RIGID | FLEXIBLE | RIGID | FLEXIBLE |
| LT | 0 | .0 | .0 | .0 | 72.7 |
| MT | 1 | .0 | 92.4 | .0 | 2980.1 |
| TS | 8 | .0 | 24933.8 | .0 | 27348.1 |
| TT | 0 | .0 | .0 | .0 | 33513.7 |
| TST | 4 | .0 | 9440.8 | .0 | 11231.3 |

Figure 7.3. Example output from program FEDESAL using ARE Inc equivalence factors.

AVERAGE 18 KIP EQUIVALENT SINGLE
AXLE LOADS PER 1000 VEHICLES
USING FHWA TRUCK WEIGHT DATA

COMMENTS: ARE Inc Equivalence Factors Used
Rigid Factors not Calculated
Example Run for Final Report

Station Location: Primary/Secondary

Road Characteristics Used to Compute ARE Inc Factors

Surface Thickness: Medium = 1 - 5 in.
Base/Subbase Thickness: Medium = 10 - 17 in. overall
Roadbed Soil Modulus: 12000.0 psi
Tire Pressure: 105.0 psi

| VEHICLE CLASS | TOTAL VEHICLE COUNTS | CURRENT 18 KIP ESAL PER 1000 VEHICLES | | FIVE-YEAR AVERAGE 18 KIP ESAL PER 1000 VEHICLES | |
|---|---|---|---|---|---|
| | | RIGID | FLEXIBLE | RIGID | FLEXIBLE |
| LT | 1 | .0 | 81.3 | .0 | 70.1 |
| MT | 2 | .0 | 1167.7 | .0 | 963.2 |
| TS | 3 | .0 | 19434.0 | .0 | 13180.7 |
| TT | 0 | .0 | .0 | .0 | .0 |
| TST | 2 | .0 | 3667.9 | .0 | 5971.9 |

Figure 7.3. Example output from program FEDESAL using ARE Inc equivalence factors (continued).

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AVERAGE 18 KIP EQUIVALENT SINGLE
AXLE LOADS PER 1000 VEHICLES
USING FHWA TRUCK WEIGHT DATA

COMMENTS: ARE Inc Equivalence Factors Used
Rigid Factors not Calculated
Example Run for Final Report

Station Location: Urban

Road Characteristics Used to Compute ARE Inc Factors

Surface Thickness: Medium = 1 - 5 in.
Base/Subbase Thickness: Medium = 10 - 17 in. overall
Roadbed Soil Modulus: 12000.0 psi
Tire Pressure: 105.0 psi

| VEHICLE CLASS | TOTAL VEHICLE COUNTS | CURRENT 18 KIP ESAL PER 1000 VEHICLES | | FIVE-YEAR AVERAGE 18 KIP ESAL PER 1000 VEHICLES | |
|---|---|---|---|---|---|
| | | RIGID | FLEXIBLE | RIGID | FLEXIBLE |
| LT | 5 | .0 | 73.8 | .0 | 72.6 |
| MT | 4 | .0 | 1679.4 | .0 | 986.0 |
| TS | 8 | .0 | 17865.0 | .0 | 12880.7 |
| TT | 0 | .0 | .0 | .0 | .0 |
| TST | 4 | .0 | 4007.6 | .0 | 6021.8 |

Figure 7.3. Example output from program FEDESAL using ARE Inc equivalence factors (continued).

Program FEDESAL will also let the user shift the current year's vehicle weight distribution to simulate increased legal truck weight limits and to estimate its corresponding effect on vehicle equivalence factors.

ARE Inc processed the last five years of Arizona FHWA "W" table data through the FEDESAL program in order to accumulate the necessary historical axle weight distributions and vehicle counts for producing five-year moving average 18-kip vehicle equivalence factors. Both the FHWA weight data and corresponding summary data for the last five years was provided on floppy disk to ADOT.

For routine operation, FHWA formatted weight data is made available to the microcomputer and then used as input to the 18KESAL vehicle factor program. ARE Inc and AASHTO 18-kip single axle equivalence factors are stored on floppy disk for use by the program. The ARE factors were developed to account for variations in tire pressure. The AASHTO factors were extended to account for higher tire pressures of 110 psi and 145 psi. (Development of the extended AASHTO equivalence factors is documented in Appendix G). Previous years' 18KESAL vehicle summary data is also stored on disk and updated by the current year's weight data if directed by the user.

The FEDESAL program outputs 18KESAL vehicle factors which are the average number of 18KESAL's per 1000 vehicles. These factors were previously calculated by hand using the W-4 tables that are sent to ADOT by the FHWA. These 18-kip vehicle factors are then used in conjunction with traffic data for roads statewide to calculate 10 and 20-year cumulative 18KESAL's. For complete user information and program documentation, consult the program user's manual (Ref. 1).

An option has also been incorporated into the FEDESAL computer program which will allow ADOT to estimate the effect of changes in vehicle load limit laws on average vehicle equivalence factors. Adjustments are made on a per truck basis for the truck weight inputs. 18KESAL vehicle equivalence factors are determined under the current and proposed load limit laws. The calculated effect of the change on the current year's data is applied to the five-year running average values to obtain proposed law vehicle equivalence factors. As such, the predicted factors will be based on the per truck data available to the program plus best estimates of five-year running average vehicle equivalence values. More information on the method of performing this axle load distribution shifting is given in the program users manual (Ref. 1).

PROGRAM WIMESAL OVERVIEW

The second program developed for equivalent load calculations is called WIMESAL. This is a project-level 18KESAL prediction program for weigh-in-motion (WIM) data. The program reads WIM data on an individual highway section and produces estimates of base-year, ten-year and twenty-year accumulated equivalent loads. This will allow much more accurate estimates of the number of equivalent loads applied to a particular highway section.

Program WIMESAL has the option of using ARE Inc equivalence factors (for the specific structure of the highway section under consideration) or AASHTO equivalence factors which, at the user's option, may be adjusted for higher tire pressure. The available options for equivalence factor selection are given in Chapter 4 - "Equivalence Factor Development" and the program user's manual (Ref. 1). The output is an estimate of the total cumulative number of 18KESAL's on individual highway sections. These total 18KESAL estimates are presented for the base-year and as ten-year and twenty-year predictions given a growth factor for the section. An example of the output from program WIMESAL is shown in Figure 7.4.

The WIM project-level 18KESAL prediction program will have wide applicability to ADOT pavement designers. WIM data on an individual design section can be collected for several weeks, or longer, before designing an overlay. Program WIMESAL is then run on the data to produce projected traffic for a ten or twenty-year design period. These projections can be used directly for design or compared to the estimates using the statewide vehicle factors from program FEDESAL. The designer would then have the choice of which traffic loading level to use or

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PREDICTED ACCUMULATED LOADS AND
AVERAGE 18 KIP EQUIVALENT SINGLE
AXLE LOADS PER 1000 VEHICLES
USING WIM TRUCK WEIGHT DATA

LOCATION: Test Section
TRAFFIC
GROWTH: 1.50% per year
COMMENTS: ARE Inc Equivalence Factors Used
Rigid Factors not Calculated
Example Run for Final Report

Road Characteristics Used to Compute ARE Inc factors

| | | |
|---|---|---|
| Surface Thickness: | Medium | = 1 - 5 in. |
| Base/Subbase Thickness: | Thick | > 17 in. overall |
| Roadbed Soil Modulus: | 15000.0 psi | |
| Tire Pressure: | 90.0 psi | |

PREDICTED TOTAL ACCUMULATED EQUIVALENT LOADS

| VEHICLE CLASS | FLEXIBLE 1-YEAR | 10-YEAR | 20-YEAR |
|---|---|---|---|
| 5 | 4824. | 51622. | 110725. |
| 6 | 12730. | 136222. | 292188. |
| 7 | 0. | 0. | 0. |
| 8 | 11239. | 119688. | 255644. |
| 9 | 652832. | 6963483. | 14894410. |
| 10 | 0. | 0. | 0. |
| 11 | 0. | 0. | 0. |
| 12 | 70469. | 751874. | 1608661. |
| 13 | 0. | 0. | 0. |
| TOTAL | 752095. | 8022889. | 17161630. |

Figure 7.4. Example output from WIM program using ARE Inc factors.

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PREDICTED ACCUMULATED LOADS AND
AVERAGE 18 KIP EQUIVALENT SINGLE
AXLE LOADS PER 1000 VEHICLES
USING WIM TRUCK WEIGHT DATA

LOCATION: Test Section
TRAFFIC
GROWTH: 1.50% per year
COMMENTS: ARE Inc Equivalence Factors Used
Rigid Factors not Calculated
Example Run for Final Report

Road Characteristics Used to Compute ARE Inc factors

Surface Thickness: Medium = 1 - 5 in.
Base/Subbase Thickness: Thick > 17 in. overall
Roadbed Soil Modulus: 15000.0 psi
Tire Pressure: 90.0 psi

| VEHICLE CLASS | VEHICLE COUNTS | ESTIMATED AVERAGE ADT | AVERAGE NUMBER OF 18 KIP ESAL PER 1000 VEHICLES RIGID | FLEXIBLE | ACCUMULATED WEIGHTS (1000s) S.A. S.T. | S.A. D.T. | TDM AXL | TRP AXL |
|---|---|---|---|---|---|---|---|---|
| 5 | 4 | 32 | .0 | 819.9 | 23. | 35. | 0. | 0. |
| 6 | 2 | 16 | .0 | 4327.1 | 21. | 0. | 33. | 0. |
| 7 | 0 | 0 | .0 | .0 | 0. | 0. | 0. | 0. |
| 8 | 3 | 24 | .0 | 2546.9 | 26. | 30. | 34. | 0. |
| 9 | 18 | 144 | .0 | 24656.6 | 185. | 36. | 901. | 0. |
| 10 | 0 | 0 | .0 | .0 | 0. | 0. | 0. | 0. |
| 11 | 0 | 0 | .0 | .0 | 0. | 0. | 0. | 0. |
| 12 | 5 | 40 | .0 | 9581.1 | 49. | 197. | 102. | 0. |
| 13 | 0 | 0 | .0 | .0 | 0. | 0. | 0. | 0. |
| TOTAL | 32 | 256 | .0 | 41931.5 | | | | |

Figure 7.4. Example output from WIM program using ARE Inc factors (continued).

PREDICTED ACCUMULATED LOADS AND
AVERAGE 18 KIP EQUIVALENT SINGLE
AXLE LOADS PER 1000 VEHICLES
USING WIM TRUCK WEIGHT DATA

LOCATION: Test Section
TRAFFIC
GROWTH: 1.50% per year
COMMENTS: ARE Inc Equivalence Factors Used
Rigid Factors not Calculated
Example Run for Final Report

Road Characteristics Used to Compute ARE Inc factors

Surface Thickness: Medium = 1 - 5 in.
Base/Subbase Thickness: Thick > 17 in. overall
Roadbed Soil Modulus: 15000.0 psi
Tire Pressure: 90.0 psi

Total elapsed time: 3 hours and 0 minutes

Dates and times of WIM data collection

| Begin | | End | |
|---|---|---|---|
| Date | Time | Date | Time |
| 9/15/82 | 7:30 | 9/15/82 | 8:15 |
| 9/23/82 | 9: 0 | 9/23/82 | 9:30 |
| 9/30/82 | 12:15 | 9/30/82 | 12:45 |
| 10/ 1/82 | 11:20 | 10/ 1/82 | 12:35 |

WIM data files used as input

1 WIM.DAT

Figure 7.4. Example output from WIM program using ARE Inc factors (continued).

whether to make adjustments to one estimate based on the other in order to arrive at a desired traffic level. For complete user information and program documentation consult the program user's manual (Ref. 1).

## PROGRAM TRAF18K OVERVIEW

Program TRAF18K is a FORTRAN program which uses average 18KESAL vehicle factors together with traffic volume and classification data for a highway section to produce base year, ten-year and twenty-year estimates of cumulative 18KESAL's on that section. The program was originally supplied to ARE Inc by ADOT. The original version was made functional on an IBM-PC and compatible with the 18KESAL vehicle factors developed by program FEDESAL in the form of regression equations as desired by ADOT. Figure 7.5 shows the flow of program TRAF18K to produce cumulative 18KESAL predictions. The inputs are the same as the version supplied to ARE Inc by ADOT so the user's manual should still be valid. An example of the output provided by TRAF18K is shown in Figure 7.6. A single summary line is produced for each traffic section being analyzed. Complete program documentation is provided in Volume 2 of this report (Ref. 1).

Figure 7.1 illustrates the interaction between program FEDESAL and the "n" year cumulative 18KESAL program, TRAF18K. There may be many personnel within ADOT who will want access to program TRAF18K. In Figure 7.1, there are four inputs (blocks H, I, J and K) that could come from sources other than the microcomputer used to run program TRAF18K. Input H are in the form of regression equations developed from the output of the FEDESAL microcomputer program shown in Figure 7.1. The coefficients of the regression equations for every vehicle class are stored in a disk file and may be edited by the user with the editing routines built into program TRAF18K. Inputs I, J and K of Figure 7.1 are currently maintained on ADOT's mainframe computer. For microcomputer application, these data must be available to every user's microcomputer.

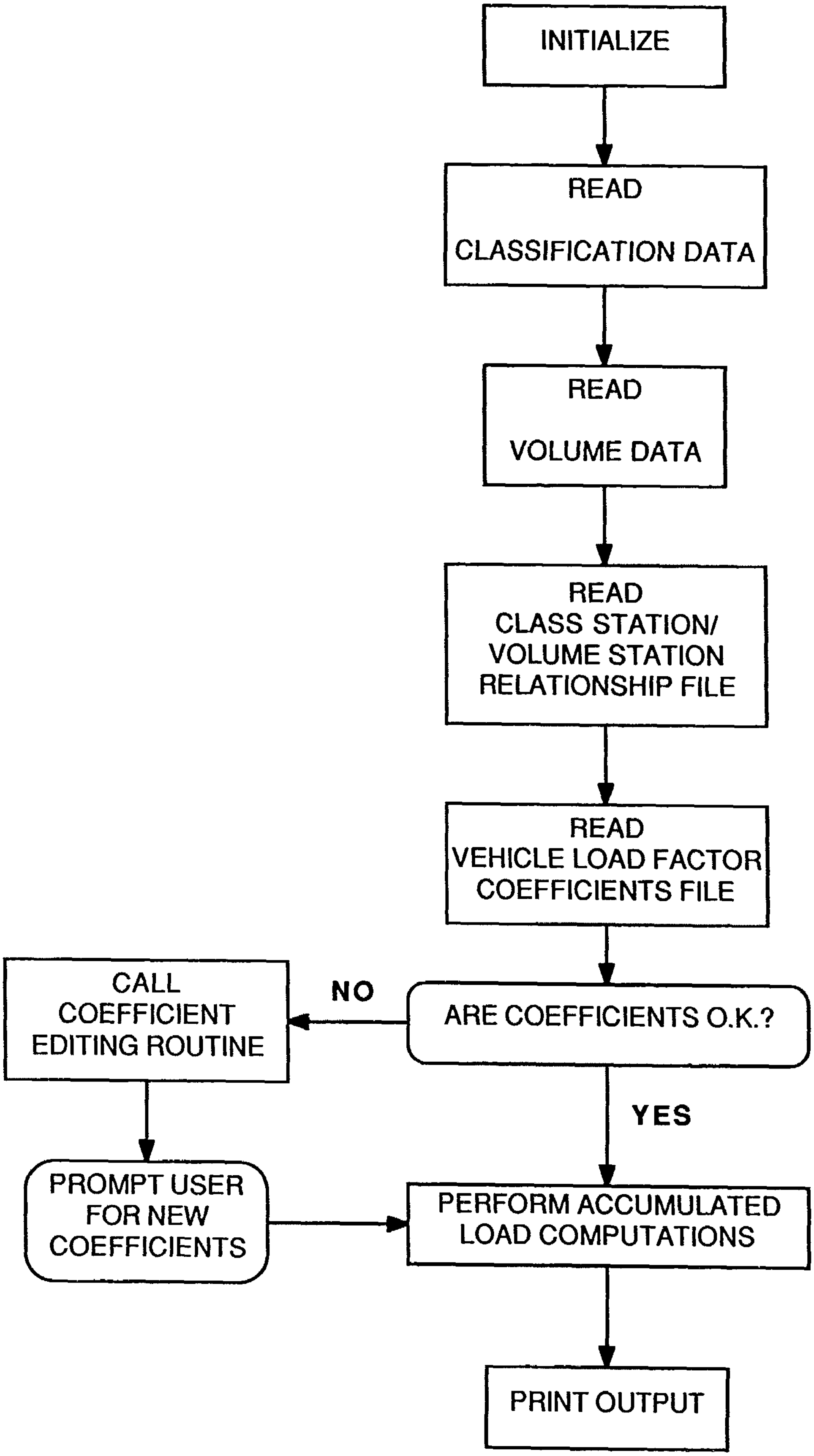



Figure 7.5. Flowchart for program TRAF18K.

## PROGRAM McPAD OVERVIEW

The first version of the mechanistic pavement design computer program, McPAD-1, was developed to provide a means for generating flexible pavement structural designs based upon 18-kip equivalent single axle load (ESAL) traffic projections derived from the new mechanistic equivalence factors. To provide a basis for comparison, the program also has the capability for generating corresponding flexible pavement structural designs using the procedure presented in the current AASHTO Guide for Design of Pavement Structures (1986). This option does, however, require additional input information, most notably, the 18-kip ESAL traffic projection derived from AASHTO load equivalence factors.

McPAD-1 is designed to operate on an IBM-PC compatible microcomputer under either MS-DOS or PC-DOS. Because of the use of an elastic layer subprogram to generate the required mechanistic pavement responses and the need to evaluate multiple structures, the McPAD-1 program can take an extended period of time (5 minutes to 1 hour) to evaluate one problem. Consequently, the program is designed to operate in "batch" mode, or in other words, data is provided to the program and it is allowed to execute without additional user interaction until execution terminates. To facilitate input data preparation, however, a menu-driven data file generation routine is included that allows the user to create design problems in an interactive environment. Unlike the FORTRAN based batch component of the program, the interactive data file generator is written in dBASE III+ and compiled with FOXBASE (to eliminate the need for the dBASE III+ software package to execute).

Figure 7.6 illustrates the primary data entry screen for the McPAD-1 program. As can be seen, the program does incorporate some of the same reliability concepts for mechanistic design as are included in the current AASHTO Guide based design procedure. The problem is that additional research is required to develop more precise recommendations on the overall standard deviation that should be used for mechanistic design.

McPAD-1 PAVEMENT STRUCTURAL DESIGN INPUTS

Problem Name MCPAD1-EX1
Description McPAD-1 Example Problem, AASHTO Materials, Light Traffic

No. of Layers in Pavement Structure 3

| | Mechanistic Based Design | AASHTO Guide Based Design |
|---|---|---|
| Projected 18-kip ESAL Traffic | 749291 | 100000 |
| Desired Reliability (%) | 95.000 | 95.000 |
| Overall Standard Deviation | 0.490 | 0.490 |

| | | Mechanistic Based Design | | | | | AASHTO Guide | |
|---|---|---|---|---|---|---|---|---|
| Layer No. | Layer Description | Elastic Modulus (psi) | Poisson Ratio | Min. Thick. (in) | Max. Thick. (in) | Thick. Incr. (in) | AASHTO Layer Coef. | Spec. Thick. (in) |
| 1 | Hot-Mix Asphalt Conc | 450000 | 0.300 | 4.00 | 6.00 | 1.00 | 0.44 | 4.0 |
| 2 | Granular Base | 30000 | 0.350 | 6.00 | 12.00 | 3.00 | 0.14 | 6.0 |
| 3 | Granular Subbase | 15000 | 0.400 | 6.00 | 18.00 | 3.00 | 0.11 | 0.0 |
| Soil | Silty Clay | 3000 | 0.450 | | | | | |

To Exit - Press the Cntrl & End Keys Simultaneously a Few Times

Figure 7.6. Primary input data entry screen for McPAD-1 program.

At this time, it is recommended that the same overall standard deviation values suggested in the AASHTO Guide be used for mechanistic design.

Further examination of Figure 7.6 indicates that the McPAD-1 program can consider up to four pavement layers above the subgrade (roadbed) soil for both mechanistic or AASHTO Guide based design. For mechanistic design, the user must enter the fundamental engineering material properties (i.e., elastic modulus and Poisson's ration) for each layer along with specific layer thickness constraints. The program will then "build" a pavement by incrementing layer thicknesses from the bottom-up until design 18-kip ESAL traffic criteria are satisfied. The allowable 18-kip ESAL traffic for a candidate design is calculated using one of two different single axle damage models (as documented in Chapter 3). The asphalt concrete tensile strain based model is used for surface layer thicknesses of three inches or more. The roadbed soil vertical compressive strain model is used only for those cases where the maximum potential surface layer thickness is three inches or less. Since there is a difference in the mechanistic load equivalence factors between thin and thick surface pavements, it is up to the user to ensure that the traffic projections specified are compatible with the desired type of pavement structural design.

For structural design based on the AASHTO Guide, the user need only specify the layer coefficients for each layer considered and the elastic (resilient) modulus of the roadbed soil. The program will then calculate the minimum thicknesses required for each layer using the layered analysis approach presented in the Guide. If desired, the user can specify any or all layer thicknesses.

With data for one (or more) design problems the program will conduct the appropriate analyses and send the results (output file) directly to the printer. Figure 7.7 provides example output from a single problem. The top half of the page summarizes the input data provided by the user. (Note that the results of some internal calculations are presented to show the effect of reliability on 18-kip ESAL design traffic calculations).

McPAD-1: MECHANISTIC FLEXIBLE PAVEMENT STRUCTURAL DESIGN PROGRAM
Version 1.0 - December 1987
Arizona Department of Transportation

Problem Name: MCPAD1-EX2
Description: McPAD-1 Example Problem, AASHTO Materials, Moderate Traffic

Design Input Summary:

| | Mechanistic Based Design | AASHTO Guide Based Design |
|---|---|---|
| Projected 18-kip ESAL Traffic | 4292292 | 572847 |
| Desired Reliability (Percent) | 95.000 | 95.000 |
| Overall Standard Deviation | .490 | .490 |
| Reliability Factor * | 6.400 | 6.400 |
| Design 18-kip ESAL Traffic * | 27468999 | 3665997 |

(* = Calculated Internally)

| | | Mechanistic Based Design | | | | | AASHTO Guide Based Design | |
|---|---|---|---|---|---|---|---|---|
| Layer No. | Layer Description | Elastic Modulus (psi) | Poisson Ratio | Min Thick (in) | Max Thick (in) | Thick Incr (in) | AASHTO Layer Coeff | Spec Thick (in) |
| 1 | Hot-Mix Asphalt Conc | 450000 | .300 | 3.00 | 6.00 | 1.00 | .440 | 5.00 |
| 2 | Granular Base | 30000 | .350 | 6.00 | 12.00 | 2.00 | .140 | 6.00 |
| 3 | Granular Subbase | 15000 | .400 | 6.00 | 20.00 | 2.00 | .110 | .00 |
| 4 | Silty Clay | 3000 | .450 | | | | | |

Design Results:

| | Mechanistic Solution | AASHTO Guide Solution |
|---|---|---|
| Layer 1 Design Thickness (in) | 5.00 | 5.00 |
| Layer 2 Design Thickness (in) | 6.00 | 6.00 |
| Layer 3 Design Thickness (in) | 20.00 | 16.13 |
| Allowable 18-kip ESAL Traffic | 28105296 | 3667303 |
| Reliability Achieved (Percent) | 95.206 | 95.003 |

Figure 7.7. Example output from McPAD-1 program.

The bottom half of the page presents the results of the design analyses, i.e., design layer thicknesses and allowable 18-kip ESAL traffic estimates. Since for all mechanistic designs (and AASHTO Guide designs where all layer thicknesses are specified) the allowable traffic will be greater than the design traffic, the program calculates and presents the level of reliability that is actually achieved.

Like the other three programs, more specific information on the application and operations of the McPAD-1 computer program is provided in the user's manual (Volume 2 of this report).

# CHAPTER 8. PROGRAM TESTING AND VERIFICATION

The 18KESAL prediction programs were exercised and tested before delivery to ADOT. The tests were to verify program accuracy, examine program output with respect to field performance, and determine program sensitivity to the input variables.

Sensitivity tests were executed over the range of options for ARE Inc equivalence factors. The details and results of these tests are presented in the following section and can be used to choose the best level of ARE Inc factors for a certain situation. For example, if a highway section has a history of premature failure, a new overlay can be designed using 18KESAL values derived at a higher tire pressure to increase the 18KESAL prediction and thus the overlay thickness.

The method used to initially verify the program's accuracy was to match an intermediate output with the numbers listed on the W-4 tables. This was accomplished for station 001 for the weight data from 1982 and 1984. These analyses consisted of 138 and 103 trucks, respectively, with all five Arizona truck types represented. All results, including vehicle counts and equivalent axle loads matched the output from the W-4 tables exactly. Although this does not prove the program is infallible, it does show that the methods of coding truck types and the program logic to process the weight data is accurate. An extension of this test was performed to calculate five-year moving average vehicle equivalence factors. These averages were provided to ARE Inc by ADOT for years 74, 75, 76, 78 and 80 loadometer data. ARE Inc had raw loadometer data for 76, 78, 80, 82 and 84. The averages of these five years as calculated by program FEDESAL were compared to the values supplied by ADOT. The results showed close correspondence even though the data used in each case was different.

## SENSITIVITY TESTING OF ARE EQUIVALENCE FACTORS

Sensitivity tests were run covering the range of options available in the programs. The largest component of the factorial are the inputs used to select a set of ARE Inc equivalence factors. The following combinations were used in the runs:

1. Surface Thickness - All 3 basic options.
2. Base Thickness - All 3 basic options.
3. Modulus of Roadbed Soil - The 3 default levels plus direct input of 1) 1000 psi, and 2) 40,000 psi.
4. Tire Pressure - The 3 default levels plus an additional value of 170 psi (to explore the impacts of extremely high pressures).

This produced a 3x3x5x4 factorial or 180 total runs. In making all runs, the option to "evaluate this year's data only" (option 1) was used. The option of using AASHTO equivalence factors was run independently as a basis for comparison with the ARE Inc factor runs.

The FEDESAL program was modified to read the pavement structure and tire pressure parameters (used to choose the correct equivalence factor set) from a disk file. The file was created to completely cover the factorial described above. Truck weight data for 1982 was used for the sensitivity runs because there was a good distribution of trucks in each vehicle class. All 180 combinations of parameters described above were run.

The results showed an effect of all parameters on the number of equivalent loads estimated. Tire pressure and roadbed soil modulus had the most significant effect. The general trends are as follows:

- o Number of equivalent loads increases as tire pressure increases.
- o Number of equivalent loads increases as roadbed soil modulus increases.
- o Number of equivalent loads increases as base/subbase thickness increases, except for the case with zero surface thickness where equivalent loads increase with decreasing base/subbase thickness.
- o Number of equivalent loads decreases as surface thickness increases, except for the case with zero surface thickness where equivalent loads are low.

The behavior of the equivalent load predictions with varying structure thickness is not easily explained. One possible explanation is that the equivalence factors for zero surface thickness (to simulate surface treatments) were developed with a damage model based on subgrade vertical strain as the pavement response parameter and the other factors for 3 and 6-inch surfaces were developed with a different model based on horizontal tensile strain at the bottom of the asphalt layer.

Appendix H shows the detailed results of the sensitivity runs. The first two columns of the table in the appendix are the roadbed soil modulus and tire pressure, respectively. The third column is an index (J) which defines the structure thickness. The following combinations of surface and base thicknesses correspond to each J level:

| J | Surface Thickness | Base Thickness | Approx SN |
|---|---|---|---|
| 1 | 0" | 8" | 1.1 |
| 2 | 0" | 14" | 2.0 |
| 3 | 0" | 20" | 2.8 |
| 4 | 3" | 8" | 2.4 |
| 5 | 3" | 14" | 3.3 |
| 6 | 3" | 20" | 4.1 |
| 7 | 6" | 8" | 3.8 |
| 8 | 6" | 14" | 4.6 |
| 9 | 6" | 20" | 5.4 |

The next five columns of the table in Appendix H are the calculated number of equivalent single axle loads per 1000 trucks for each of the five Arizona vehicle classes. These were calculated for interstate highways and flexible pavements using 1982 truck weight data. It can be assumed that results for other highway classes or other years would exhibit similar trends. A number of plots were made to graphically illustrate the behavior of the equivalent load predictions with varying input parameters.

Tire Pressure Effect. Figures 8.1 and 8.2 show a typical relationship between estimated 18KESAL and tire pressure with other factors held constant. The fixed values of the constant variables are shown on the plots in each case. It can be seen from these plots that tire pressure does have a significant effect on the number of estimated loads predicted by the program, given the same weight data. The higher estimation of equivalent loads reflects the increased damage inflicted on the pavement.

Roadbed Soil Modulus Effect. Plots showing the change in predicted 18KESAL with varying roadbed soil modulus are shown in Figures 8.3 and 8.4. It can be seen from the plots that equivalent loads generally increase with increasing roadbed soil modulus. Although this seems to be illogical, closer examination indicates that application of these equivalence factors in conjunction with the damage models from which they were developed do indeed give reasonable results. The following example is provided to demonstrate the adequacy of these equivalence factors when used in combination with the damage models.

Let's assume that we are going to evaluate a conventional flexible pavement (i.e., 3-inch AC surface, 6-inch granular base and 8-inch granular subbase) in which the roadbed soil resilient modulus at three locations is 4,000, 12,000, and 20,000 psi. For the sake of simplicity, let's further assume that the facility is only subjected to 10,000 yearly repetitions of a typical tractor trailer with a tire pressure of 110 psi. Table 8.1 summarizes the results of the analyses for the three locations.

At each location, the 18-kip single axle equivalence factor per 1000 vehicles (column 3) for a typical Arizona tractor trailer is determined using Figure 8.4. The yearly 18KESAL applications (column 4) is determined by multiplying the equivalence factor by the assumed 10,000 yearly vehicle repetitions. Column 5 represents the maximum asphalt concrete tensile strain corresponding to the pavement structure and roadbed soil resilient modulus. (Note: Since the normal range of modular ratio between unbound pavement layers is between 1.5 and 3.0, a value of 2.0 was used to define the subbase and base moduli at each location). The

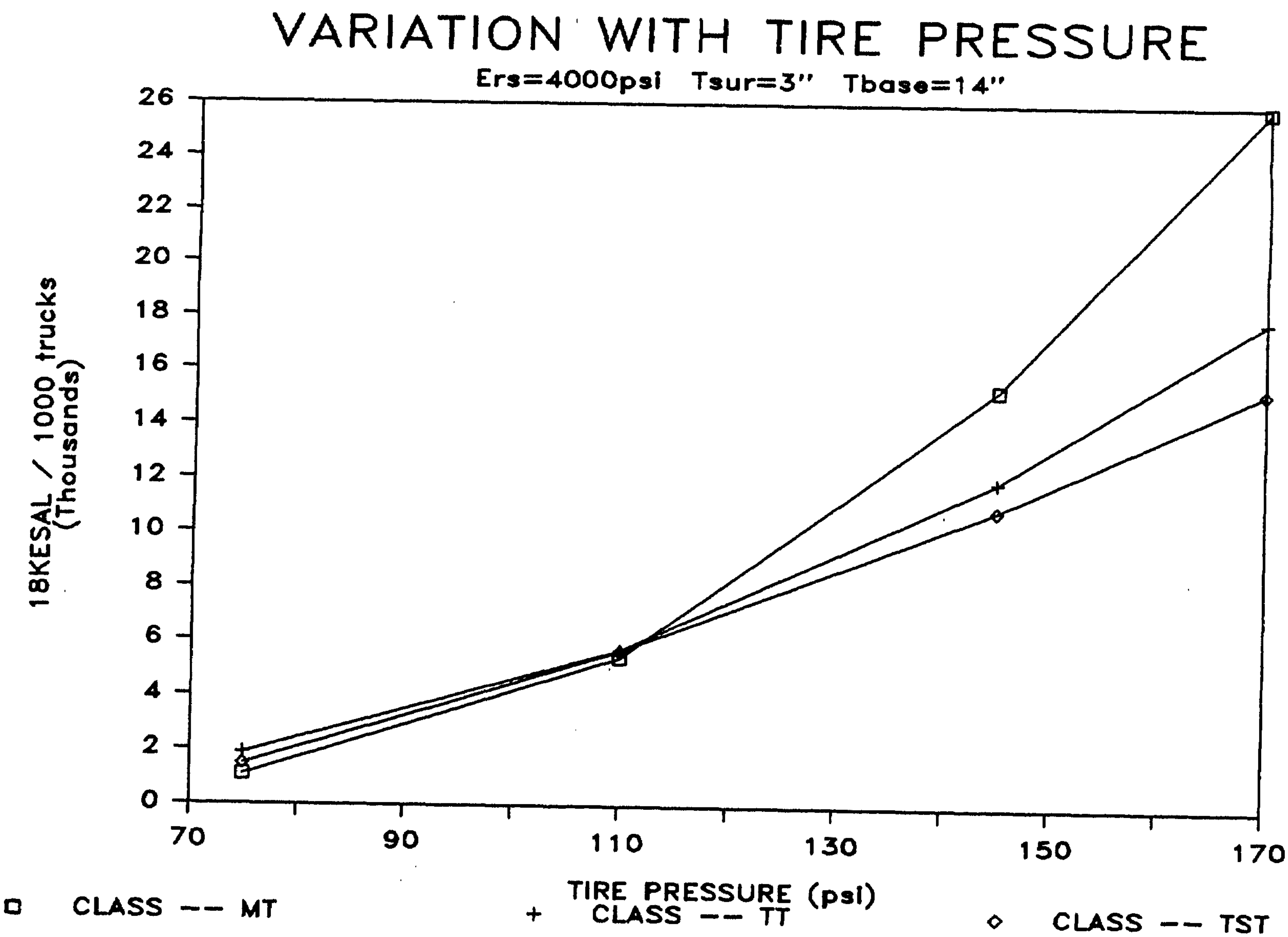



Figure 8.1. Plot showing typical effect of tire pressure for Ers = 4000 psi.

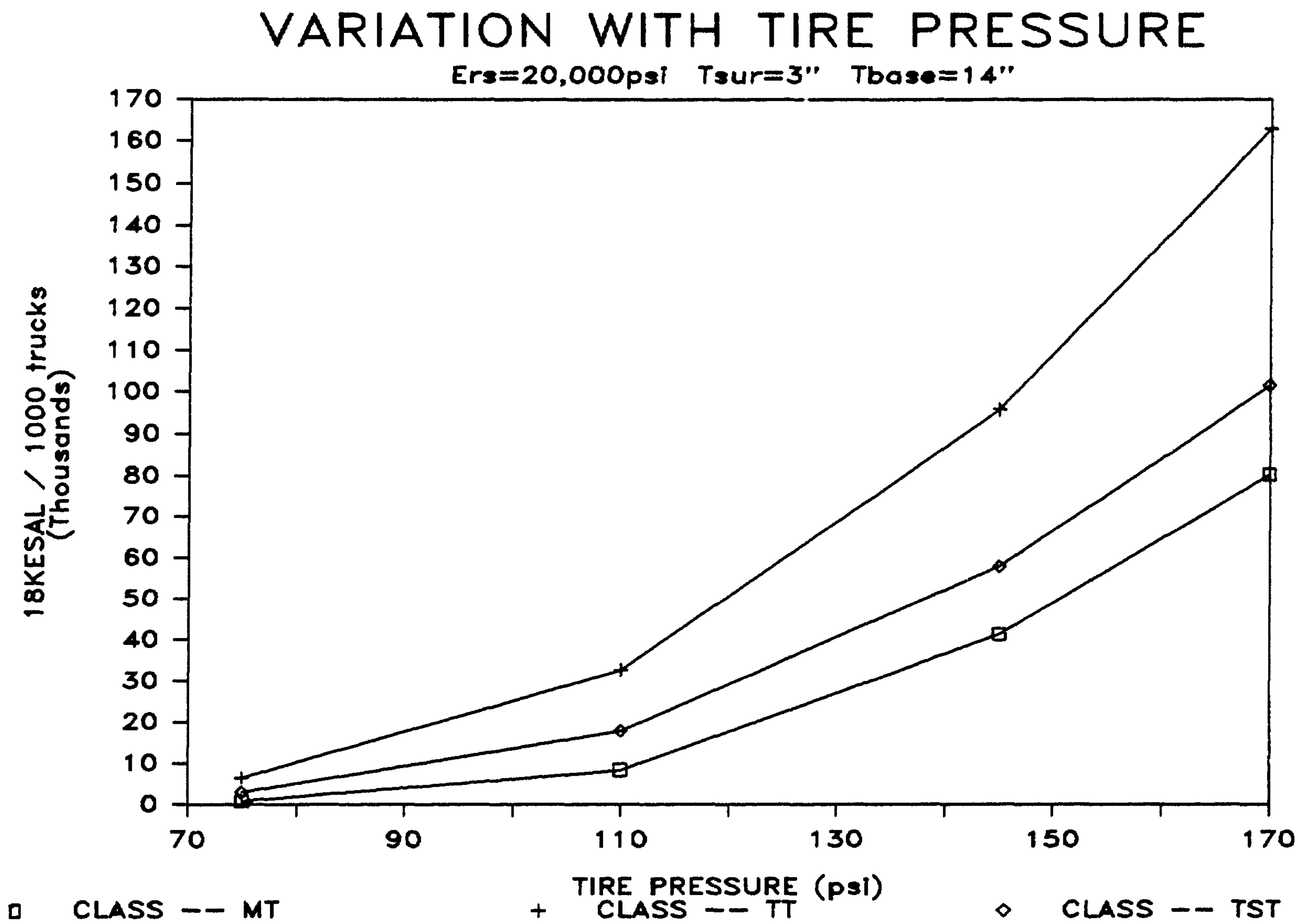



Figure 8.2. Plot showing typical effect of tire pressure for Ers = 20,000 psi.

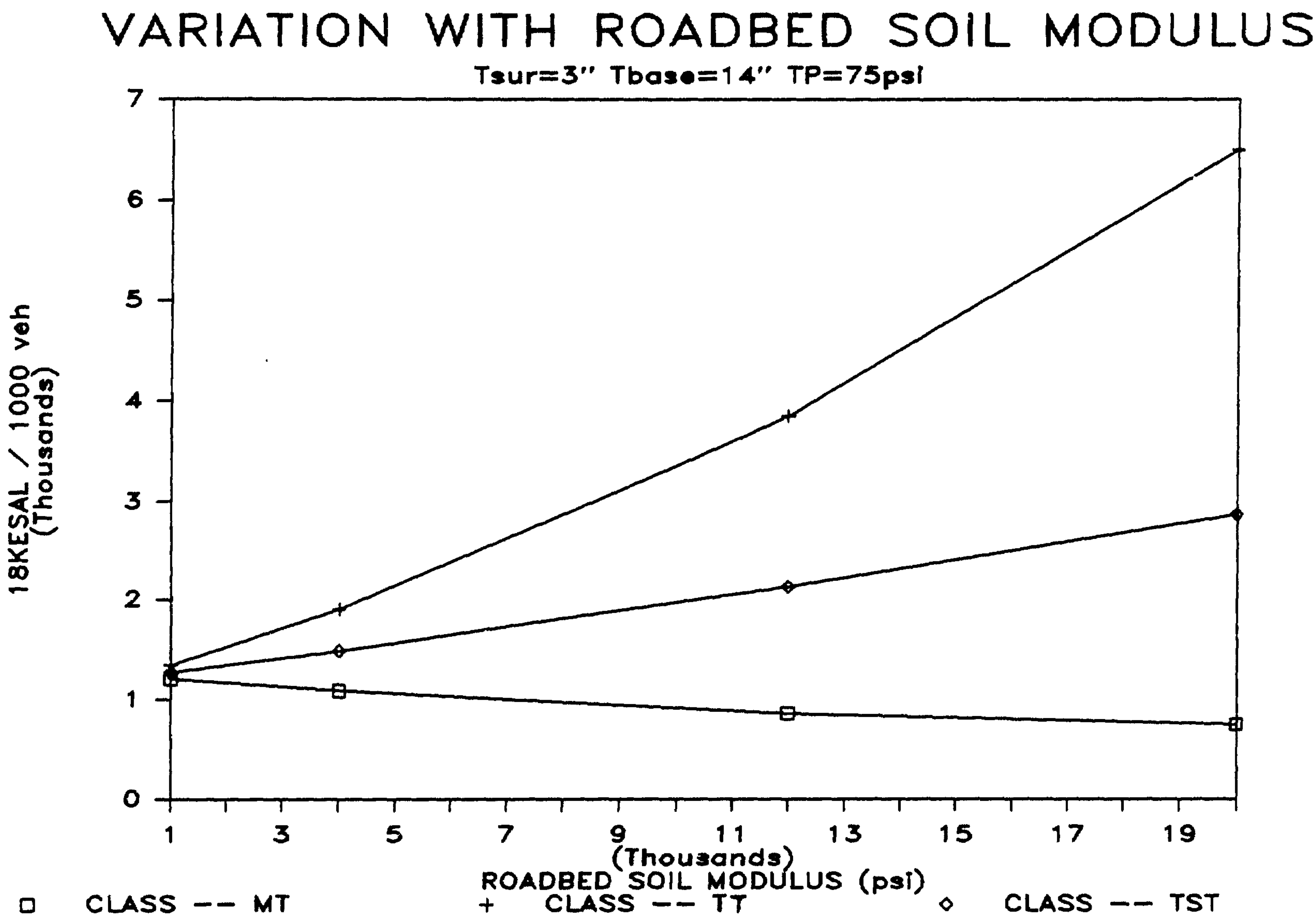



Figure 8.3. Plot showing typical effect of roadbed soil modulus.

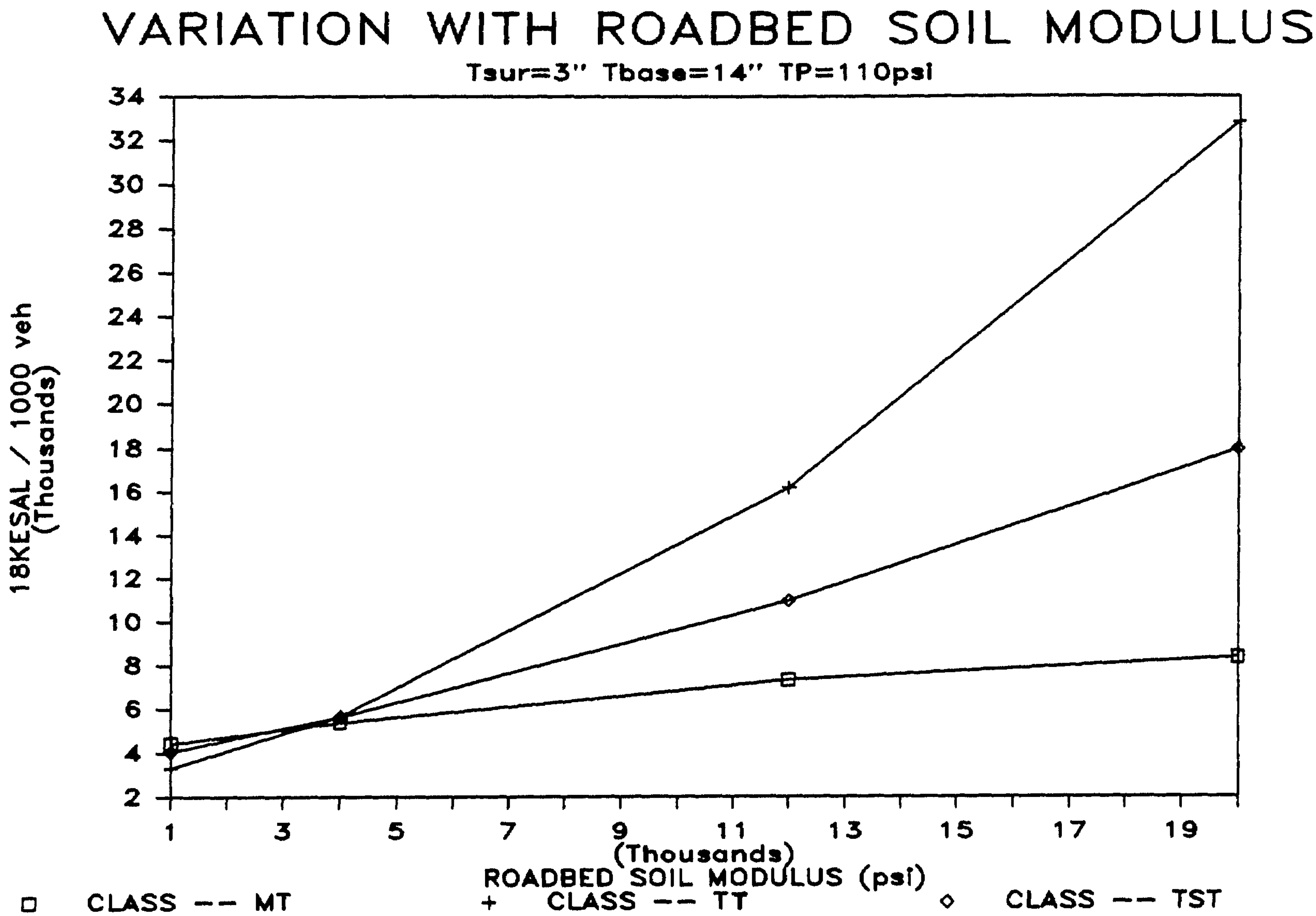
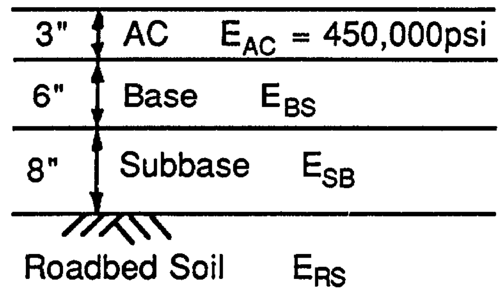



Figure 8.4. Plot showing typical effect of roadbed soil modulus in 18KESAL prediction.

Table 8.1. Illustration of effects of roadbed soil resilient modulus in a flexible pavement evaluation situation.

Pavement Structure:




| (1) Location | (2) Roadbed soil Resilient Modulus $E_{RS}$ (psi) | (3) 18-kip Single Axle Equiv. Factor for Typical Arizona Tractor Trailer: TP=110psi (per 1000 vehicles) | (4) Yearly 18-kip ESAL Applications* | (5) Asphalt Concrete Tensile Strain due to 18-kip Axle load, $\varepsilon_{AC}$ ($10^{-6}$ in/in) | (6) Total Allowable 18-kip ESAL Applications (millions) | (7) Yearly Damage |
|---|---|---|---|---|---|---|
| 1 | 4,000 | 5,700 | 57,000 | 593 | 0.019 | 3.04 |
| 2 | 12,000 | 16,200 | 162,000 | 336 | 1.35 | 0.12 |
| 3 | 20,000 | 32,800 | 328,000 | 241 | 159.0 | 0.0021 |

* Assumes 10,000 yearly application of a typical Arizona tractor trailer.

total allowable 18KESAL repetitions (column 6) is determined using the appropriate damage model from Table 3.8. Finally, the yearly damage (column 7) is computed as the ratio the expected yearly load repetitions (column 4) to the allowable repetitions (column 6). Inspection of columns 4, 6 and 7 shows that roadbed soil modulus has a greater effect on the allowable load repetitions than it does the projected yearly repetitions; consequently, the yearly damage decreases with increasing roadbed soil modulus.

Obviously this is a complicated interaction that is not readily understood. Essentially, what's happening is that the capacity for the pavement-soil structure to carry traffic increases so dramatically with increasing soil modulus that it more than offsets the increase in projected traffic associated with the higher load equivalence factors.

Surface and Base/Subbase Thickness Effects. The typical effects of surface and base/subbase thickness on 18KESAL estimations are shown graphically in Figures 8.5 and 8.6.

With regard to surface layer thickness, it can be seen that the effect on vehicle equivalence factors can be extreme in some cases (e.g., high roadbed soil modulus). It can also be seen that as surface thickness increases from 0 to 3 and then from 3 to 6 inches, the vehicle equivalence factor increases, peaks and then decreases. Although a different damage model was used for the zero surface thickness case, it is hypothesized that this trend would still have existed even if the asphalt concrete tensile strain based model had been used to develop equivalence factors for thicknesses approaching zero. It is believed that this phenomenon is related to the fact that strains in the asphalt concrete become very small (even compressive) in a thin surface layer. This does not mean that thin surface pavements will necessarily last longer; it just means that the mode of failure switches to another location. This explains why the roadbed soil vertical strain model was used and why it is recommended for pavements with thin surfaces.

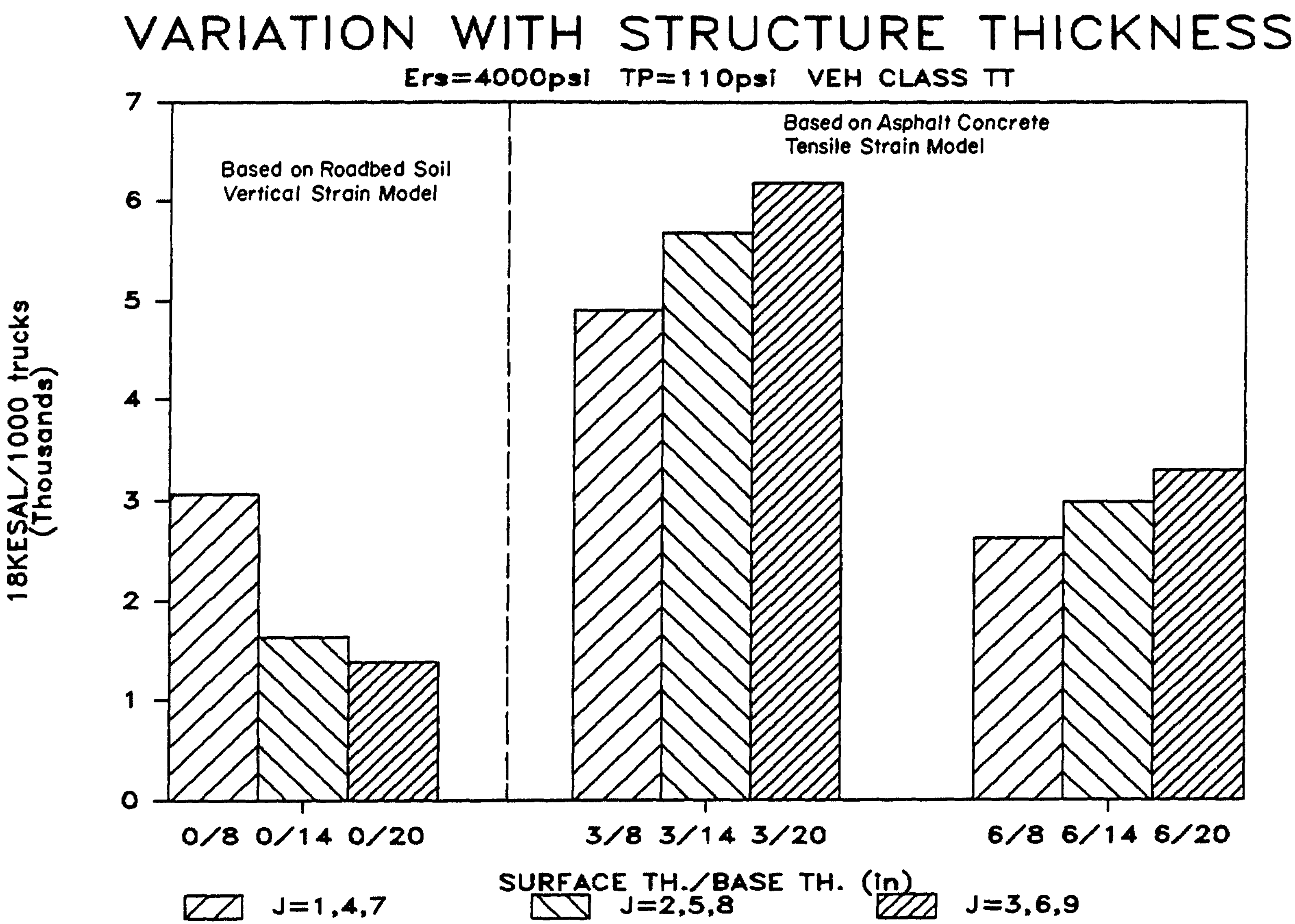



Figure 8.5. Plot showing effect of structure thickness on 18KESAL predictions for Ers = 4000 psi.

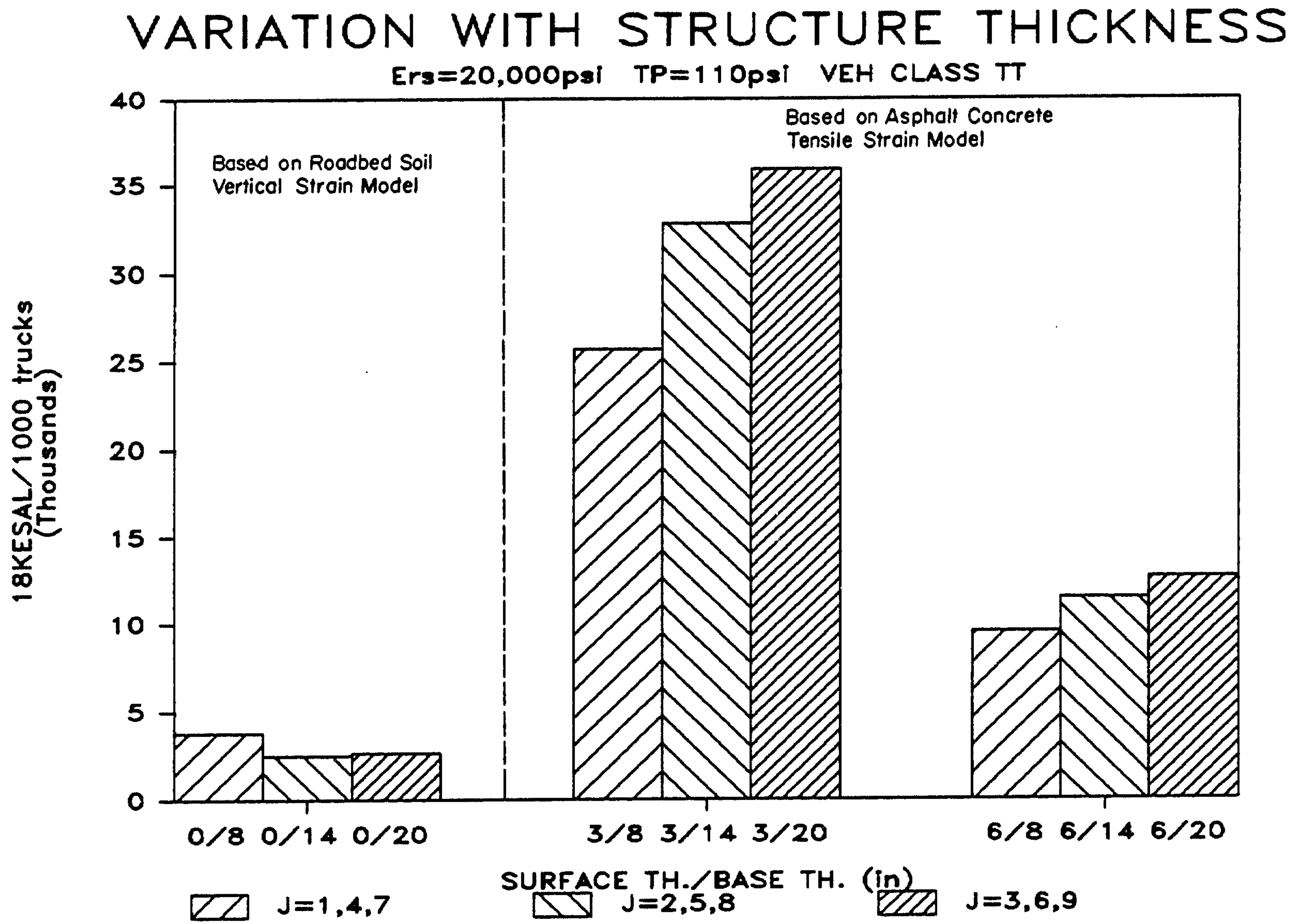



Figure 8.6. Plot showing effect of structure thickness on 18KESAL predictions for Ers = 20,000 psi.

With regard to the combined base/subbase layer thickness, it can be seen that the effect is relatively small compared to that of surface thickness and roadbed soil resilient modulus. In fact, because of the comparatively, minor effect, the use of an intermediate combined value of, say, 14 inches would be appropriate for vehicle equivalence factor estimations. It should also be noted that although increasing the combined base/subbase thickness increases the equivalence factor, its effect on the overall pavement design/evaluation process would be similar to that of increased roadbed soil modulus, i.e., the impact on allowable traffic offsets the impact on projected traffic.

## PROGRAM APPLICATION COMPARISONS

Program FEDESAL was tested with the truck weight data and the traffic volume and classification data from Arizona highways. Truck weight data from 1976, 78, 80, 82 and 84 were used to calculate five-year moving average 18KESAL per 1000 trucks which will be called vehicle equivalence factors (VEF). Two different sets of VEF averages were calculated using two different sets of single axle equivalence factors: 1) AASHTO factors at SN=5 and $p_t$=2.5, and 2) ARE Inc factors at a tire pressure of 75 psi and an average structure. The program was executed five times with each set of factors using option 2: "calculate five-year averages and update five-year average file" (see program users manual, Ref 1). Successive years of data were used for each run so that after the fifth run, a complete five-year moving average file existed on disk. At this point, twelve Arizona highway sections, originally used for the SODA design procedure development (Ref 11), were chosen to examine the output of the new 18KESAL prediction programs in terms of result applications.

The 1984 traffic data for each SODA section was used to calculate estimated design traffic using the AASHTO procedures and compared to the design traffic predicted with the new ARE Inc algorithms. Design thicknesses for each of the sections were determined using the SODA method and compared to thickness actually built on the SODA sections. A comparison of SODA design thicknesses with thicknesses derived from the mechanistic ARE Inc equivalence factors is not possible because the SODA procedure was empirically derived based on load predictions using AASHTO equivalence factors. For this reason, it gives reasonable design thicknesses when using the lower 18KESAL estimates given by the AASHTO procedure and would give meaningless thickness values using the new ARE factors. Table 8.2 presents the results of these analyses. The first four columns of the table include the SODA section number and the actual values used for design 18KESAL, actual as-built overlay thickness, and design overlay thickness. These values were taken directly from Reference 11 and were determined using ADOT procedures in years ranging from 1974 to 1980. The next column is the estimated 18KESAL from programs FEDESAL and TRAF18K using 1984 traffic data. These can be compared to the Arizona design 18KESAL with the realization that they are based on different years of traffic data. The next column is the estimated overlay thickness produced by SODA based on the FEDESAL 18KESAL values using AASHO factors. The SODA limitation of a 6-inch maximum thickness was removed to examine the effects. The second to last column is the predicted 18KESAL values using ARE factors at 75 psi for comparison to 18KESAL values predicted with AASHTO factors. The last column is the relative condition scores of each of the SODA sections as determined by the condition survey performed as part of the field investigations discussed in Chapter 5.

It can be seen that the ARE equivalence factors produced significantly higher estimates of equivalent loads than the AASHTO factors. This may indicate that the AASHTO equivalence factors tend to underestimate equivalent loads. This is a possibility based upon the rapid rates of deterioration observed on some of the SODA sections analyzed as indicated by their condition scores. Design thicknesses could not be produced with the higher ARE Inc 18KESAL factors because the SODA design procedure's damage criteria is incompatible with the new mechanistic method's damage criteria and a comparison would not be meaningful.

This comparison shows that the empirically developed SODA design procedure is not suitable for direct application with the new ARE Inc equivalence factors. Since the SODA procedure was developed based on AASHTO equivalence factors, they should continue to produce the most reasonable results in the SODA procedure. The new mechanistically-based

Table 8.2. Results of ESAL Comparisons using AASHTO Equivalence Factors and ARE Inc Equivalence Factors at 75 psi.

| SODA Section # (Ref 11) | Arizona Design 18KESAL | Actual Overlay Thickness | Arizona Design Thickness | FEDESAL Design 18KESAL AASHTO Factors | Design Thickness AASHTO Facs. | FEDESAL Design 18KESAL ARE Facs. 75 psi | Condition Score |
|---|---|---|---|---|---|---|---|
| 1 | 3,420,800 | 1.8 | 5.6 | 3,666,200 | 5.8 | 27,469,000 | 85 |
| 2 | 2,387,700 | 1.8 | 6.0 | 3,228,900 | 8.9(6.0) | 25,408,000 | 83 |
| 3 | 2,387,700 | 1.8 | 3.9 | 3,228,900 | 4.8 | 25,408,000 | 76 |
| 4 | 2,387,700 | 1.8 | 3.9 | 3,228,900 | 4.8 | 25,408,000 | 73 |
| 8 | 2,520,100 | 6.8 | 2.1 | 3,232,200 | 2.5 | 22,544,000 | 87 |
| 9 | 2,520,100 | 6.5 | 6.0 | 3,232,200 | 7.3(6.0) | 22,544,000 | 87 |
| 10 | 3,032,000 | 2.8 | 0.6 | 3,370,700 | 0.4 | 23,044,000 | 100 |
| 11 | 3,032,000 | 3.3 | 5.9 | 3,370,700 | 6.2(6.0) | 23,094,000 | 88 |
| 16 | 95,500 | 2.3 | 0.0 | 73,000 | 0.0 | 495,000 | 79 |
| 19 | 199,000 | 1.8 | 0.0 | 379,800 | 0.0 | 2,452,000 | 96 |
| 20 | 199,000 | 1.8 | 0.0 | 372,800 | 0.0 | 2,452,000 | 86 |
| 21 | 340,000 | 3.3 | 0.0 | 196,407 | 0.0 | 1,268,000 | 100 |

overlay design procedure produces reasonable results with the ARE Inc factors since it was developed with the new damage models and the same variables considered in equivalence factor development.

# CHAPTER 9. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research project was to study the effects of increased pavement loading being applied by modern trucks. A mechanistic approach was used to analyze the problem with the goal of developing new procedures to account for increased loads and tire pressures. Results from the original studies at the AASHO Road Test showed that pavement damage increases exponentially with increasing loads. The rigorous mechanistic analyses applied in this study have also shown this. More importantly, the research done on this project has shown that increasing tire pressures also have a large effect on pavement damage rates.

In using results from the AASHO Road Test, it must be recognized that certain limitations apply to the interpretation and application of test results and especially to load equivalence factors. These limitations include such factors as roadbed soil type, environment, and construction materials. The interpretation of results also applies to tire pressure and axle configuration, i.e., 75 psi tire pressure and single axle (dual tire) and tandem axle (dual tire) configurations.

Data collected as part of this investigation, and supported by information in the literature, confirms that actual truck tire pressures under operating conditions are likely to be in the range of 90 to 130 psi. Also, although not documented by this investigation, it is considered likely that legal axle load limits will increase in the near future in order to take advantage of developments in truck and tire manufacturing capabilities.

In order to extend the findings from the AASHO Road Test, a mechanistic approach was used to 1) evaluate changing tire pressures, increased loads and steering axle damage and 2) to isolate single axle, tandem axle and tridem axle effects. The results of this effort is summarized in Chapters 3 and 4 with interpretations in each of the remaining chapters in the report.

Based on the use of mechanistic design procedures, new 18KESAL factors were produced and thus meet the primary objectives of this project. The damage models so developed have retained serviceability loss as the criteria for "failure". In this regard, the new factors are compatible with the current AASHTO load equivalence factors. However, it is important to recognize that the new load equivalence values are uniquely associated with the mechanistic damage models from which they were derived. Thus, it is not possible to substitute load equivalence values from the mechanistic model for the load equivalence values which appear in the current AASHTO Guide. The value of the new factors is not only to show the relative effects of tire pressure on pavement damage, but also as a tool in a new mechanistic design procedure. The new McPAD-1 program makes it possible to take 18-kip ESAL traffic projections derived from the mechanistic load equivalence factors (via the TRAF18K computer program) and translate them along with other inputs into actual mechanistic-based pavement structural designs. The new program will obviously require some testing, verification and perhaps enhancement before it can be incorporated into practice, but it does seem initially to provide a sound engineering basis for accurately treating the problems of increased loads and tire pressures in the design process.

Since a comparison of the new mechanistic load equivalence factors with the current AASHTO factors indicated a very significant difference, it was necessary to develop an interim means for treating increased tire pressures that was compatible with the currently used AASHTO factors. Appendix G presents the extended AASHTO factors and documents their development. Basically, an "empirical-mechanistic" approach was used that provided the desired compatibility and insured that if a given change in tire pressure produced the same change in strain as given change in axle load, then the equivalency factor resulting from the change in strain was the same as that for the change in axle load.

IMPLEMENTATION

The computer programs FEDESAL and TRAF18K (for loadometer and traffic data) and WIMESAL (for weigh-in-motion (WIM) data) are ready for implementation by ADOT. These programs have been designed to work with either AASHTO compatible or ARE Inc (mechanistic) load equivalence factors. The use of the FEDESAL program with AASHTO compatible load equivalence factors will facilitate analysis of Arizona DOT loadometer data and result in considerable savings of time previously required for this activity. The WIMESAL program provides similar capabilities for use with weigh-in-motion data for site specific data interpretation.

Procedures have been developed to adjust predicted load equivalence values to account for increased tire pressure. One approach is to adjust the AASHTO values based on a correlation between the AASHO equation and pavement strain. A second approach would be to revise the ADOT design procedures using the mechanistic approach which has been partially developed on this project. This second approach is considered preliminary until additional data is obtained, preferably from Arizona pavements, to provide needed credibility and calibration for this method.

RIGID PAVEMENTS

To complete the set of damage models and equivalence factors for Arizona, rigid pavement parameters and data must be analyzed. A procedure similar to that used for flexible pavements on this project could be applied. AASHO rigid pavement sections should be analyzed to determine seasonal material properties and damage estimates to a terminal serviceability level of 2.5. Statistical analysis will produce predictive damage equations from which equivalence factors can be developed.

During the development of the rigid pavement models, the current flexible pavement models should be carefully reviewed and updated with any new findings from the rigid pavement research. Such updates could be in the form of a refined technique to more accurately evaluate seasonal material property variation. Identification or quantification of other significant variables, improved statistical analysis methods or other enhancements could be considered as part of this development.

## WIM RESEARCH

The new capability for the use of WIM measurements for routine estimation of 18KESAL on overlay design projects is a very important project result. The WIMESAL analysis program was developed through a contract extension on this project. The program is functional and implementable and could lead to a successful program of WIM measurements for equivalent load prediction and overlay design. Research is needed on the accuracy and reliability of the data obtained with Arizona's WIM equipment. Development of a plan for application and management of a successful WIM program is needed. This will include specifications and budgets for equipment purchase and deployment and a system for prioritizing or optimizing the location of available WIM equipment. Finally, the WIMESAL program could possibly be incorporated into an overlay design method or overall pavement management system. The available benefits of a successful WIM measurement program make this an important area for future research considerations.

## APPLICATIONS TO OVERLAY DESIGN

Although the scope of this project did not permit application of the new mechanistic methods to overlay design, it is pertinent to note that ADOT is planning a study in this area and that ARE Inc has applied such methods to the development of overlay design procedures. It should be possible to combine information obtained for the SODA project with mechanistic overlay design procedures to develop a new generation of overlay design procedures. Such developments could also take advantage of methods proposed in the new AASHTO Guide.

## SUMMARY

This investigation has resulted in the development of new computer programs to;

- o analyze loadometer data from permanent weigh stations in the State of Arizona,

- analyze weigh-in-motion data to provide information similar to that obtained from fixed weigh stations,

- analyze the effect of increased legal load limits on truck equivalence values, and

- use mechanistic relationships to calculate load equivalence factors as a function of tire pressure, structure, truck classifications, single axle - single wheel, single axle - dual wheels, tandem axle - dual wheels and tridem axle - dual wheels, year and even location in the case of the WIM program.

- develop mechanistic-based flexible pavement structural designs that are compatible with 18KESAL traffic projections resulting from the new mechanistic load equivalence factors.

This study also provided the following information;

- field data to show that current operating tire pressures on trucks during the summer in Arizona are averaging 105 psi, and

- recommendations for the implementation of the project results by ADOT and for continued studies to exploit the findings of this investigation.

## REFERENCES


1. High, R., and S.W. Hudson, "Evaluation of Increased Pavement Loading, Volume II - ESAL Program Documentation", ARE Inc, prepared for Arizona DOT, April, 1986.

2. Marshek, K.M., W.R. Hudson, R.B. Connell, H.H. Chen, and C.L. Saraf, "Experimental Investigation of Truck Tire Inflation Pressure on Pavement-Tire Contact Area and Pressure Distribution," Center for Transportation Research, Report No. 386-1, The University of Texas at Austin, 1985.

3. Marshek, K.M., W.R. Hudson, H.H. Chen, C.L. Saraf, and R.B. Connell, "Effect of Truck Tire Inflation Pressure and Axle Load on Pavement Performance," Center for Transportation Research, Report No. 386-2F, The University of Texas at Austin, 1985.

4. Connell, R.B., "Experimental Determination of Truck Tire Contact Pressures and Their Effect on Flexible and Rigid Pavement Performance," M.S. Thesis, The University of Texas at Austin, 1985.

5. Marshek, Kurt M., Hsien H. Chen, Richard B. Connell, and W. Ronald Hudson, "Experimental Determination of Truck Tire-Pavement Contact Pressure Distribution," presented at 65th Annual Meeting of Transportation Research Board, Washington, D.C., January 1986.

6. Chen, Hsien H. Kurt M. Marshek, and C.L. Saraf, "The Effects of Truck Tire Contact Pressure Distribution on the Design of Flexible Pavements--A 3D Finite Element Approach," presented at 65th Annual Meeting of Transportation Research Board, Washington, D.C., January 1986.

7. Marshek, K. M., H. H. Chen, R. B. Connell, and C.L. Saraf, "The Effects of Truck Tire Inflation Pressure and Axle Load on Flexible and Rigid Pavement Performance," presented at 65th Annual Meeting of Transportation Research Board, Washington, D.C., January 1986.

8. Middleton, D.R., F.L. Roberts and T. Chira-Chavala, "Measurement and Analysis of Truck Tire Pressures on Texas Highways," Prepared for the annual meeting of the Transportation Research Board, January 1986.

9. Roberts, Freddy L. and Barry T. Rosson, "Effects of Higher Tire Pressures on Strain in Thin ACP," paper presented at 65th Annual Meeting of the Transportation Research Board, Washington, D.C., 1985.

10. "Materials - Preliminary Engineering and Design Manual," Arizona Department of Transportation, Materials Services, Phoenix, Arizona, 1977.

11. Eisenberg, John F., George B. Way, James P. Delton, and John E. Lawson, "Overlay Deflection Design Method for Arizona," Report No. FHWA/AZ83/182, Arizona Department of Transportation, Phoenix, Arizona, March 1984.

12. "The AASHO Road Test - Report 3 - Traffic Operations and Pavement Maintenance," Highway Research Board Special Report 61C, Publication 952, Highway Research Board, Washington, D.C., 1962.

13. Tielking, J.T. and Schapery, R.A., "A Method for Shell Contact Analysis," Computer Methods in Applied Mechanics and Engineering, Vol. 26, No. 2, pp. 181-195, May 1981.

14. Tielking, J.T. and Schapery, R.A., "Calculation of Tire-Pavement Shear Forces," ASME Symposium Proceedings, The General Problem of Rolling Contact, ASME AMD-Vol. 40, pp. 19-39, 1980.

15. "ILLIPAVE - A Finite Element Program for the Analysis of Pavements," Construction Engineering Laboratory and the Transportation Facilities Group, Department of Civil Engineering, University of Illinois at Urbana, Illinois, May 1982.

16. AASHTO Interim Guide for Design of Pavement Structures, 1972 (Chapter III Revised, 1981), American Association of State Highway and Transportation Officials, Washington, D.C., 1981.

17. Finn, F., C.L. Saraf, R. Kulkarni, K. Nair, W. Smith and A. Abdullah, "Development of Pavement Structural Subsystems," Volume 1, Final Report, NCHRP Project 1-10B, Transportation Research Board, Washington, D.C., 1977.

18. Miner, Milton A., "Cumulative Damage in Fatigue," Journal of Applied Mechanics, ASME, September 1945.

19. The AASHO Road Test, Report 5, Pavement Research, Highway Research Board, Special Report 61E, National Academy of Sciences - National Research Council, Washington, D.C., 1972.

20. Ahlborn, Gale, "Elastic Layered System with Normal Loads," The Institute of Transportation and Traffic Engineering, University of California, Berkeley, California, May 1972.

21. Taute, Arthur, B.F. McCullough and W.R. Hudson, "Improvements to the Materials Characterization and Fatigue Life Prediction Methods of the Texas Rigid Pavement Overlay Design Procedure," Research Report 249-1, Center for Transportation Research, University of Texas at Austin, November, 1981.

22. Gerald, Curtis, Applied Numerical Analysis, Addison Wesley, 1980.

23. "Asphalt Concrete Overlays of Flexible Pavements - Vol. 1, Development of New Design Criteria," Report No. FHWA-RD-75-75, Federal Highway Administration, Washington, D.C., June 1975.

24. Al-Rashid, Nasser I., Clyde E. Lee, and William P. Dawkins, "A Theoretical and Experimental Study of Dynamic Highway Loading," Research Report No. 108-1F, Center for Highway Research, The University of Texas at Austin, May 1972.

25. Machemehl, R.B. and C.E. Lee, "Dynamic Traffic Loading of Pavements," Research Report No. 160-1F, Center for Highway Research, The University of Texas at Austin, December 1974.

26. Bellini, W.R., and E.N. Thrower, "A Digital Computer Program to Simulate the Passage of a Vehicle Over a Road Surface," Road Research Laboratory Report LR 181, Ministry of Transport, Crothorne, England 1968.

27. McKenzie, D.W. and W.R. Hudson, "Road Profile Evaluation for Compatible Pavement Evaluation," A paper prepared for presentation at the 61st annual meeting of the Transportation Research Board, Washington, D.C., (1982).

28. Barker, W.R. and Brabston, "Development of a Structural Design Procedure for Flexible Airport Pavements," U.S. Army Water Ways Experiment Station, Report No. FAA-RD-74-199, U.S. Dept. of Transportation, Federal Aviation Administration, September, 1975, Washington, D.C.

29. BISAR, Computer Program User's Manual, Masterdam: Koninklijke/Shell-Laboratorium, 1972.

30. "Pavement Condition Survey Manual For The Rapid City Pavement Evaluation and Management System," ARE Inc Engineering Consultants, June 1987.

UNCITED REFERENCES

A. Hutter, Werner, "Sensitivity Analysis of Truck Weights on Pavement Deterioration," Report No. CDH-DTP-R-83-2, Colorado Department of Highways, Denver, Colorado, February 1983.

B. "1980 Year Book," Tire and Rim Association Inc., Akron, Ohio, 1980.

C. "Layered Pavement Systems," Transportation Research Record 810, Transportation Research Board, Washington, D.C., 1981.

D. "National Weigh in Motion Conference," paper presented at Stapleton Plaza Hotel July 11-15, 1983, Proceedings, Colorado Department of Highways, Denver, Colorado, 1983.

E. Edris, Earl V. Jr. and Robert L. Lytton, "Dynamic Properties of Subgrade Soils, Including Environmental Effects," Texas Transportation Institute, Research Report 164-3, Texas A&M University, College Station, Texas, May 1976.

F. Machemehl, Randy B., Clyde E. Lee, and Michael C. Walton "Truck Weight Surveys By In-Motion Weighing." Center for Highway Research, Research Report-181-IF, The University of Texas at Austin, September 1975.

G. Clark, Samuel K., 2nd ed. Mechanics of Pneumatic Tires, Washington, D.C., U.S. Department of Transportation, 1982.

H. Carmichael, R.C. III, et al, "Effects of Changes in Legal Load Limits on Pavement Costs: Volume 1- Development of Evaluation Procedure - Volume 2 - Documentation for Program NULOAD," FHWA Report No. FHWA-RD-78-98, Federal Highway Administration, September 1978.

I. ARE Inc, "Effects on Flexible Highways of Increased Legal Vehicle Weights Using VESYS IIM," Final Report No. FHWA-RD-77-116, Federal Highway Administration, January 1978.

J. "1985 Year Book," Tire and Rim Association Inc., Akron, Ohio, 1975.

K. "Changes in Legal Vehicle Weights and Dimensions, Some Economic Effects on Highways," NCHRP Report 141, Highway Research Board, Washington, D.C. 1973.

# APPENDIX A

## TYPICAL TRUCK TIRE FOOTPRINT SHAPES

This appendix presents reduced versions of seven different truck tire footprints. The first two were provided by one of the major tire companies. The others were provided by Smithers Scientific Services Inc.

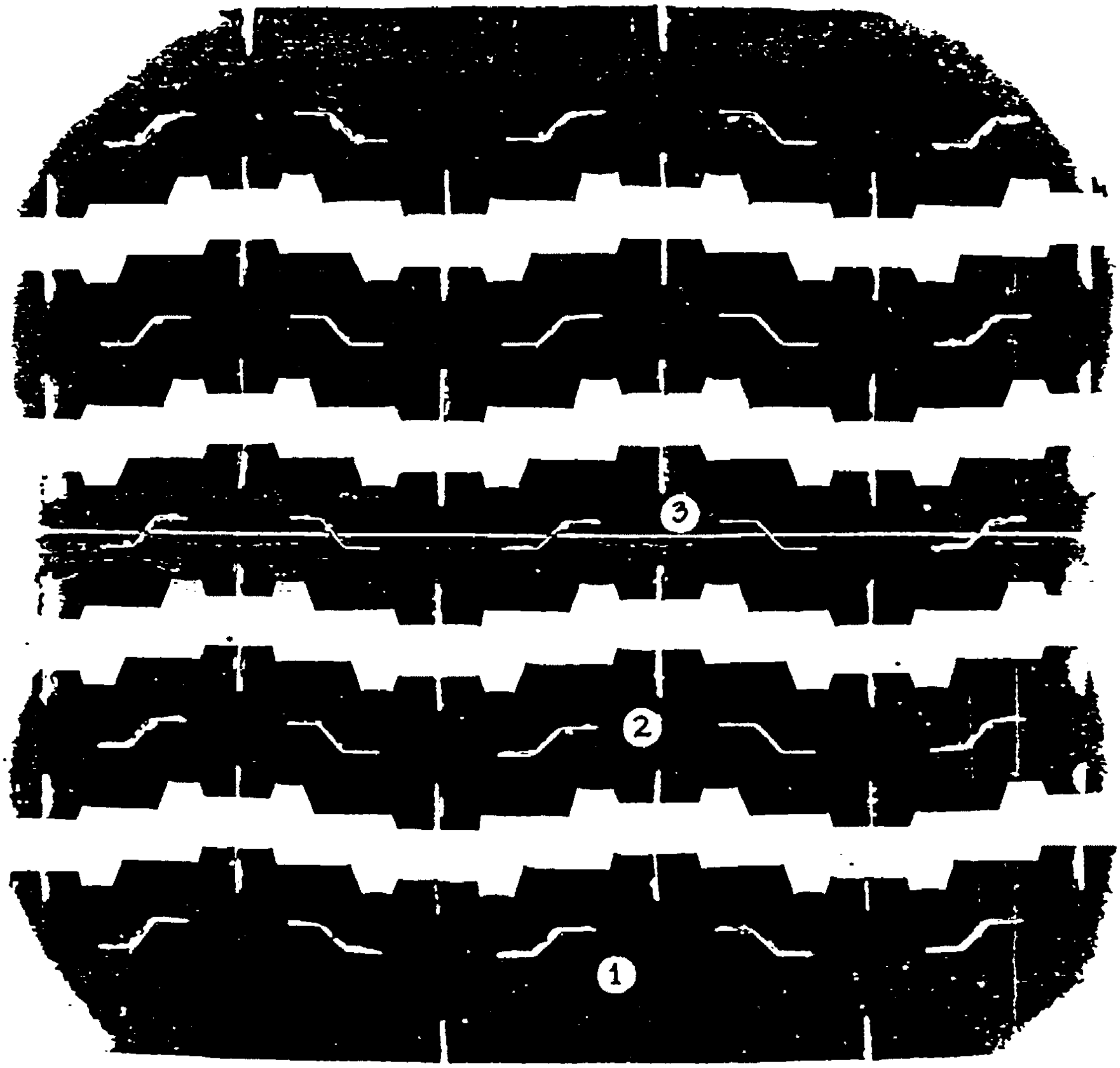
UNISTEEL G159 LP

STATIC FOOTPRINT - FULL SCALE

5675 LB @ 95 PSI

Goodyear

295/75R22.5 LRG




(1) SHOULDER (2) INTERMEDIATE (3) TREAD CENTER

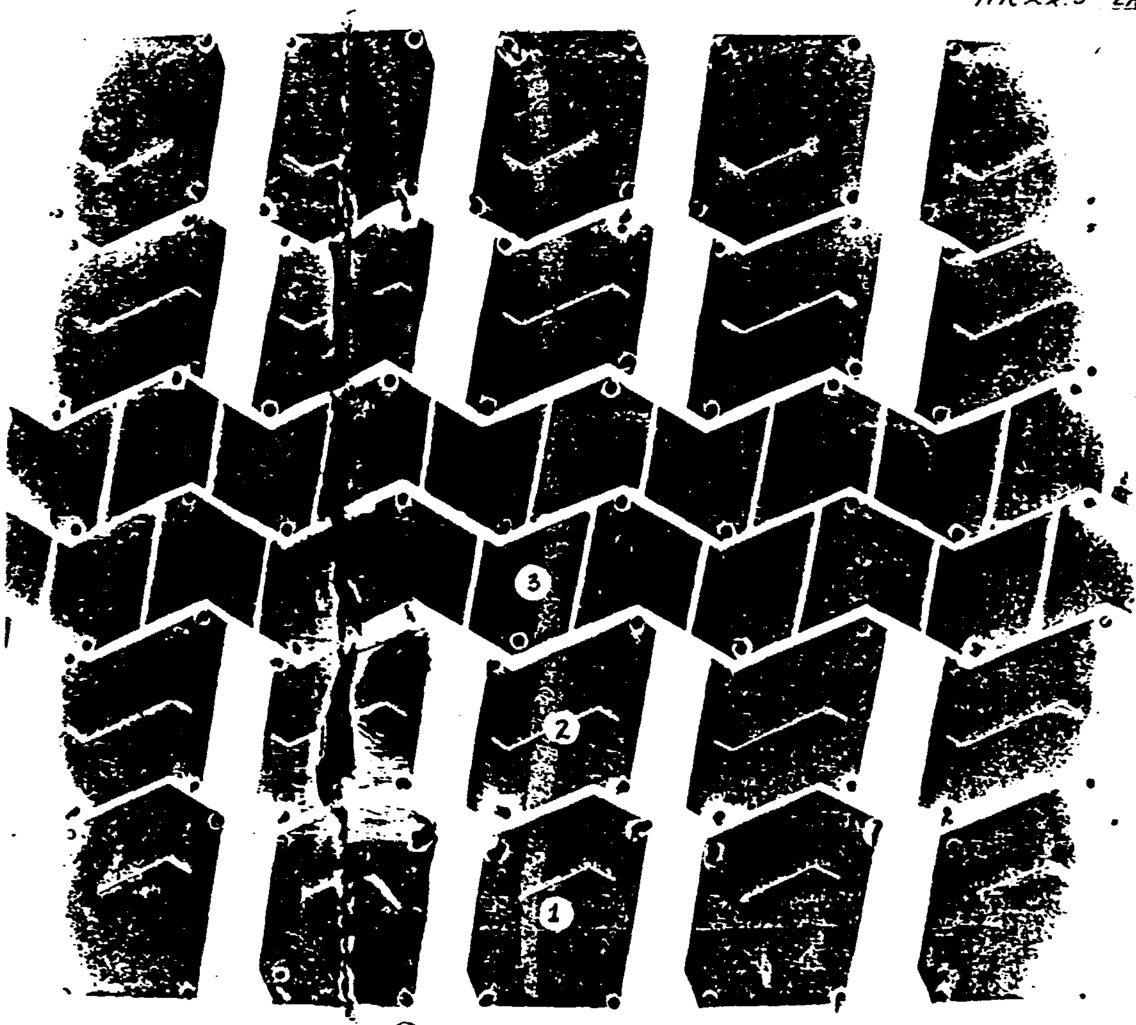
UNISTEEL G167

STATIC FOOTPRINT - FULL SCALE

5300 LB @ 95 PSI

Goodyear

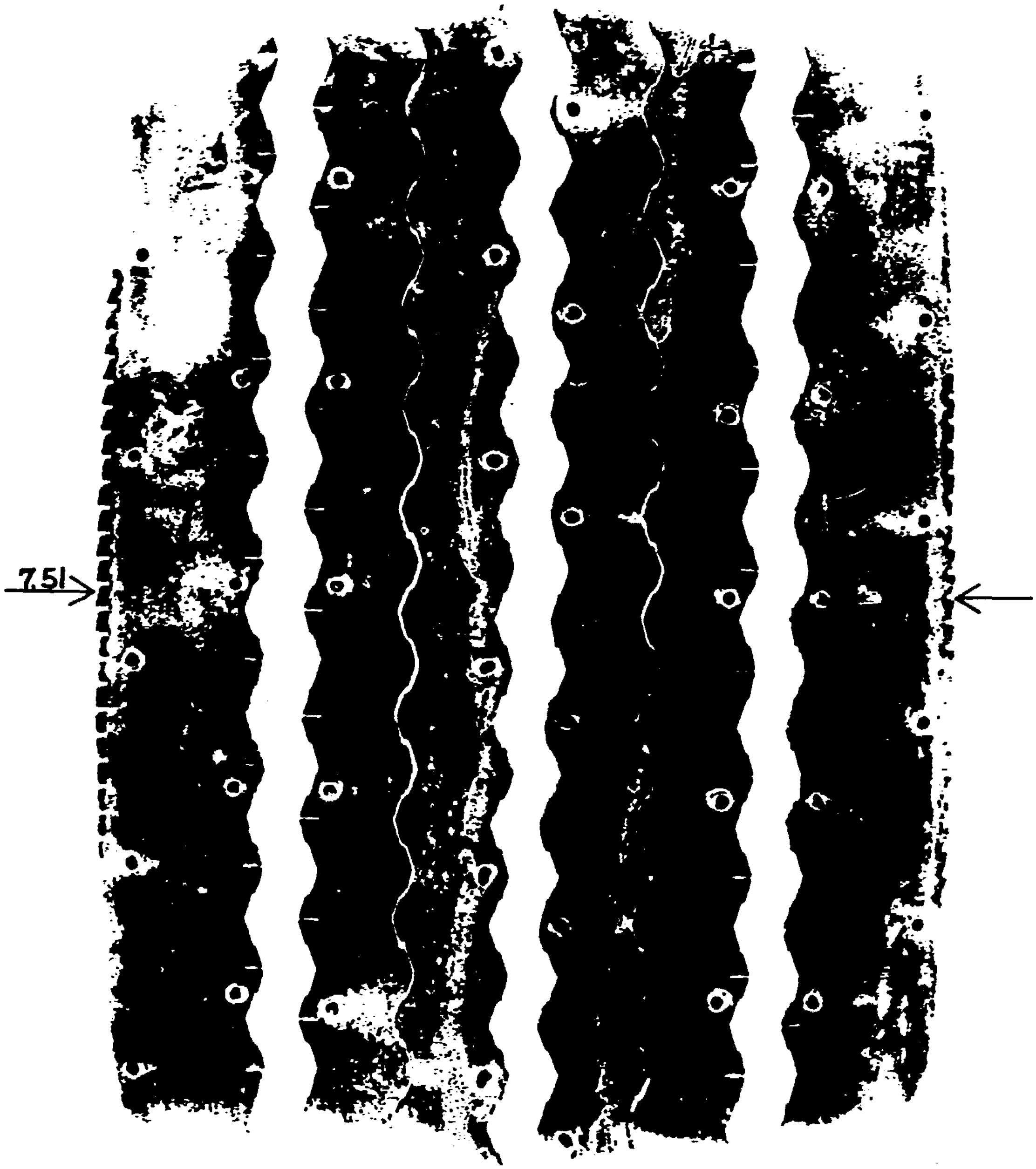
11R22.5 LRG




(1) SHOULDER

(2) INTERMEDIATE

(3) TREAD CENTER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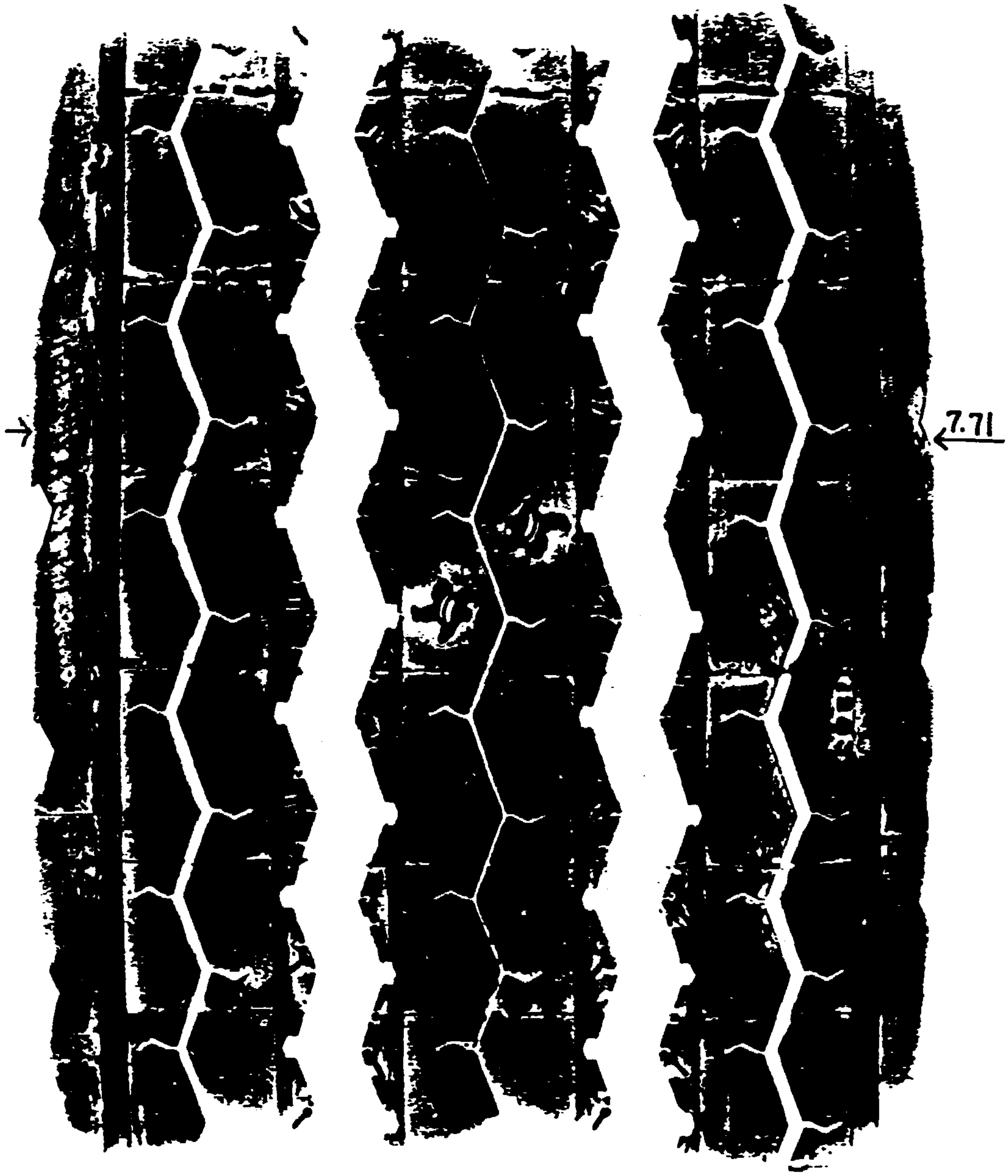
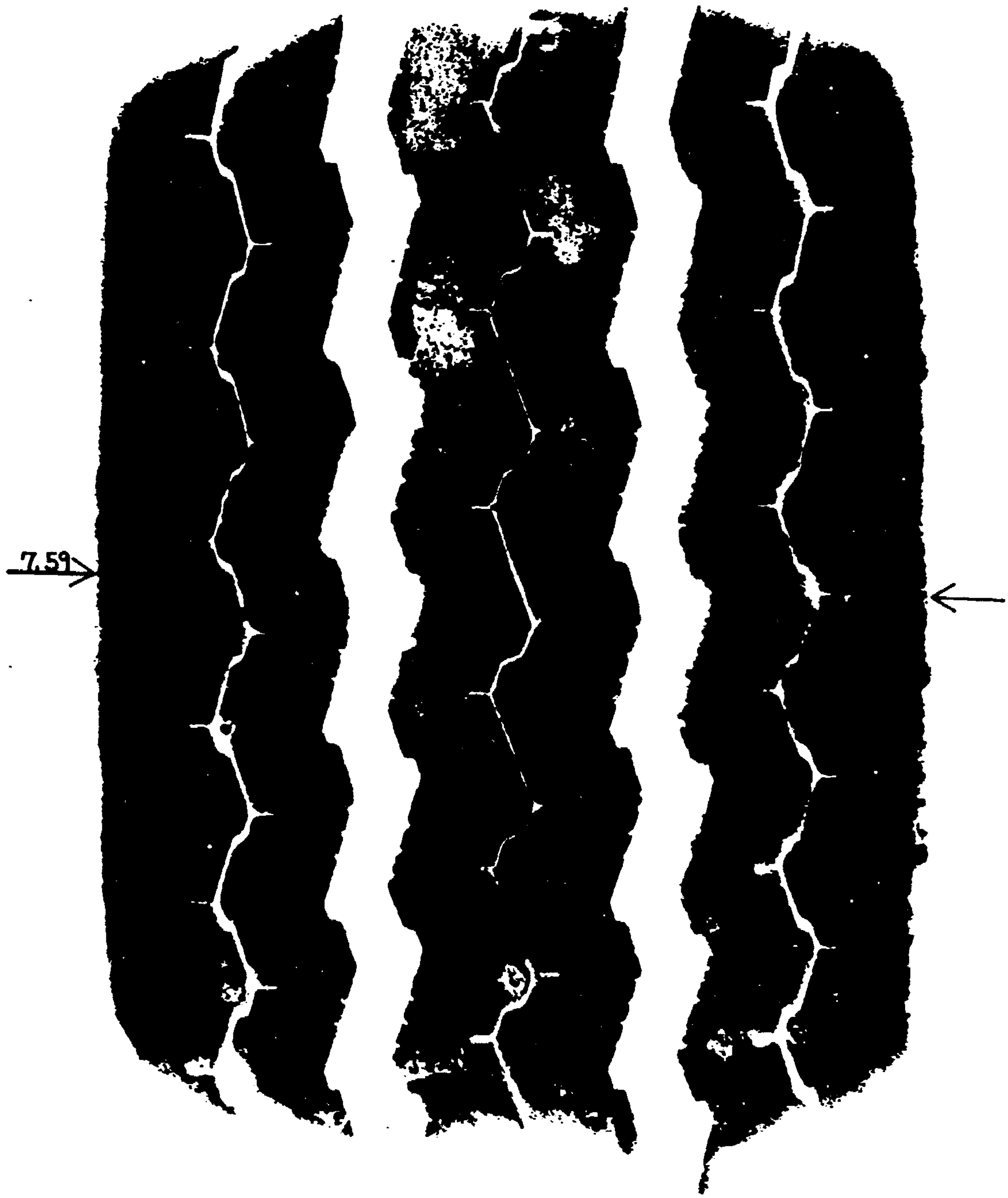
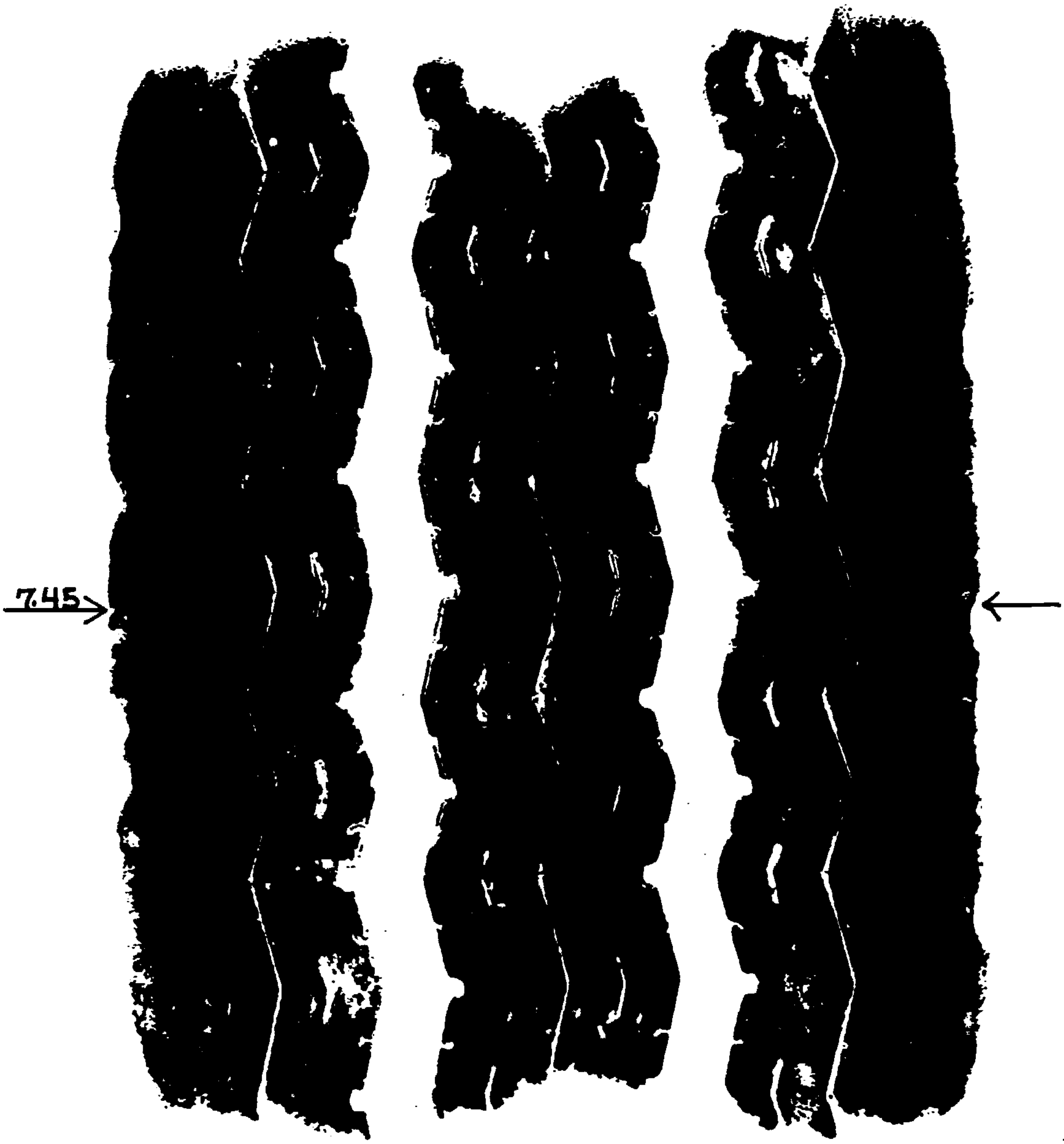

7.71

FIRESTONE
7368-T

11R24.5

Smithers Scientific Services, Inc.
December 31, 1984

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# APPENDIX B
## SINGLE AXLE DATA BASE

This appendix contains the data base generated for the 33 AASHO Road Test single axle (Lane 1) sections considered in this study. The following should be used to interpret the coded information.

The beginning of each section starts with a single line identified by the Section Number in the first 3 columns. The Section Number is followed sequentially by the Loop Number, the number of seasons encountered before failure, the thicknesses (in inches) of AC surface, base and subbase, the trailing dual-tired single axle load (in pounds), the steering axle load (in pounds) and the number of trailing dual-tired single axle load repetitions sustained before failure ($p_t$ = 2.5) was reached. Subsequent lines within each section are coded as follows:

Season Number (1 = spring, 2 = summer, 3 = fall, 4 = winter),
Target deflection (inches)
Predicted deflection corresponding to assigned material properties
Asphalt concrete elastic modulus (psi)
Base modulus (psi)
Subbase modulus (psi)
Roadbed soil modulus (psi)
Roadbed soil deviator stress (psi) due to wheel load
Roadbed soil deviator stress (psi) due to wheel load and overburden
Roadbed soil vertical strain (compressive, $10^{-3}$ in/in)
Roadbed soil vertical stress (compressive, psi)
Asphalt concrete tensile strain ($10^{-3}$ in/in)
Asphalt concrete tensile stress (psi)
Asphalt concrete shear strain ($10^{-3}$ in/in)
Asphalt concrete shear stress (psi)
Number of load repetitions sustained

Note that for each season, there are two rows of data. The first row in a season represents the trailing dual tired single axle load; the second row represents the steering axle load.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 111 3 10 | | | | 2.0 | 6.0 | 8.0 | | | 12000. | | 4000. | | | 621000. | |
| 3 | .025 | .025 | 450000. | 23985. | 13885. | 6221. | 4.12 | 4.33 | .6352 | 4.12 | .3606 | 207.6 | .7005 | 121.2 | 5200. |
| 3 | .013 | .014 | 450000. | 19562. | 12420. | 6194. | 1.83 | 2.03 | .2950 | 1.85 | .3274 | 199.7 | .6495 | 112.4 | 2600. |
| 4 | .001 | .005 | 1700000. | 50000. | 50000. | 50000. | 5.96 | 6.17 | .1142 | 6.26 | .1267 | 280.7 | .2365 | 154.6 | 64400. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.62 | 2.83 | .0526 | 2.74 | .0999 | 233.4 | .1949 | 127.4 | 32200. |
| 1 | .042 | .043 | 710000. | 15038. | 8518. | 3100. | 3.36 | 3.57 | 1.0472 | 3.36 | .3953 | 368.0 | .7169 | 195.8 | 28200. |
| 1 | .020 | .019 | 710000. | 13170. | 8809. | 3280. | 1.40 | 1.61 | .4275 | 1.43 | .2989 | 296.2 | .5722 | 156.2 | 14100. |
| 2 | .030 | .030 | 230000. | 22345. | 12218. | 5000. | 4.08 | 4.29 | .7803 | 4.08 | .4590 | 128.1 | .9669 | 85.5 | 172200. |
| 2 | .015 | .017 | 230000. | 19793. | 11413. | 5129. | 1.82 | 2.03 | .3547 | 1.83 | .4431 | 131.2 | .9314 | 82.4 | 86100. |
| 3 | .025 | .025 | 450000. | 23985. | 13885. | 6221. | 4.12 | 4.33 | .6352 | 4.12 | .3606 | 207.6 | .7005 | 121.2 | 82700. |
| 3 | .012 | .014 | 450000. | 19562. | 12420. | 6194. | 1.83 | 2.03 | .2950 | 1.85 | .3274 | 199.7 | .6495 | 112.4 | 41350. |
| 4 | .023 | .023 | 1700000. | 20318. | 13751. | 6587. | 3.68 | 3.88 | .5412 | 3.77 | .2097 | 468.7 | .3725 | 243.6 | 32600. |
| 4 | .010 | .010 | 1700000. | 15421. | 12614. | 7161. | 1.57 | 1.78 | .2205 | 1.66 | .1548 | 371.1 | .2923 | 191.1 | 16300. |
| 4 | .001 | .005 | 1700000. | 50000. | 50000. | 50000. | 5.96 | 6.17 | .1142 | 6.26 | .1267 | 280.7 | .2365 | 154.6 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.62 | 2.83 | .0526 | 2.74 | .0999 | 233.4 | .1949 | 127.4 | 24350. |
| 1 | .038 | .038 | 710000. | 16354. | 9346. | 3662. | 3.53 | 3.74 | .9305 | 3.53 | .3767 | 350.4 | .6864 | 187.4 | 46000. |
| 1 | .018 | .018 | 710000. | 13289. | 9220. | 3753. | 1.49 | 1.70 | .3973 | 1.53 | .2965 | 293.7 | .5679 | 155.1 | 23000. |
| 4 | .001 | .005 | 1700000. | 50000. | 50000. | 50000. | 5.96 | 6.17 | .1142 | 6.26 | .1267 | 280.7 | .2365 | 154.6 | 89900. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.62 | 2.83 | .0526 | 2.74 | .0999 | 233.4 | .1949 | 127.4 | 44950. |
| 1 | .060 | .060 | 710000. | 12602. | 6278. | 2000. | 2.94 | 3.15 | 1.4233 | 2.93 | .4441 | 414.3 | .7979 | 217.9 | 51100. |
| 1 | .034 | .020 | 710000. | 102880. | 5906. | 1466. | .48 | .69 | .3351 | .57 | .1039 | 88.9 | .2332 | 63.7 | 25550. |
| 155 3 12 | | | | 3.0 | 6.0 | 8.0 | | | 12000. | | 4000. | | | 637000. | |
| 3 | .033 | .033 | 450000. | 16553. | 10166. | 3873. | 3.03 | 3.26 | .7610 | 3.07 | .3512 | 203.7 | .6407 | 110.9 | 5200. |
| 3 | .016 | .014 | 450000. | 13721. | 10434. | 4035. | 1.22 | 1.44 | .3030 | 1.27 | .2526 | 157.4 | .4883 | 84.5 | 2600. |
| 4 | .001 | .005 | 1700000. | 50000. | 50000. | 50000. | 4.79 | 5.01 | .0931 | 5.17 | .0928 | 203.0 | .1687 | 110.3 | 64400. |
| 4 | .001 | .002 | 1700000. | 50000. | 50000. | 50000. | 1.97 | 2.19 | .0397 | 2.12 | .0649 | 152.5 | .1257 | 82.2 | 32200. |
| 1 | .042 | .042 | 710000. | 11560. | 7736. | 2714. | 2.51 | 2.74 | .9070 | 2.61 | .3179 | 295.2 | .5627 | 153.7 | 10100. |
| 1 | .018 | .016 | 710000. | 9571. | 8571. | 3167. | 1.01 | 1.23 | .3201 | 1.09 | .2030 | 202.8 | .3846 | 105.0 | 5050. |
| 1 | .057 | .057 | 710000. | 9549. | 5945. | 1776. | 2.14 | 2.37 | 1.1865 | 2.23 | .3514 | 327.5 | .6193 | 169.1 | 18100. |
| 1 | .024 | .019 | 710000. | 9119. | 7717. | 2384. | .88 | 1.11 | .3738 | .97 | .2082 | 208.2 | .3938 | 107.6 | 9050. |
| 2 | .048 | .048 | 230000. | 14032. | 7696. | 2500. | 2.93 | 3.16 | 1.1368 | 2.93 | .5357 | 156.2 | 1.0109 | 89.4 | 53400. |
| 2 | .020 | .019 | 230000. | 13735. | 9132. | 3176. | 1.26 | 1.49 | .3991 | 1.30 | .3853 | 119.4 | .7697 | 68.1 | 26700. |
| 2 | .038 | .038 | 230000. | 16119. | 9523. | 3500. | 3.26 | 3.48 | .9004 | 3.27 | .4880 | 141.1 | .9349 | 82.7 | 118800. |
| 2 | .017 | .016 | 230000. | 14374. | 10226. | 4196. | 1.42 | 1.65 | .3406 | 1.47 | .3753 | 115.9 | .7528 | 66.6 | 59400. |
| 3 | .034 | .034 | 450000. | 16196. | 9946. | 3718. | 2.99 | 3.22 | .7827 | 3.03 | .3552 | 206.2 | .6473 | 112.0 | 82700. |
| 3 | .016 | .011 | 450000. | 14955. | 12117. | 6224. | 1.46 | 1.68 | .2356 | 1.53 | .2423 | 150.5 | .4705 | 81.4 | 41350. |
| 4 | .037 | .037 | 1700000. | 11611. | 8142. | 2599. | 1.87 | 2.10 | .7137 | 2.02 | .1828 | 410.7 | .3198 | 209.1 | 32600. |
| 4 | .014 | .012 | 1700000. | 10183. | 9951. | 3643. | .77 | .99 | .2137 | .88 | .1026 | 247.3 | .1924 | 125.8 | 16300. |
| 4 | .001 | .005 | 1700000. | 50000. | 50000. | 50000. | 4.79 | 5.01 | .0931 | 5.17 | .0928 | 203.0 | .1687 | 110.3 | 48700. |
| 4 | .001 | .002 | 1700000. | 50000. | 50000. | 50000. | 1.97 | 2.19 | .0397 | 2.12 | .0649 | 152.5 | .1257 | 82.2 | 24350. |
| 1 | .025 | .025 | 710000. | 14649. | 11818. | 5825. | 3.30 | 3.52 | .5527 | 3.45 | .2741 | 252.9 | .4891 | 133.6 | 46000. |
| 1 | .010 | .014 | 710000. | 9210. | 9029. | 3856. | 1.10 | 1.33 | .2887 | 1.20 | .2024 | 202.2 | .3833 | 104.7 | 23000. |
| 4 | .001 | .005 | 1700000. | 50000. | 50000. | 50000. | 4.79 | 5.01 | .0931 | 5.17 | .0928 | 203.0 | .1687 | 110.3 | 89900. |
| 4 | .001 | .002 | 1700000. | 50000. | 50000. | 50000. | 1.97 | 2.19 | .0397 | 2.12 | .0649 | 152.5 | .1257 | 82.2 | 44950. |
| 1 | .073 | .073 | 710000. | 8234. | 4646. | 1277. | 1.89 | 2.12 | 1.4601 | 1.98 | .3813 | 356.6 | .6706 | 183.1 | 67100. |
| 1 | .040 | .034 | 710000. | 6893. | 5249. | 957. | .58 | .80 | .6153 | .66 | .2318 | 232.8 | .4364 | 119.2 | 33550. |
| 623 4 3 | | | | 3.0 | 6.0 | 8.0 | | | 18000. | | 6000. | | | 83000. | |
| 3 | .061 | .060 | 450000. | 16139. | 8290. | 2874. | 4.03 | 4.25 | 1.3649 | 4.06 | .4677 | 268.6 | .8429 | 145.9 | 5200. |
| 3 | .030 | .022 | 450000. | 15215. | 9673. | 3473. | 1.68 | 1.91 | .4855 | 1.72 | .3138 | 194.8 | .6094 | 105.5 | 2600. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 7.08 | 7.31 | .1380 | 7.67 | .1167 | 251.5 | .2104 | 137.5 | 64400. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.92 | 3.15 | .0589 | 3.15 | .0817 | 191.4 | .1587 | 103.8 | 32200. |
| 1 | .070 | .069 | 710000. | 11902. | 6858. | 2325. | 3.51 | 3.73 | 1.4793 | 3.62 | .4268 | 393.2 | .7499 | 204.8 | 13400. |
| 1 | .050 | .049 | 710000. | 7400. | 4729. | 986. | .88 | 1.10 | .8989 | .97 | .3059 | 306.9 | .5763 | 157.4 | 6700. |
| 601 4 10 | | | | 3.0 | 6.0 | 12.0 | | | 18000. | | 6000. | | | 621000. | |
| 3 | .041 | .041 | 450000. | 20933. | 12727. | 4139. | 3.31 | 3.59 | .7834 | 3.32 | .3821 | 216.4 | .7022 | 121.5 | 5200. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | .020 | .015 | 450000. | 18748. | 14188. | 6594. | 1.57 | 1.84 | .2380 | 1.61 | .2784 | 171.0 | .5478 | 94.8 | 2600. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 5.57 | 5.85 | .1092 | 5.89 | .1166 | 251.2 | .2102 | 137.4 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.17 | 2.45 | .0437 | 2.30 | .0816 | 191.3 | .1586 | 103.7 | 34400. |
| 1 | .055 | .055 | 710000. | 14444. | 9047. | 2730. | 2.81 | 3.09 | 1.0121 | 2.85 | .3742 | 342.5 | .6610 | 180.5 | 28000. |
| 1 | .033 | .026 | 710000. | 10620. | 8606. | 2240. | .96 | 1.24 | .4319 | 1.02 | .2570 | 256.2 | .4883 | 133.4 | 14000. |
| 2 | .040 | .039 | 230000. | 22367. | 13541. | 4700. | 3.73 | 4.01 | .7742 | 3.74 | .4617 | 127.0 | .9182 | 81.2 | 168000. |
| 2 | .025 | .023 | 230000. | 16320. | 11129. | 3438. | 1.32 | 1.60 | .3860 | 1.36 | .4301 | 131.0 | .8764 | 77.5 | 84000. |
| 3 | .034 | .034 | 450000. | 23195. | 14569. | 5458. | 3.65 | 3.92 | .6529 | 3.66 | .3567 | 201.0 | .6614 | 114.5 | 82700. |
| 3 | .022 | .016 | 450000. | 18112. | 13227. | 5331. | 1.43 | 1.71 | .2696 | 1.47 | .2837 | 174.6 | .5571 | 96.4 | 41350. |
| 4 | .036 | .036 | 1700000. | 17714. | 12041. | 4196. | 2.68 | 2.95 | .6306 | 2.78 | .2047 | 453.3 | .3570 | 233.5 | 32600. |
| 4 | .021 | .014 | 1700000. | 13248. | 11992. | 4519. | 1.01 | 1.29 | .2263 | 1.10 | .1267 | 304.7 | .2385 | 156.0 | 16300. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 5.57 | 5.85 | .1092 | 5.89 | .1166 | 251.2 | .2102 | 137.4 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.17 | 2.45 | .0437 | 2.30 | .0816 | 191.3 | .1586 | 103.7 | 24350. |
| 1 | .040 | .040 | 710000. | 17279. | 11779. | 4362. | 3.32 | 3.59 | .7463 | 3.37 | .3351 | 305.0 | .5958 | 162.7 | 46000. |
| 1 | .028 | .028 | 710000. | 10421. | 8343. | 1974. | .90 | 1.18 | .4606 | .97 | .2595 | 258.8 | .4928 | 134.6 | 23000. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 5.57 | 5.85 | .1092 | 5.89 | .1166 | 251.2 | .2102 | 137.4 | 89900. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.17 | 2.45 | .0437 | 2.30 | .0816 | 191.3 | .1586 | 103.7 | 44950. |
| 1 | .051 | .051 | 710000. | 15177. | 9738. | 3043. | 2.91 | 3.19 | .9408 | 2.96 | .3632 | 332.0 | .6427 | 175.5 | 51100. |
| 1 | .037 | .028 | 710000. | 10395. | 8206. | 1898. | .89 | 1.16 | .4703 | .95 | .2603 | 259.6 | .4943 | 135.0 | 25550. |
| 577 | 4 | 12 | 4.0 | 6.0 | 8.0 | | | 18000. | | 6000. | | | | 760000. | |
| 3 | .045 | .045 | 450000. | 15338. | 9926. | 3722. | 3.59 | 3.83 | .9449 | 3.71 | .3729 | 214.7 | .6666 | 115.4 | 5200. |
| 3 | .024 | .019 | 450000. | 11987. | 9648. | 3564. | 1.33 | 1.57 | .3758 | 1.42 | .2422 | 151.8 | .4649 | 80.5 | 2600. |
| 4 | .001 | .006 | 1700000. | 50000. | 50000. | 50000. | 5.69 | 5.93 | .1119 | 6.30 | .0918 | 197.9 | .1642 | 107.4 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.26 | 2.50 | .0456 | 2.48 | .0585 | 137.7 | .1133 | 74.1 | 34400. |
| 1 | .060 | .060 | 710000. | 10195. | 7014. | 2336. | 2.66 | 2.90 | 1.1289 | 2.86 | .3401 | 314.7 | .5950 | 162.5 | 23800. |
| 1 | .038 | .025 | 710000. | 7602. | 7224. | 2021. | .87 | 1.11 | .4379 | 1.00 | .1972 | 197.8 | .3716 | 101.5 | 11900. |
| 2 | .055 | .055 | 230000. | 14574. | 8941. | 3203. | 3.96 | 4.20 | 1.2075 | 4.03 | .5366 | 154.0 | .9910 | 87.7 | 70800. |
| 2 | .036 | .027 | 230000. | 11167. | 8211. | 2582. | 1.41 | 1.65 | .5467 | 1.47 | .3886 | 122.1 | .7634 | 67.5 | 35400. |
| 2 | .045 | .045 | 230000. | 16944. | 10508. | 4193. | 4.31 | 4.55 | 1.0022 | 4.39 | .4888 | 138.9 | .9146 | 80.9 | 101400. |
| 2 | .032 | .023 | 230000. | 11922. | 9265. | 3349. | 1.58 | 1.82 | .4724 | 1.64 | .3751 | 117.4 | .7403 | 65.5 | 50700. |
| 3 | .036 | .036 | 450000. | 17737. | 12066. | 5087. | 3.99 | 4.23 | .7689 | 4.13 | .3421 | 195.6 | .6156 | 106.5 | 82700. |
| 3 | .024 | .020 | 450000. | 11359. | 9429. | 3196. | 1.26 | 1.50 | .3986 | 1.36 | .2463 | 154.6 | .4722 | 81.7 | 41350. |
| 4 | .039 | .039 | 1700000. | 12324. | 9428. | 3293. | 2.19 | 2.43 | .6617 | 2.44 | .1768 | 391.1 | .3045 | 199.1 | 32600. |
| 4 | .020 | .016 | 1700000. | 8605. | 9258. | 2903. | .69 | .93 | .2442 | .84 | .0951 | 229.5 | .1780 | 116.4 | 16300. |
| 4 | .001 | .006 | 1700000. | 50000. | 50000. | 50000. | 5.69 | 5.93 | .1119 | 6.30 | .0918 | 197.9 | .1642 | 107.4 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.26 | 2.50 | .0456 | 2.48 | .0585 | 137.7 | .1133 | 74.1 | 24350. |
| 1 | .050 | .050 | 710000. | 11538. | 8245. | 3018. | 2.95 | 3.19 | .9676 | 3.16 | .3185 | 294.5 | .5596 | 152.8 | 46000. |
| 1 | .028 | .013 | 710000. | 10342. | 10749. | 5811. | 1.43 | 1.67 | .2481 | 1.58 | .1748 | 174.4 | .3316 | 90.6 | 23000. |
| 4 | .001 | .006 | 1700000. | 50000. | 50000. | 50000. | 5.69 | 5.93 | .1119 | 6.30 | .0918 | 197.9 | .1642 | 107.4 | 89900. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.26 | 2.50 | .0456 | 2.48 | .0585 | 137.7 | .1133 | 74.1 | 44950. |
| 1 | .072 | .072 | 710000. | 9008. | 5963. | 1813. | 2.39 | 2.63 | 1.3091 | 2.58 | .3631 | 335.8 | .6321 | 172.6 | 99300. |
| 1 | .044 | .030 | 710000. | 7206. | 6563. | 1543. | .76 | 1.00 | .5013 | .88 | .2027 | 203.5 | .3816 | 104.2 | 49650. |
| 2 | .067 | .066 | 230000. | 13066. | 7328. | 2485. | 3.66 | 3.90 | 1.4374 | 3.71 | .5811 | 168.1 | 1.0634 | 94.1 | 90800. |
| 2 | .039 | .022 | 230000. | 12884. | 9337. | 3399. | 1.57 | 1.81 | .4638 | 1.63 | .3660 | 114.3 | .7252 | 64.1 | 45400. |
| 625 | 4 | 11 | 4.0 | 6.0 | 12.0 | | | 18000. | | 6000. | | | | 679000. | |
| 3 | .040 | .040 | 450000. | 17432. | 11708. | 3830. | 2.78 | 3.07 | .7133 | 2.83 | .3415 | 195.2 | .6143 | 106.3 | 5200. |
| 3 | .023 | .018 | 450000. | 12822. | 11034. | 3463. | 1.00 | 1.29 | .2893 | 1.06 | .2323 | 145.1 | .4476 | 77.5 | 2600. |
| 4 | .001 | .006 | 1700000. | 50000. | 50000. | 50000. | 4.61 | 4.90 | .0909 | 4.97 | .0917 | 197.7 | .1641 | 107.3 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.74 | 2.03 | .0351 | 1.87 | .0585 | 137.6 | .1132 | 74.0 | 34400. |
| 1 | .050 | .050 | 710000. | 12321. | 8830. | 2666. | 2.24 | 2.53 | .8324 | 2.34 | .3051 | 281.4 | .5368 | 146.6 | 28000. |
| 1 | .033 | .022 | 710000. | 8709. | 8677. | 2275. | .75 | 1.04 | .3317 | .83 | .1859 | 186.1 | .3515 | 96.0 | 14000. |
| 2 | .038 | .038 | 230000. | 19300. | 12743. | 4608. | 3.33 | 3.62 | .7076 | 3.36 | .4401 | 123.4 | .8366 | 74.0 | 168000. |
| 2 | .024 | .023 | 230000. | 12733. | 10122. | 2773. | 1.04 | 1.33 | .3781 | 1.10 | .3608 | 112.4 | .7160 | 63.3 | 84000. |
| 3 | .032 | .032 | 450000. | 19723. | 13901. | 5368. | 3.14 | 3.43 | .5754 | 3.20 | .3167 | 179.9 | .5738 | 99.3 | 82700. |
| 3 | .023 | .019 | 450000. | 12530. | 10901. | 3190. | .96 | 1.25 | .3021 | 1.02 | .2341 | 146.4 | .4508 | 78.0 | 41350. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | .035 | .035 | 1700000. | 13995. | 10933. | 3523. | 1.89 | 2.18 | .5342 | 2.05 | .1648 | 364.8 | .2851 | 186.4 | 32600. |
| 4 | .024 | .020 | 1700000. | 8629. | 9305. | 1883. | .49 | .78 | .2646 | .59 | .0956 | 230.7 | .1789 | 117.0 | 16300. |
| 4 | .001 | .006 | 1700000. | 50000. | 50000. | 50000. | 4.61 | 4.90 | .0909 | 4.97 | .0917 | 197.7 | .1641 | 107.3 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.74 | 2.03 | .0351 | 1.87 | .0585 | 137.6 | .1132 | 74.0 | 24350. |
| 1 | .040 | .040 | 710000. | 13809. | 10557. | 3729. | 2.57 | 2.86 | .6805 | 2.68 | .2854 | 262.1 | .5031 | 137.4 | 46000. |
| 1 | .026 | .017 | 710000. | 9385. | 9687. | 3416. | .90 | 1.19 | .2668 | .99 | .1798 | 179.7 | .3406 | 93.0 | 23000. |
| 4 | .001 | .006 | 1700000. | 50000. | 50000. | 50000. | 4.61 | 4.90 | .0909 | 4.97 | .0917 | 197.7 | .1641 | 107.3 | 89900. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.74 | 2.03 | .0351 | 1.87 | .0585 | 137.6 | .1132 | 74.0 | 44950. |
| 1 | .063 | .063 | 710000. | 10673. | 7449. | 1917. | 1.95 | 2.241.0085 | | 2.05 | .3279 | 303.4 | .5752 | 157.1 | 99300. |
| 1 | .042 | .028 | 710000. | 8141. | 7725. | 1544. | .62 | .91 | .4068 | .71 | .1922 | 192.6 | .3628 | 99.1 | 49650. |
| 2 | .065 | .065 | 230000. | 14457. | 8330. | 2126. | 2.52 | 2.811.1654 | | 2.54 | .5367 | 154.0 | .9907 | 87.6 | 9800. |
| 2 | .042 | .019 | 230000. | 12240. | 89100. | 2068. | .38 | .67 | .1912 | .53 | .3155 | 96.6 | .6392 | 56.5 | 4900. |
| 419 | 5 | 3 | 3.0 | 6.0 | 8.0 | | | 22400. | | 6000. | | | | 73000. | |
| 3 | .060 | .060 | 450000. | 19300. | 10264. | 3810. | 5.37 | 5.591.3716 | | 5.42 | .4698 | 265.6 | .8511 | 147.3 | 5200. |
| 3 | .037 | .035 | 450000. | 11565. | 6667. | 1722. | 1.25 | 1.48 | .7316 | 1.30 | .3570 | 223.6 | .6854 | 118.6 | 2600. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 8.73 | 8.95 | .1701 | 9.47 | .1313 | 279.5 | .2348 | 153.5 | 64400. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.92 | 3.15 | .0589 | 3.15 | .0817 | 191.4 | .1587 | 103.8 | 32200. |
| 1 | .085 | .085 | 710000. | 12626. | 6750. | 2350. | 4.34 | 4.571.8112 | | 4.48 | .4995 | 445.5 | .8516 | 232.6 | 3400. |
| 1 | .059 | .046 | 710000. | 6723. | 4077. | 768. | .78 | 1.001.0285 | | .87 | .3185 | 319.9 | .5991 | 163.6 | 1700. |
| 487 | 5 | 3 | 3.0 | 6.0 | 12.0 | | | 22400. | | 6000. | | | | 77000. | |
| 3 | .045 | .045 | 450000. | 23880. | 13991. | 4843. | 4.26 | 4.53 | .8599 | 4.27 | .3939 | 219.5 | .7269 | 125.8 | 5200. |
| 3 | .020 | .021 | 450000. | 15641. | 11267. | 3368. | 1.19 | 1.46 | .3537 | 1.23 | .3028 | 187.4 | .5900 | 102.1 | 2600. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 6.88 | 7.15 | .1349 | 7.29 | .1312 | 279.2 | .2346 | 153.4 | 64400. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.17 | 2.45 | .0437 | 2.30 | .0816 | 191.3 | .1586 | 103.7 | 32200. |
| 1 | .065 | .063 | 710000. | 15980. | 9604. | 3000. | 3.56 | 3.841.1673 | | 3.61 | .4184 | 372.5 | .7235 | 197.6 | 7400. |
| 1 | .037 | .039 | 710000. | 9334. | 6690. | 1128. | .69 | .97 | .6218 | .76 | .2749 | 274.8 | .5204 | 142.1 | 3700. |
| 471 | 5 | 3 | 3.0 | 9.0 | 8.0 | | | 22400. | | 6000. | | | | 79000. | |
| 3 | .055 | .055 | 450000. | 19335. | 9434. | 3775. | 4.31 | 4.571.1135 | | 4.26 | .4403 | 247.7 | .8024 | 138.9 | 5200. |
| 3 | .034 | .029 | 450000. | 12875. | 7566. | 2004. | 1.04 | 1.30 | .5188 | 1.07 | .3278 | 204.2 | .6338 | 109.7 | 2600. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 7.22 | 7.49 | .1415 | 7.71 | .1309 | 278.7 | .2342 | 153.1 | 64400. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.31 | 2.57 | .0465 | 2.46 | .0815 | 191.1 | .1585 | 103.6 | 32200. |
| 1 | .095 | .095 | 710000. | 11473. | 5249. | 1798. | 3.26 | 3.521.7793 | | 3.26 | .5002 | 446.1 | .8526 | 232.8 | 9400. |
| 1 | .050 | .038 | 710000. | 8443. | 5769. | 1259. | .80 | 1.07 | .6435 | .87 | .2801 | 280.2 | .5297 | 144.6 | 4700. |
| 455 | 5 | 4 | 4.0 | 6.0 | 8.0 | | | 22400. | | 6000. | | | | 96600. | |
| 3 | .050 | .050 | 450000. | 17371. | 10922. | 4281. | 4.62 | 4.861.0582 | | 4.77 | .4143 | 231.3 | .7257 | 125.6 | 5200. |
| 3 | .031 | .028 | 450000. | 9944. | 7555. | 1912. | .99 | 1.23 | .5229 | 1.08 | .2627 | 165.4 | .5009 | 86.7 | 2600. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 7.03 | 7.27 | .1382 | 7.79 | .1078 | 225.4 | .1876 | 122.7 | 64400. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.26 | 2.50 | .0456 | 2.48 | .0585 | 137.7 | .1133 | 74.1 | 32200. |
| 1 | .075 | .073 | 710000. | 10700. | 7060. | 2400. | 3.33 | 3.571.3745 | | 3.56 | .4087 | 364.4 | .6900 | 188.4 | 10100. |
| 1 | .040 | .036 | 710000. | 6755. | 5977. | 1216. | .68 | .92 | .5652 | .79 | .2083 | 209.3 | .3918 | 107.0 | 5050. |
| 1 | .105 | .103 | 710000. | 8445. | 4975. | 1500. | 2.74 | 2.981.8157 | | 2.96 | .4653 | 416.8 | .7824 | 213.6 | 16900. |
| 1 | .052 | .043 | 710000. | 6331. | 5336. | 945. | .60 | .84 | .6428 | .71 | .2148 | 216.0 | .4034 | 110.1 | 8450. |
| 453 | 5 | 3 | 4.0 | 6.0 | 8.0 | | | 22400. | | 6000. | | | | 90600. | |
| 3 | .045 | .045 | 450000. | 18742. | 11944. | 4947. | 4.85 | 5.09 | .9604 | 5.01 | .3949 | 220.1 | .6957 | 120.4 | 5200. |
| 3 | .030 | .028 | 450000. | 10020. | 7605. | 1940. | 1.00 | 1.24 | .5188 | 1.08 | .2620 | 165.0 | .4997 | 86.5 | 2600. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 7.03 | 7.27 | .1382 | 7.79 | .1078 | 225.4 | .1876 | 122.7 | 64400. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.26 | 2.50 | .0456 | 2.48 | .0585 | 137.7 | .1133 | 74.1 | 32200. |
| 1 | .075 | .073 | 710000. | 10700. | 7060. | 2400. | 3.33 | 3.571.3745 | | 3.56 | .4087 | 364.4 | .6900 | 188.4 | 21000. |
| 1 | .039 | .033 | 710000. | 6977. | 6262. | 1361. | .71 | .95 | .5339 | .83 | .2056 | 206.5 | .3867 | 105.6 | 10500. |
| 425 | 5 | 9 | 4.0 | 6.0 | 12.0 | | | 22400. | | 6000. | | | | 505000. | |
| 3 | .040 | .040 | 450000. | 20959. | 13938. | 5177. | 3.79 | 4.08 | .7193 | 3.85 | .3606 | 200.1 | .6424 | 111.2 | 5200. |
| 3 | .024 | .022 | 450000. | 11962. | 9953. | 2374. | .83 | 1.12 | .3532 | .90 | .2400 | 150.3 | .4611 | 79.8 | 2600. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.69 | 5.98 | .1124 | 6.15 | .1077 | 225.2 | .1875 | 122.6 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.74 | 2.03 | .0351 | 1.87 | .0585 | 137.6 | .1132 | 74.0 | 34400. |
| 1 | .055 | .055 | 710000. | 13990. | 9679. | 3144. | 2.95 | 3.24 | .9284 | 3.07 | .3508 | 310.8 | .5964 | 162.9 | 28000. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .034 | .025 | 710000. | 8395. | 8256. | 1868. | .68 | .97 | .3677 | .77 | .1890 | 189.2 | .3570 | 97.5 | 14000. |
| 2 | .050 | .050 | 230000. | 19656. | 12388. | 4128. | 3.90 | 4.19 | .9266 | 3.94 | .4925 | 136.6 | .9327 | 82.5 | 168000. |
| 2 | .033 | .024 | 230000. | 12619. | 9937. | 2634. | 1.02 | 1.31 | .3889 | 1.07 | .3626 | 113.1 | .7190 | 63.6 | 84000. |
| 3 | .045 | .045 | 450000. | 19514. | 12740. | 4350. | 3.56 | 3.85 | .8049 | 3.62 | .3780 | 210.1 | .6690 | 115.8 | 82700. |
| 3 | .024 | .015 | 450000. | 14488. | 12676. | 4956. | 1.16 | 1.45 | .2346 | 1.22 | .2217 | 138.0 | .4293 | 74.3 | 41350. |
| 4 | .040 | .040 | 1700000. | 15562. | 11658. | 3953. | 2.46 | 2.75 | .6184 | 2.65 | .1945 | 416.5 | .3262 | 213.3 | 32600. |
| 4 | .020 | .013 | 1700000. | 10386. | 11196. | 3860. | .68 | .97 | .1789 | .79 | .0896 | 215.9 | .1680 | 109.9 | 16300. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.69 | 5.98 | .1124 | 6.15 | .1077 | 225.2 | .1875 | 122.6 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.74 | 2.03 | .0351 | 1.87 | .0585 | 137.6 | .1132 | 74.0 | 24350. |
| 1 | .050 | .050 | 710000. | 14699. | 10515. | 3617. | 3.12 | 3.41 | .8515 | 3.24 | .3396 | 300.5 | .5784 | 157.9 | 46000. |
| 1 | .025 | .016 | 710000. | 10036. | 9985. | 3600. | .92 | 1.21 | .2579 | 1.01 | .1773 | 177.0 | .3362 | 91.8 | 23000. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.69 | 5.98 | .1124 | 6.15 | .1077 | 225.2 | .1875 | 122.6 | 25000. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.74 | 2.03 | .0351 | 1.87 | .0585 | 137.6 | .1132 | 74.0 | 12500. |
| 417 | 5 | 4 | 4.0 | 9.0 | 8.0 | | | 22400. | | 6000. | | | | | 168000. |
| 3 | .050 | .050 | 450000. | 17174. | 9823. | 3885. | 3.70 | 3.98 | .9350 | 3.73 | .3992 | 222.5 | .7020 | 121.5 | 5200. |
| 3 | .028 | .021 | 450000. | 11229. | 9272. | 2813. | .98 | 1.25 | .3496 | 1.04 | .2426 | 152.1 | .4655 | 80.6 | 2600. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.94 | 6.22 | .1173 | 6.47 | .1075 | 224.9 | .1872 | 122.4 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.84 | 2.11 | .0370 | 1.99 | .0585 | 137.5 | .1131 | 74.0 | 34400. |
| 1 | .075 | .075 | 710000. | 10504. | 6375. | 2108. | 2.71 | 2.99 | 1.2725 | 2.81 | .3979 | 354.3 | .6722 | 183.6 | 28000. |
| 1 | .045 | .032 | 710000. | 7200. | 6605. | 1327. | .61 | .89 | .4680 | .70 | .1995 | 200.2 | .3759 | 102.6 | 14000. |
| 2 | .090 | .091 | 230000. | 12470. | 5624. | 1900. | 3.33 | 3.61 | 1.7172 | 3.30 | .6622 | 188.1 | 1.1954 | 105.7 | 66000. |
| 2 | .050 | .030 | 230000. | 10882. | 7256. | 1873. | .96 | 1.24 | .5151 | 1.00 | .3858 | 121.2 | .7585 | 67.1 | 33000. |
| 477 | 5 | 12 | 4.0 | 9.0 | 12.0 | | | 22400. | | 6000. | | | | | 1099000. |
| 3 | .035 | .034 | 450000. | 21670. | 14253. | 5976. | 3.34 | 3.67 | .5504 | 3.36 | .3380 | 187.1 | .6078 | 105.2 | 5200. |
| 3 | .019 | .017 | 450000. | 12662. | 11455. | 3677. | .86 | 1.18 | .2343 | .91 | .2287 | 142.8 | .4412 | 76.4 | 2600. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.85 | 5.18 | .0960 | 5.18 | .1074 | 224.7 | .1871 | 122.3 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.44 | 1.77 | .0290 | 1.54 | .0584 | 137.4 | .1131 | 74.0 | 34400. |
| 1 | .045 | .045 | 710000. | 14999. | 10692. | 3996. | 2.77 | 3.10 | .6860 | 2.84 | .3230 | 285.1 | .5515 | 150.6 | 28000. |
| 1 | .028 | .018 | 710000. | 8796. | 9498. | 2922. | .72 | 1.05 | .2504 | .80 | .1811 | 181.1 | .3428 | 93.6 | 14000. |
| 2 | .040 | .040 | 230000. | 21547. | 13287. | 5362. | 3.52 | 3.85 | .6454 | 3.53 | .4436 | 121.1 | .8555 | 75.7 | 168000. |
| 2 | .026 | .021 | 230000. | 12703. | 10382. | 3008. | .89 | 1.22 | .2968 | .93 | .3540 | 110.1 | .7043 | 62.3 | 84000. |
| 3 | .035 | .034 | 450000. | 21670. | 14253. | 5976. | 3.34 | 3.67 | .5504 | 3.36 | .3380 | 187.1 | .6078 | 105.2 | 82700. |
| 3 | .020 | .019 | 450000. | 12216. | 10757. | 2878. | .77 | 1.09 | .2679 | .82 | .2324 | 145.2 | .4477 | 77.5 | 41350. |
| 4 | .040 | .039 | 1700000. | 15347. | 11100. | 3740. | 2.10 | 2.43 | .5597 | 2.22 | .1904 | 407.2 | .3194 | 208.8 | 32600. |
| 4 | .023 | .013 | 1700000. | 9974. | 11084. | 3585. | .58 | .91 | .1654 | .67 | .0896 | 216.0 | .1681 | 109.9 | 16300. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.85 | 5.18 | .0960 | 5.18 | .1074 | 224.7 | .1871 | 122.3 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.44 | 1.77 | .0290 | 1.54 | .0584 | 137.4 | .1131 | 74.0 | 24350. |
| 1 | .040 | .039 | 710000. | 15836. | 11738. | 4838. | 2.98 | 3.31 | .6101 | 3.06 | .3121 | 275.1 | .5343 | 145.9 | 46000. |
| 1 | .027 | .020 | 710000. | 8658. | 9204. | 2454. | .67 | 1.00 | .2751 | .74 | .1828 | 182.8 | .3457 | 94.4 | 23000. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.85 | 5.18 | .0960 | 5.18 | .1074 | 224.7 | .1871 | 122.3 | 89900. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.44 | 1.77 | .0290 | 1.54 | .0584 | 137.4 | .1131 | 74.0 | 44950. |
| 1 | .050 | .050 | 710000. | 14403. | 9768. | 3384. | 2.59 | 2.92 | .7583 | 2.65 | .3324 | 293.8 | .5667 | 154.7 | 99300. |
| 1 | .029 | .020 | 710000. | 8651. | 9158. | 2505. | .68 | 1.00 | .2724 | .75 | .1827 | 182.8 | .3457 | 94.4 | 49650. |
| 2 | .035 | .035 | 230000. | 22613. | 14812. | 6694. | 3.82 | 4.15 | .5601 | 3.84 | .4276 | 116.0 | .8306 | 73.5 | 314600. |
| 2 | .022 | .017 | 230000. | 13318. | 11691. | 4933. | 1.11 | 1.44 | .2263 | 1.16 | .3454 | 107.1 | .6900 | 61.0 | 157300. |
| 3 | .030 | .030 | 450000. | 23032. | 16088. | 7741. | 3.67 | 4.00 | .4668 | 3.71 | .3232 | 178.5 | .5853 | 101.3 | 115200. |
| 3 | .018 | .013 | 450000. | 13331. | 12816. | 6210. | 1.08 | 1.41 | .1746 | 1.14 | .2228 | 138.8 | .4309 | 74.6 | 57600. |
| 469 | 5 | 10 | 5.0 | 6.0 | 8.0 | | | 22400. | | 6000. | | | | | 560000. |
| 3 | .050 | .050 | 450000. | 14195. | 9831. | 3711. | 3.60 | 3.85 | .9572 | 3.80 | .3763 | 210.4 | .6468 | 111.9 | 5200. |
| 3 | .028 | .019 | 450000. | 9701. | 9394. | 2946. | .94 | 1.19 | .3212 | 1.05 | .1893 | 119.3 | .3608 | 62.5 | 2600. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 5.72 | 5.98 | .1134 | 6.46 | .0883 | 184.1 | .1524 | 99.6 | 68800. |
| 4 | .001 | .002 | 1700000. | 50000. | 50000. | 50000. | 1.77 | 2.03 | .0359 | 1.98 | .0436 | 102.7 | .0842 | 55.0 | 34400. |
| 1 | .060 | .060 | 710000. | 10001. | 7638. | 2598. | 2.64 | 2.90 | 1.0123 | 2.91 | .3240 | 289.8 | .5467 | 149.3 | 28000. |
| 1 | .031 | .019 | 710000. | 7243. | 8171. | 2481. | .71 | .96 | .2900 | .84 | .1413 | 141.8 | .2660 | 72.6 | 14000. |
| 2 | .070 | .070 | 230000. | 12439. | 7744. | 2700. | 3.90 | 4.15 | 1.4186 | 4.02 | .5834 | 164.9 | 1.0296 | 91.1 | 49200. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | .040 | .030 | 230000. | 8888. | 7266. | 1812. | .95 | 1.21 | .5316 | 1.04 | .3202 | 101.9 | .6200 | 54.8 | 24600. |
| 2 | .060 | .060 | 230000. | 13920. | 9081. | 3400. | 4.23 | 4.48 | 1.2206 | 4.36 | .5410 | 152.1 | .9643 | 85.3 | 118800. |
| 2 | .035 | .023 | 230000. | 9937. | 8734. | 2819. | 1.18 | 1.43 | .4213 | 1.27 | .3029 | 95.9 | .5903 | 52.2 | 59400. |
| 3 | .045 | .045 | 450000. | 15308. | 10922. | 4304. | 3.80 | 4.06 | .8717 | 4.01 | .3602 | 200.9 | .6213 | 107.5 | 82700. |
| 3 | .024 | .018 | 450000. | 9784. | 9484. | 2971. | .94 | 1.19 | .3196 | 1.05 | .1889 | 119.0 | .3601 | 62.3 | 41350. |
| 4 | .045 | .045 | 1700000. | 10956. | 9051. | 2898. | 1.84 | 2.10 | .6392 | 2.15 | .1707 | 369.2 | .2866 | 187.4 | 32600. |
| 4 | .020 | .015 | 1700000. | 7661. | 9434. | 2634. | .47 | .73 | .1855 | .62 | .0686 | 165.7 | .1282 | 83.8 | 16300. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 5.72 | 5.98 | .1134 | 6.46 | .0883 | 184.1 | .1524 | 99.6 | 48700. |
| 4 | .001 | .002 | 1700000. | 50000. | 50000. | 50000. | 1.77 | 2.03 | .0359 | 1.98 | .0436 | 102.7 | .0842 | 55.0 | 24350. |
| 1 | .040 | .040 | 710000. | 12824. | 10842. | 4706. | 3.41 | 3.67 | .7196 | 3.74 | .2832 | 251.6 | .4801 | 131.1 | 46000. |
| 1 | .026 | .016 | 710000. | 7407. | 8923. | 3410. | .82 | 1.08 | .2455 | .97 | .1378 | 138.2 | .2598 | 70.9 | 23000. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 5.72 | 5.98 | .1134 | 6.46 | .0883 | 184.1 | .1524 | 99.6 | 80000. |
| 4 | .001 | .002 | 1700000. | 50000. | 50000. | 50000. | 1.77 | 2.03 | .0359 | 1.98 | .0436 | 102.7 | .0842 | 55.0 | 40000. |
| 445 | 5 | 11 | 5.0 | 6.0 | 12.0 | | | 22400. | | 6000. | | | | 701000. | |
| 3 | .035 | .035 | 450000. | 18975. | 14120. | 5620. | 3.35 | 3.65 | .5880 | 3.46 | .3146 | 173.9 | .5494 | 95.1 | 5200. |
| 3 | .024 | .019 | 450000. | 10432. | 10327. | 2575. | .70 | 1.01 | .2761 | .78 | .1831 | 115.1 | .3499 | 60.6 | 2600. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.74 | 5.05 | .0941 | 5.21 | .0882 | 183.9 | .1522 | 99.5 | 68800. |
| 4 | .001 | .002 | 1700000. | 50000. | 50000. | 50000. | 1.40 | 1.71 | .0283 | 1.54 | .0436 | 102.7 | .0841 | 55.0 | 34400. |
| 1 | .050 | .050 | 710000. | 12142. | 9512. | 3073. | 2.36 | 2.66 | .7634 | 2.52 | .2927 | 260.5 | .4957 | 135.4 | 28000. |
| 1 | .029 | .019 | 710000. | 7434. | 8804. | 2266. | .58 | .88 | .2588 | .68 | .1384 | 138.8 | .2608 | 71.2 | 14000. |
| 2 | .045 | .045 | 230000. | 17889. | 12317. | 4407. | 3.54 | 3.85 | .7905 | 3.61 | .4529 | 125.6 | .8300 | 73.4 | 168000. |
| 2 | .026 | .022 | 230000. | 10711. | 9766. | 2495. | .84 | 1.15 | .3413 | .91 | .2903 | 91.5 | .5688 | 50.3 | 84000. |
| 3 | .035 | .035 | 450000. | 18975. | 14120. | 5620. | 3.35 | 3.65 | .5880 | 3.46 | .3146 | 173.9 | .5494 | 95.1 | 82700. |
| 3 | .021 | .016 | 450000. | 10816. | 10991. | 3277. | .79 | 1.09 | .2431 | .87 | .1796 | 112.8 | .3439 | 59.5 | 41350. |
| 4 | .035 | .034 | 1700000. | 13637. | 11628. | 3955. | 1.88 | 2.18 | .4750 | 2.10 | .1541 | 332.0 | .2591 | 169.4 | 32600. |
| 4 | .019 | .013 | 1700000. | 8031. | 10416. | 2869. | .44 | .75 | .1590 | .56 | .0667 | 161.0 | .1248 | 81.6 | 16300. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.74 | 5.05 | .0941 | 5.21 | .0882 | 183.9 | .1522 | 99.5 | 48700. |
| 4 | .001 | .002 | 1700000. | 50000. | 50000. | 50000. | 1.40 | 1.71 | .0283 | 1.54 | .0436 | 102.7 | .0841 | 55.0 | 24350. |
| 1 | .040 | .040 | 710000. | 13603. | 11314. | 4325. | 2.73 | 3.03 | .6269 | 2.91 | .2738 | 242.7 | .4649 | 126.9 | 46000. |
| 1 | .024 | .015 | 710000. | 7857. | 9594. | 3292. | .68 | .99 | .2110 | .79 | .1345 | 134.8 | .2540 | 69.3 | 23000. |
| 4 | .001 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.74 | 5.05 | .0941 | 5.21 | .0882 | 183.9 | .1522 | 99.5 | 89900. |
| 4 | .001 | .002 | 1700000. | 50000. | 50000. | 50000. | 1.40 | 1.71 | .0283 | 1.54 | .0436 | 102.7 | .0841 | 55.0 | 44950. |
| 1 | .055 | .055 | 710000. | 11536. | 8784. | 2666. | 2.22 | 2.52 | .8273 | 2.38 | .3014 | 268.7 | .5100 | 139.3 | 99300. |
| 1 | .031 | .021 | 710000. | 7305. | 8529. | 1984. | .54 | .85 | .2781 | .64 | .1398 | 140.2 | .2634 | 71.9 | 49650. |
| 2 | .050 | .050 | 230000. | 16717. | 11354. | 3772. | 3.35 | 3.65 | .8736 | 3.41 | .4737 | 131.8 | .8611 | 76.2 | 31800. |
| 2 | .029 | .021 | 230000. | 10988. | 10161. | 2900. | .91 | 1.21 | .3152 | .98 | .2867 | 90.2 | .5627 | 49.8 | 15900. |
| 303 | 6 | 3 | 4.0 | 6.0 | 8.0 | | | 30000. | | 9000. | | | | 80000. | |
| 3 | .055 | .055 | 450000. | 20920. | 13220. | 5465. | 6.55 | 6.79 | 1.1748 | 6.76 | .4728 | 244.0 | .7818 | 135.3 | 5200. |
| 3 | .020 | .022 | 450000. | 14674. | 11443. | 4854. | 2.26 | 2.50 | .4679 | 2.37 | .2898 | 180.3 | .5613 | 97.2 | 2600. |
| 4 | .001 | .010 | 1700000. | 50000. | 50000. | 50000. | 9.27 | 9.51 | .1827 | 10.32 | .1368 | 265.9 | .2224 | 145.4 | 64400. |
| 4 | .001 | .004 | 1700000. | 50000. | 50000. | 50000. | 3.34 | 3.58 | .0674 | 3.68 | .0745 | 174.8 | .1446 | 94.5 | 32200. |
| 1 | .085 | .085 | 710000. | 12514. | 7884. | 2872. | 4.74 | 4.98 | 1.6305 | 5.04 | .4935 | 418.7 | .8113 | 217.8 | 10400. |
| 1 | .060 | .083 | 710000. | 5583. | 3621. | 635. | .73 | .97 | 1.1773 | .87 | .3101 | 312.4 | .5813 | 158.8 | 5200. |
| 323 | 6 | 3 | 4.0 | 6.0 | 12.0 | | | 30000. | | 9000. | | | | 80000. | |
| 3 | .060 | .059 | 450000. | 21081. | 12967. | 4272. | 4.61 | 4.90 | 1.0625 | 4.69 | .4659 | 239.8 | .7706 | 133.4 | 5200. |
| 3 | .025 | .027 | 450000. | 14371. | 10817. | 3093. | 1.38 | 1.67 | .4497 | 1.45 | .2919 | 181.7 | .5649 | 97.8 | 2600. |
| 4 | .001 | .010 | 1700000. | 50000. | 50000. | 50000. | 7.54 | 7.83 | .1489 | 8.16 | .1367 | 265.7 | .2222 | 145.3 | 64400. |
| 4 | .001 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.60 | 2.89 | .0523 | 2.80 | .0745 | 174.7 | .1445 | 94.5 | 32200. |
| 1 | .115 | .115 | 710000. | 11358. | 6268. | 1670. | 3.05 | 3.34 | 1.8130 | 3.20 | .5251 | 448.3 | .8667 | 232.1 | 10400. |
| 1 | .065 | .076 | 710000. | 7089. | 4887. | 629. | .59 | .88 | .9534 | .69 | .2837 | 285.0 | .5336 | 145.7 | 5200. |
| 253 | 6 | 9 | 4.0 | 6.0 | 16.0 | | | 30000. | | 9000. | | | | 451000. | |
| 3 | .045 | .045 | 450000. | 25428. | 16836. | 5747. | 3.97 | 4.31 | .6810 | 4.02 | .4025 | 203.7 | .6740 | 116.7 | 5200. |
| 3 | .016 | .016 | 450000. | 18815. | 15836. | 6946. | 1.50 | 1.84 | .2173 | 1.56 | .2544 | 156.4 | .4999 | 86.5 | 2600. |
| 4 | .001 | .010 | 1700000. | 50000. | 50000. | 50000. | 6.17 | 6.51 | .1222 | 6.56 | .1366 | 265.5 | .2220 | 145.2 | 64400. |
| 4 | .001 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.06 | 2.40 | .0415 | 2.19 | .0744 | 174.7 | .1445 | 94.5 | 32200. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .067 | .067 | 710000. | 16476. | 11156. | 3116. | 3.06 | 3.40 | .9716 | 3.15 | .4118 | 343.5 | .6701 | 181.9 | 32400. |
| 1 | .040 | .040 | 710000. | 9904. | 8315. | 1322. | .67 | 1.02 | .5160 | .75 | .2409 | 240.6 | .4564 | 124.6 | 16200. |
| 2 | .065 | .064 | 230000. | 22833. | 13806. | 3578. | 3.58 | 3.92 | .9858 | 3.62 | .5500 | 136.0 | .9711 | 85.9 | 66600. |
| 2 | .035 | .035 | 230000. | 15161. | 10699. | 2043. | .97 | 1.31 | .4757 | 1.02 | .4185 | 128.8 | .8431 | 74.6 | 33300. |
| 2 | .049 | .049 | 230000. | 25743. | 16852. | 5548. | 4.24 | 4.58 | .7525 | 4.29 | .4958 | 120.4 | .8935 | 79.0 | 101400. |
| 2 | .026 | .028 | 230000. | 16228. | 12333. | 3262. | 1.21 | 1.55 | .3728 | 1.26 | .4013 | 122.7 | .8141 | 72.0 | 50700. |
| 3 | .042 | .042 | 450000. | 26444. | 17646. | 6400. | 4.13 | 4.47 | .6360 | 4.18 | .3920 | 197.7 | .6583 | 113.9 | 82700. |
| 3 | .020 | .021 | 450000. | 16410. | 13629. | 4439. | 1.25 | 1.59 | .2835 | 1.31 | .2698 | 166.9 | .5264 | 91.1 | 41350. |
| 4 | .044 | .043 | 1700000. | 19880. | 14172. | 4739. | 2.90 | 3.24 | .6081 | 3.05 | .2261 | 461.4 | .3726 | 238.1 | 32690. |
| 4 | .023 | .022 | 1700000. | 11305. | 11149. | 2596. | .71 | 1.05 | .2773 | .80 | .1192 | 287.1 | .2238 | 146.4 | 16300. |
| 4 | .001 | .010 | 1700000. | 50000. | 50000. | 50000. | 6.17 | 6.51 | .1222 | 6.56 | .1366 | 265.5 | .2220 | 145.2 | 48700. |
| 4 | .001 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.06 | 2.40 | .0415 | 2.19 | .0744 | 174.7 | .1445 | 94.5 | 24350. |
| 1 | .055 | .055 | 710000. | 18590. | 12876. | 4204. | 3.44 | 3.78 | .8096 | 3.53 | .3846 | 318.7 | .6238 | 170.2 | 17000. |
| 1 | .030 | .037 | 710000. | 10145. | 8715. | 1520. | .72 | 1.06 | .4801 | .80 | .2377 | 237.3 | .4507 | 123.1 | 8500. |
| 321 | 6 | 3 | 4.0 | 9.0 | 8.0 | | | 30000. | | 9000. | | | | | 80000. |
| 3 | .075 | .075 | 450000. | 16803. | 8417. | 3254. | 4.59 | 4.86 | 1.3852 | 4.61 | .5245 | 273.3 | .8609 | 149.0 | 5200. |
| 3 | .021 | .023 | 450000. | 15083. | 10656. | 4234. | 1.72 | 2.00 | .4071 | 1.77 | .2826 | 175.4 | .5487 | 95.0 | 2600. |
| 4 | .001 | .010 | 1700000. | 50000. | 50000. | 50000. | 7.86 | 8.14 | .1553 | 8.58 | .1364 | 265.2 | .2218 | 145.0 | 64400. |
| 4 | .001 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.73 | 3.01 | .0551 | 2.97 | .0744 | 174.5 | .1444 | 94.4 | 32200. |
| 1 | .115 | .115 | 710000. | 9998. | 5111. | 1743. | 3.36 | 3.63 | 1.9068 | 3.48 | .5360 | 458.1 | .8852 | 236.8 | 10400. |
| 1 | .070 | .085 | 710000. | 5864. | 3715. | 562. | .60 | .88 | 1.0920 | .70 | .2976 | 299.4 | .5587 | 152.6 | 5200. |
| 267 | 6 | 4 | 4.0 | 9.0 | 12.0 | | | 30000. | | 9000. | | | | | 108000. |
| 3 | .062 | .062 | 450000. | 19836. | 11116. | 3721. | 3.68 | 4.01 | .9753 | 3.69 | .4629 | 237.9 | .7655 | 132.5 | 5200. |
| 3 | .020 | .021 | 450000. | 16199. | 12187. | 4199. | 1.30 | 1.63 | .3108 | 1.35 | .2711 | 167.7 | .5287 | 91.5 | 2600. |
| 4 | .001 | .010 | 1700000. | 50000. | 50000. | 50000. | 6.43 | 6.76 | .1273 | 6.88 | .1363 | 265.0 | .2216 | 144.9 | 64400. |
| 4 | .001 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.16 | 2.49 | .0435 | 2.31 | .0744 | 174.5 | .1443 | 94.4 | 32200. |
| 1 | .090 | .090 | 710000. | 12734. | 7396. | 2147. | 2.87 | 3.20 | 1.3246 | 2.94 | .4646 | 392.1 | .7609 | 205.1 | 32400. |
| 1 | .040 | .034 | 710000. | 9529. | 8090. | 1846. | .86 | 1.18 | .4678 | .93 | .2401 | 239.8 | .4549 | 124.2 | 16200. |
| 2 | .085 | .085 | 230000. | 18023. | 8670. | 2608. | 3.58 | 3.91 | 1.3513 | 3.56 | .6409 | 162.3 | 1.1056 | 97.8 | 6000. |
| 2 | .038 | .037 | 230000. | 13748. | 8724. | 1984. | 1.06 | 1.38 | .5342 | 1.10 | .4343 | 134.2 | .8701 | 77.0 | 3000. |
| 309 | 6 | 14 | 4.0 | 9.0 | 16.0 | | | 30000. | | 9000. | | | | | 1023000. |
| 3 | .042 | .042 | 450000. | 25772. | 15926. | 5996. | 3.41 | 3.79 | .5625 | 3.43 | .3857 | 194.1 | .6488 | 112.3 | 5200. |
| 3 | .017 | .018 | 450000. | 16454. | 13822. | 5378. | 1.16 | 1.54 | .2163 | 1.20 | .2649 | 163.6 | .5178 | 89.6 | 2600. |
| 4 | .001 | .010 | 1700000. | 50000. | 50000. | 50000. | 5.31 | 5.69 | .1053 | 5.60 | .1363 | 264.8 | .2215 | 144.9 | 68800. |
| 4 | .001 | .004 | 1700000. | 50000. | 50000. | 50000. | 1.74 | 2.12 | .0350 | 1.83 | .0743 | 174.4 | .1443 | 94.3 | 34400. |
| 1 | .066 | .066 | 710000. | 16218. | 10323. | 2979. | 2.58 | 2.96 | .8603 | 2.64 | .4021 | 334.5 | .6531 | 177.6 | 28000. |
| 1 | .033 | .028 | 710000. | 10620. | 9814. | 2251. | .76 | 1.14 | .3412 | .82 | .2271 | 226.3 | .4316 | 117.9 | 14000. |
| 2 | .058 | .058 | 230000. | 22707. | 13111. | 3970. | 3.16 | 3.54 | .7869 | 3.18 | .5270 | 129.2 | .9378 | 83.0 | 49200. |
| 2 | .028 | .025 | 230000. | 16434. | 12072. | 3758. | 1.08 | 1.46 | .2896 | 1.12 | .3922 | 119.5 | .7990 | 70.7 | 24600. |
| 2 | .048 | .048 | 230000. | 25162. | 14999. | 5335. | 3.53 | 3.91 | .6529 | 3.55 | .4874 | 117.9 | .8815 | 78.0 | 118800. |
| 2 | .023 | .024 | 230000. | 16117. | 12523. | 4179. | 1.14 | 1.52 | .2747 | 1.18 | .3946 | 120.3 | .8031 | 71.0 | 59400. |
| 3 | .046 | .046 | 450000. | 24429. | 14915. | 5172. | 3.23 | 3.61 | .6177 | 3.25 | .3994 | 201.8 | .6690 | 115.8 | 82700. |
| 3 | .023 | .023 | 450000. | 15379. | 12358. | 3301. | .93 | 1.30 | .2819 | .97 | .2735 | 169.4 | .5327 | 92.2 | 41350. |
| 4 | .045 | .044 | 1700000. | 18947. | 13189. | 4333. | 2.45 | 2.83 | .5621 | 2.55 | .2241 | 456.9 | .3690 | 236.0 | 32600. |
| 4 | .019 | .022 | 1700000. | 11139. | 11265. | 2461. | .62 | 1.00 | .2537 | .69 | .1181 | 284.3 | .2218 | 145.0 | 16300. |
| 4 | .001 | .010 | 1700000. | 50000. | 50000. | 50000. | 5.31 | 5.69 | .1053 | 5.60 | .1363 | 264.8 | .2215 | 144.9 | 48700. |
| 4 | .001 | .004 | 1700000. | 50000. | 50000. | 50000. | 1.74 | 2.12 | .0350 | 1.83 | .0743 | 174.4 | .1443 | 94.3 | 24350. |
| 1 | .050 | .050 | 710000. | 18628. | 12821. | 4623. | 3.07 | 3.45 | .6587 | 3.13 | .3697 | 304.9 | .5993 | 163.7 | 46000. |
| 1 | .020 | .018 | 710000. | 12656. | 12392. | 5160. | 1.10 | 1.48 | .2144 | 1.16 | .2120 | 210.4 | .4048 | 110.5 | 23000. |
| 4 | .001 | .010 | 1700000. | 50000. | 50000. | 50000. | 5.31 | 5.69 | .1053 | 5.60 | .1363 | 264.8 | .2215 | 144.9 | 89900. |
| 4 | .001 | .004 | 1700000. | 50000. | 50000. | 50000. | 1.74 | 2.12 | .0350 | 1.83 | .0743 | 174.4 | .1443 | 94.3 | 44950. |
| 1 | .065 | .065 | 710000. | 16373. | 10444. | 3051. | 2.61 | 2.99 | .8479 | 2.66 | .4000 | 332.6 | .6496 | 176.7 | 99300. |
| 1 | .033 | .029 | 710000. | 10532. | 9677. | 2116. | .74 | 1.12 | .3522 | .80 | .2280 | 227.2 | .4332 | 118.3 | 49650. |
| 2 | .058 | .058 | 230000. | 22707. | 13111. | 3970. | 3.16 | 3.54 | .7869 | 3.18 | .5270 | 129.2 | .9378 | 83.0 | 102100. |
| 2 | .027 | .026 | 230000. | 16045. | 11986. | 3516. | 1.05 | 1.43 | .3005 | 1.09 | .3963 | 120.9 | .8059 | 71.3 | 51050. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | .048 | .048 | 230000. | 25162. | 14999. | 5335. | 3.53 | 3.91 | .6529 | 3.55 | .4874 | 117.9 | .8815 | 78.0 | 212500. |
| 2 | .020 | .019 | 230000. | 18337. | 14438. | 6390. | 1.35 | 1.73 | .2115 | 1.39 | .3705 | 111.8 | .7629 | 67.5 | 106250. |
| 3 | .042 | .042 | 450000. | 25772. | 15926. | 5996. | 3.41 | 3.79 | .5625 | 3.43 | .3857 | 194.1 | .6488 | 112.3 | 39200. |
| 3 | .017 | .018 | 450000. | 16454. | 13822. | 5378. | 1.16 | 1.54 | .2163 | 1.20 | .2649 | 163.6 | .5187 | 89.6 | 19600. |
| 259 | 6 | 4 | 5.0 | 6.0 | 8.0 | | | 30000. | | 9000. | | | | | 91000. |
| 3 | .060 | .060 | 450000. | 16104. | 10844. | 4256. | 5.00 | 5.26 | 1.1601 | 5.27 | .4563 | 242.2 | .7594 | 130.1 | 5200. |
| 3 | .019 | .019 | 450000. | 13537. | 11944. | 5307. | 1.86 | 2.11 | .3522 | 1.99 | .2268 | 141.7 | .4369 | 75.6 | 2600. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 7.57 | 7.83 | .1501 | 8.57 | .1127 | 222.2 | .1862 | 120.6 | 64400. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.65 | 2.91 | .0536 | 2.97 | .0571 | 134.4 | .1105 | 72.3 | 32200. |
| 1 | .075 | .075 | 710000. | 11065. | 8002. | 2844. | 3.66 | 3.91 | 1.2790 | 4.01 | .4061 | 350.7 | .6820 | 181.2 | 10100. |
| 1 | .045 | .049 | 710000. | 6279. | 5699. | 1074. | .69 | .94 | .6548 | .84 | .2114 | 212.7 | .3967 | 108.3 | 5050. |
| 1 | .105 | .105 | 710000. | 8849. | 5762. | 1776. | 2.95 | 3.20 | 1.6566 | 3.27 | .4560 | 398.2 | .7702 | 204.0 | 11300. |
| 1 | .050 | .062 | 710000. | 5690. | 4931. | 776. | .58 | .83 | .7648 | .72 | .2206 | 222.2 | .4134 | 112.9 | 5650. |
| 307 | 6 | 11 | 5.0 | 6.0 | 12.0 | | | 30000. | | 9000. | | | | | 585000. |
| 3 | .039 | .039 | 450000. | 22552. | 16412. | 7014. | 4.75 | 5.06 | .6684 | 4.91 | .3684 | 190.7 | .6144 | 106.3 | 5200. |
| 3 | .014 | .015 | 450000. | 15062. | 14120. | 6947. | 1.63 | 1.94 | .2367 | 1.74 | .2132 | 132.5 | .4134 | 71.5 | 2600. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 6.29 | 6.59 | .1249 | 6.92 | .1126 | 222.0 | .1860 | 120.5 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.12 | 2.43 | .0428 | 2.32 | .0571 | 134.3 | .1104 | 72.2 | 34400. |
| 1 | .068 | .068 | 710000. | 12878. | 9264. | 2950. | 3.07 | 3.38 | 1.0358 | 3.28 | .3757 | 322.1 | .6288 | 167.6 | 28000. |
| 1 | .034 | .031 | 710000. | 8289. | 8325. | 1910. | .78 | 1.09 | .4159 | .90 | .1875 | 187.9 | .3539 | 96.6 | 14000. |
| 2 | .065 | .065 | 230000. | 17985. | 11562. | 3848. | 4.43 | 4.73 | 1.1334 | 4.51 | .5820 | 150.5 | .9966 | 88.2 | 66600. |
| 2 | .030 | .029 | 230000. | 12568. | 10145. | 2864. | 1.32 | 1.63 | .4647 | 1.39 | .3606 | 112.7 | .7130 | 63.1 | 33300. |
| 2 | .053 | .053 | 230000. | 20659. | 13862. | 5130. | 4.87 | 5.17 | .9334 | 4.96 | .5278 | 134.5 | .9161 | 81.0 | 101400. |
| 2 | .028 | .025 | 230000. | 13185. | 11129. | 3681. | 1.49 | 1.79 | .4058 | 1.55 | .3505 | 109.2 | .6959 | 61.6 | 50700. |
| 3 | .048 | .048 | 450000. | 20117. | 13912. | 5193. | 4.26 | 4.56 | .8102 | 4.40 | .3973 | 207.6 | .6597 | 114.1 | 82700. |
| 3 | .020 | .019 | 450000. | 13241. | 12122. | 4486. | 1.35 | 1.66 | .3041 | 1.45 | .2252 | 140.6 | .4341 | 75.1 | 41350. |
| 4 | .045 | .045 | 1700000. | 15039. | 11864. | 4063. | 2.53 | 2.83 | .6225 | 2.81 | .1965 | 411.2 | .3318 | 210.2 | 32600. |
| 4 | .020 | .016 | 1700000. | 9949. | 11064. | 3798. | .75 | 1.05 | .2008 | .89 | .0885 | 213.4 | .1659 | 108.5 | 16300. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 6.29 | 6.59 | .1249 | 6.92 | .1126 | 222.0 | .1860 | 120.5 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.12 | 2.43 | .0428 | 2.32 | .0571 | 134.3 | .1104 | 72.2 | 24350. |
| 1 | .050 | .051 | 710000. | 15313. | 11918. | 4372. | 3.60 | 3.91 | .8180 | 3.82 | .3416 | 289.9 | .5694 | 152.3 | 46000. |
| 1 | .021 | .019 | 710000. | 9713. | 10462. | 4137. | 1.15 | 1.45 | .2799 | 1.27 | .1740 | 173.8 | .3297 | 90.0 | 23000. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 6.29 | 6.59 | .1249 | 6.92 | .1126 | 222.0 | .1860 | 120.5 | 89900. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.12 | 2.43 | .0428 | 2.32 | .0571 | 134.3 | .1104 | 72.2 | 44950. |
| 1 | .070 | .070 | 710000. | 12628. | 9051. | 2830. | 3.02 | 3.32 | 1.0608 | 3.22 | .3794 | 325.6 | .6352 | 169.3 | 15100. |
| 1 | .040 | .040 | 710000. | 7665. | 7317. | 1296. | .64 | .95 | .5046 | .76 | .1952 | 195.9 | .3677 | 100.4 | 7550. |
| 305 | 6 | 4 | 5.0 | 6.0 | 12.0 | | | 30000. | | 9000. | | | | | 126000. |
| 3 | .040 | .040 | 450000. | 22238. | 16116. | 6764. | 4.69 | 4.99 | .6842 | 4.85 | .3717 | 192.6 | .6195 | 107.2 | 5200. |
| 3 | .015 | .018 | 450000. | 13535. | 12762. | 5221. | 1.45 | 1.76 | .2799 | 1.55 | .2220 | 138.5 | .4285 | 74.2 | 2600. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 6.29 | 6.59 | .1249 | 6.92 | .1126 | 222.0 | .1860 | 120.5 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.12 | 2.43 | .0428 | 2.32 | .0571 | 134.3 | .1104 | 72.2 | 34400. |
| 1 | .085 | .085 | 710000. | 11109. | 7710. | 2150. | 2.67 | 2.98 | 1.2395 | 2.88 | .4044 | 349.4 | .6792 | 180.7 | 28000. |
| 1 | .035 | .033 | 710000. | 8092. | 7991. | 1712. | .74 | 1.05 | .4396 | .86 | .1898 | 190.2 | .3579 | 97.7 | 14000. |
| 2 | .090 | .090 | 230000. | 14931. | 8656. | 2450. | 3.77 | 4.08 | 1.5185 | 3.84 | .6686 | 176.2 | 1.1278 | 99.8 | 24000. |
| 2 | .036 | .031 | 230000. | 12807. | 9832. | 2573. | 1.25 | 1.56 | .4885 | 1.31 | .3607 | 112.8 | .7134 | 63.1 | 12000. |
| 327 | 6 | 12 | 5.0 | 6.0 | 16.0 | | | 30000. | | 9000. | | | | | 676000. |
| 3 | .027 | .026 | 450000. | 25744. | 22385. | 12456. | 4.71 | 5.07 | .3742 | 4.87 | .3252 | 165.2 | .5478 | 94.8 | 5200. |
| 3 | .017 | .020 | 450000. | 13662. | 12838. | 3851. | 1.01 | 1.36 | .2632 | 1.08 | .2204 | 137.4 | .4258 | 73.7 | 2600. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.25 | 5.61 | .1044 | 5.67 | .1125 | 221.8 | .1859 | 120.5 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.72 | 2.08 | .0347 | 1.85 | .0571 | 134.2 | .1104 | 72.2 | 34400. |
| 1 | .057 | .057 | 710000. | 15188. | 11245. | 3451. | 2.69 | 3.05 | .7757 | 2.83 | .3423 | 290.6 | .5706 | 152.7 | 28000. |
| 1 | .026 | .024 | 710000. | 9299. | 9919. | 2479. | .75 | 1.11 | .3058 | .84 | .1766 | 176.6 | .3344 | 91.3 | 14000. |
| 2 | .057 | .057 | 230000. | 20402. | 13770. | 4106. | 3.48 | 3.84 | .8371 | 3.54 | .5251 | 133.5 | .9107 | 80.6 | 66600. |
| 2 | .026 | .025 | 230000. | 13881. | 11982. | 3486. | 1.12 | 1.48 | .3229 | 1.18 | .3390 | 105.2 | .6765 | 59.8 | 33300. |
| 2 | .047 | .047 | 230000. | 22809. | 15696. | 5473. | 3.87 | 4.23 | .6988 | 3.94 | .4863 | 122.1 | .8543 | 75.6 | 101400. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | .024 | .023 | 230000. | 14157. | 12445. | 3806. | 1.16 | 1.52 | .3069 | 1.22 | .3354 | 103.9 | .6705 | 59.3 | 50700. |
| 3 | .042 | .042 | 450000. | 22570. | 15957. | 5707. | 3.51 | 3.87 | .6095 | 3.60 | .3668 | 189.7 | .6116 | 105.8 | 82700. |
| 3 | .021 | .020 | 450000. | 13506. | 12593. | 3672. | .99 | 1.34 | .2704 | 1.06 | .2216 | 138.2 | .4278 | 74.0 | 41350. |
| 4 | .041 | .040 | 1700000. | 16824. | 13400. | 4408. | 2.25 | 2.60 | .5100 | 2.45 | .1855 | 386.3 | .3123 | 198.2 | 32600. |
| 4 | .020 | .017 | 1700000. | 9879. | 11569. | 3127. | .60 | .96 | .1953 | .71 | .0879 | 211.9 | .1648 | 107.8 | 16300. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.25 | 5.61 | .1044 | 5.67 | .1125 | 221.8 | .1859 | 120.5 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.72 | 2.08 | .0347 | 1.85 | .0571 | 134.2 | .1104 | 72.2 | 24350. |
| 1 | .045 | .044 | 710000. | 16886. | 13574. | 5021. | 3.14 | 3.50 | .6221 | 3.29 | .3193 | 268.9 | .5308 | 142.4 | 46000. |
| 1 | .020 | .018 | 710000. | 10144. | 11256. | 4374. | .98 | 1.34 | .2263 | 1.08 | .1694 | 169.0 | .3214 | 87.8 | 23000. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.25 | 5.61 | .1044 | 5.67 | .1125 | 221.8 | .1859 | 120.5 | 89900. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.72 | 2.08 | .0347 | 1.85 | .0571 | 134.2 | .1104 | 72.2 | 44950. |
| 1 | .064 | .064 | 710000. | 14114. | 10388. | 2914. | 2.50 | 2.86 | .8550 | 2.64 | .3545 | 302.1 | .5918 | 158.1 | 99300. |
| 1 | .033 | .029 | 710000. | 8962. | 9242. | 1834. | .65 | 1.00 | .3567 | .73 | .1806 | 180.7 | .3415 | 93.3 | 49650. |
| 2 | .073 | .072 | 230000. | 18416. | 11600. | 2856. | 3.00 | 3.361.0394 | | 3.07 | .5691 | 146.6 | .9762 | 86.4 | 6800. |
| 2 | .034 | .030 | 230000. | 13157. | 10796. | 2317. | .92 | 1.27 | .3984 | .98 | .3497 | 108.9 | .6946 | 61.4 | 3400. |
| 313 | 6 | 9 | 5.0 | 9.0 | 8.0 | | | 30000. | | 9000. | | | | 441000. | |
| 3 | .050 | .049 | 450000. | 18565. | 11874. | 5200. | 4.56 | 4.86 | .8655 | 4.68 | .4062 | 212.8 | .6745 | 116.5 | 5200. |
| 3 | .017 | .019 | 450000. | 12561. | 11311. | 4717. | 1.48 | 1.77 | .3154 | 1.58 | .2282 | 142.7 | .4392 | 76.0 | 2600. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 6.53 | 6.82 | .1297 | 7.25 | .1124 | 221.6 | .1857 | 120.4 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.22 | 2.51 | .0448 | 2.44 | .0570 | 134.2 | .1104 | 72.2 | 34400. |
| 1 | .080 | .080 | 710000. | 10688. | 6904. | 2415. | 3.00 | 3.301.2361 | | 3.20 | .4030 | 347.9 | .6766 | 179.9 | 28000. |
| 1 | .035 | .035 | 710000. | 7342. | 7172. | 1640. | .76 | 1.06 | .4723 | .89 | .1948 | 195.5 | .3669 | 100.2 | 14000. |
| 2 | .068 | .068 | 230000. | 16595. | 9253. | 3754. | 4.75 | 5.041.2424 | | 4.78 | .5996 | 155.71.0235 | | 90.5 | 66600. |
| 2 | .031 | .030 | 230000. | 11339. | 8733. | 2852. | 1.45 | 1.74 | .5091 | 1.50 | .3731 | 117.1 | .7343 | 65.0 | 33300. |
| 2 | .058 | .058 | 230000. | 18196. | 10851. | 4666. | 5.10 | 5.391.0734 | | 5.15 | .5609 | 144.3 | .9654 | 85.4 | 101400. |
| 2 | .028 | .027 | 230000. | 11855. | 9540. | 3476. | 1.58 | 1.87 | .4562 | 1.64 | .3643 | 114.0 | .7193 | 63.6 | 50700. |
| 3 | .055 | .055 | 450000. | 17145. | 10692. | 4409. | 4.30 | 4.60 | .9631 | 4.41 | .4256 | 224.1 | .7070 | 121.7 | 82700. |
| 3 | .024 | .022 | 450000. | 12000. | 10496. | 3905. | 1.36 | 1.65 | .3503 | 1.45 | .2332 | 146.0 | .4480 | 77.5 | 41350. |
| 4 | .050 | .050 | 1700000. | 13172. | 9831. | 3564. | 2.48 | 2.78 | .6975 | 2.77 | .2047 | 430.0 | .3464 | 219.2 | 32600. |
| 4 | .021 | .017 | 1700000. | 9219. | 10448. | 3334. | .72 | 1.01 | .2205 | .87 | .0906 | 218.5 | .1696 | 110.9 | 16300. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 6.53 | 6.82 | .1297 | 7.25 | .1124 | 221.6 | .1857 | 120.4 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.22 | 2.51 | .0448 | 2.44 | .0570 | 134.2 | .1104 | 72.2 | 24350. |
| 1 | .040 | .040 | 710000. | 15813. | 12911. | 6585. | 4.49 | 4.78 | .6759 | 4.79 | .3238 | 272.9 | .5382 | 144.3 | 7000. |
| 1 | .023 | .026 | 710000. | 8085. | 8471. | 2565. | .95 | 1.25 | .3765 | 1.09 | .1861 | 186.5 | .3513 | 95.9 | 3500. |
| 331 | 6 | 10 | 5.0 | 9.0 | 12.0 | | | 30000. | | 9000. | | | | 557000. | |
| 3 | .032 | .032 | 450000. | 23666. | 17756. | 9200. | 4.48 | 4.82 | .4809 | 4.60 | .3435 | 176.0 | .5758 | 99.6 | 5200. |
| 3 | .021 | .018 | 450000. | 13150. | 12697. | 5053. | 1.22 | 1.56 | .2421 | 1.29 | .2210 | 137.9 | .4267 | 73.9 | 2600. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.45 | 5.79 | .1084 | 5.92 | .1123 | 221.4 | .1856 | 120.3 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.80 | 2.14 | .0362 | 1.94 | .0570 | 134.1 | .1103 | 72.1 | 34400. |
| 1 | .062 | .062 | 710000. | 13367. | 9366. | 3134. | 2.75 | 3.10 | .8734 | 2.88 | .3574 | 304.7 | .5967 | 159.4 | 28000. |
| 1 | .033 | .029 | 710000. | 8332. | 8684. | 1939. | .70 | 1.04 | .3644 | .79 | .1839 | 184.1 | .3472 | 94.8 | 14000. |
| 2 | .057 | .057 | 230000. | 19279. | 11620. | 4200. | 3.80 | 4.15 | .8925 | 3.83 | .5343 | 136.3 | .9251 | 81.8 | 66600. |
| 2 | .026 | .028 | 230000. | 12520. | 10194. | 2838. | 1.10 | 1.44 | .3881 | 1.15 | .3533 | 110.2 | .7007 | 62.0 | 33300. |
| 2 | .045 | .045 | 230000. | 21757. | 14328. | 6099. | 4.34 | 4.69 | .7014 | 4.39 | .4887 | 122.8 | .8581 | 75.9 | 101400. |
| 2 | .024 | .023 | 230000. | 13208. | 11445. | 4071. | 1.29 | 1.64 | .3194 | 1.35 | .3431 | 106.6 | .6834 | 60.5 | 50700. |
| 3 | .038 | .038 | 450000. | 22019. | 15546. | 6959. | 4.05 | 4.39 | .5748 | 4.14 | .3611 | 186.3 | .6027 | 104.3 | 82700. |
| 3 | .020 | .018 | 450000. | 12992. | 12380. | 4696. | 1.18 | 1.52 | .2523 | 1.25 | .2224 | 138.8 | .4291 | 74.3 | 41350. |
| 4 | .036 | .036 | 1700000. | 16481. | 13479. | 5455. | 2.59 | 2.93 | .4744 | 2.82 | .1824 | 378.8 | .3066 | 194.5 | 32600. |
| 4 | .012 | .013 | 1700000. | 10052. | 12072. | 4836. | .75 | 1.10 | .1583 | .88 | .0863 | 208.1 | .1620 | 105.9 | 16300. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.45 | 5.79 | .1084 | 5.92 | .1123 | 221.4 | .1856 | 120.3 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.80 | 2.14 | .0362 | 1.94 | .0570 | 134.1 | .1103 | 72.1 | 24350. |
| 1 | .040 | .041 | 710000. | 16348. | 13251. | 6073. | 3.60 | 3.94 | .5881 | 3.77 | .3168 | 266.4 | .5263 | 141.2 | 46000. |
| 1 | .015 | .018 | 710000. | 9373. | 10731. | 4488. | 1.04 | 1.38 | .2336 | 1.15 | .1728 | 172.6 | .3274 | 89.4 | 23000. |
| 4 | .001 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.45 | 5.79 | .1084 | 5.92 | .1123 | 221.4 | .1856 | 120.3 | 77000. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.80 | 2.14 | .0362 | 1.94 | .0570 | 134.1 | .1103 | 72.1 | 38500. |

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325 6  4            6.0    6.0    8.0            30000.    9000.                            102000.
  3 .052 .052  450000. 15203. 11520.  4503. 4.21 4.49 .9277 4.52 .3856 207.2 .6529 110.6     5200.
  3 .018 .015  450000. 12486. 12559.  6022. 1.57 1.84 .2633 1.73 .1795 112.4 .3448  59.7     2600.
  4 .001 .008 1700000. 50000. 50000. 50000. 6.28 6.55 .1251 7.21 .0937 187.1 .1579 101.1    64400.
  4 .001 .003 1700000. 50000. 50000. 50000. 2.15 2.42 .0435 2.43 .0449 105.8 .0867  56.7    32200.
  1 .080 .080  710000.  8793.  6955.  2167. 2.50 2.771.1543 2.84 .3547 312.1 .6053 159.9    10100.
  1 .038 .037  710000.  6285.  6825.  1335.  .58  .86 .4487  .74 .1579 158.8 .2962  80.9     5050.
  1 .105 .105  710000.  7315.  5358.  1474. 2.04 2.311.3906 2.36 .3844 341.5 .6583 174.1    22300.
  1 .042 .049  710000.  5717.  5980.   919.  .48  .75 .5381  .63 .1652 166.4 .3096  84.5    11150.
257 6 12            6.0    6.0   12.0            30000.    9000.                            713000.
  3 .042 .042  450000. 18523. 14152.  5568. 3.75 4.07 .6674 3.93 .3440 182.3 .5822  99.1     5200.
  3 .013 .013  450000. 13981. 14697.  8006. 1.44 1.76 .1811 1.56 .1695 105.7 .3274  56.7     2600.
  4 .001 .008 1700000. 50000. 50000. 50000. 5.30 5.62 .1057 5.92 .0936 186.9 .1578 101.1    68800.
  4 .001 .003 1700000. 50000. 50000. 50000. 1.75 2.07 .0353 1.94 .0449 105.7 .0866  56.6    34400.
  1 .060 .060  710000. 11819.  9388.  3010. 2.51 2.83 .8325 2.74 .3119 271.1 .5298 140.4    28000.
  1 .026 .024  710000.  7672.  8981.  2313.  .68 1.00 .2989  .81 .1438 144.3 .2711  74.0    14000.
  2 .067 .066  230000. 15331. 10522.  3366. 3.70 4.021.0858 3.81 .5518 146.2 .9391  82.8    49200.
  2 .031 .031  230000. 10530.  9345.  2257. 1.00 1.33 .4487 1.09 .3072  97.0 .6000  53.1    24600.
  2 .056 .056  230000. 17243. 12167.  4332. 4.06 4.38 .9261 4.18 .5127 134.4 .8761  77.5   118800.
  2 .027 .028  230000. 10944.  9938.  2667. 1.09 1.41 .4113 1.17 .3011  94.9 .5896  52.2    59400.
  3 .046 .046  450000. 17644. 13074.  4863. 3.55 3.87 .7247 3.73 .3549 188.9 .6007 102.1    82700.
  3 .023 .021  450000. 11088. 11170.  3366.  .97 1.29 .2913 1.08 .1865 117.2 .3570  61.8    41350.
  4 .045 .045 1700000. 12713. 10976.  3402. 1.78 2.11 .5285 2.07 .1633 347.7 .2795 176.9    32600.
  4 .019 .016 1700000.  8730. 11009.  3145.  .52  .84 .1707  .66 .0686 165.6 .1284  83.9    16300.
  4 .001 .008 1700000. 50000. 50000. 50000. 5.30 5.62 .1057 5.92 .0936 186.9 .1578 101.1    48700.
  4 .001 .003 1700000. 50000. 50000. 50000. 1.75 2.07 .0353 1.94 .0449 105.7 .0866  56.6    24350.
  1 .050 .050  710000. 12947. 10818.  3912. 2.83 3.15 .7215 3.08 .2964 256.1 .5026 133.3    46000.
  1 .020 .019  710000.  8311.  9918.  3440.  .83 1.15 .2439  .96 .1388 139.0 .2620  71.6    23000.
  4 .001 .008 1700000. 50000. 50000. 50000. 5.30 5.62 .1057 5.92 .0936 186.9 .1578 101.1    89900.
  4 .001 .003 1700000. 50000. 50000. 50000. 1.75 2.07 .0353 1.94 .0449 105.7 .0866  56.6    44950.
  1 .070 .070  710000. 10633.  8359.  2415. 2.26 2.58 .9355 2.49 .3264 285.2 .5554 147.1    99300.
  1 .029 .025  710000.  7701.  8820.  2161.  .66  .98 .3094  .78 .1445 145.0 .2723  74.4    49650.
  2 .060 .060  230000. 16481. 11520.  3931. 3.92 4.24 .9849 4.03 .5274 138.8 .8989  79.5    43800.
  2 .028 .025  230000. 11312. 10495.  3279. 1.21 1.53 .3704 1.29 .2954  92.9 .5799  51.3    21900.
263 6 10            6.0    9.0    8.0            30000.    9000.                            512000.
  3 .050 .050  450000. 15603. 10821.  4420. 3.64 3.95 .8152 3.80 .3711 198.5 .6280 106.5     5200.
  3 .014 .013  450000. 12856. 13424.  7155. 1.44 1.75 .2032 1.58 .1745 109.1 .3360  58.1     2600.
  4 .001 .008 1700000. 50000. 50000. 50000. 5.49 5.80 .1094 6.18 .0935 186.7 .1576 100.9    68800.
  4 .001 .003 1700000. 50000. 50000. 50000. 1.82 2.13 .0369 2.04 .0448 105.6 .0866  56.6    34400.
  1 .072 .072  710000.  9796.  7218.  2375. 2.36 2.67 .9927 2.59 .3337 292.1 .5683 150.4    28000.
  1 .028 .028  710000.  7022.  8084.  1914.  .64  .95 .3399  .77 .1488 149.4 .2799  76.4    14000.
  2 .074 .074  230000. 13332.  8070.  3031. 3.84 4.151.2513 3.92 .5869 156.8 .9971  87.6    49200.
  2 .024 .025  230000. 11136.  9667.  3305. 1.29 1.60 .3929 1.37 .2979  93.8 .5841  51.7    24600.
  2 .063 .063  230000. 14845.  9454.  3782. 4.16 4.471.0854 4.25 .5492 145.3 .9346  82.4   118800.
  2 .031 .028  230000. 10120.  9048.  2833. 1.21 1.52 .4295 1.29 .3082  97.4 .6015  53.2    59400.
  3 .047 .046  450000. 16335. 11717.  5000. 3.82 4.13 .7564 4.00 .3609 192.3 .6106 103.7    82700.
  3 .019 .019  450000. 10784. 10992.  4168. 1.13 1.44 .2750 1.25 .1866 117.2 .3569  61.8    41350.
  4 .048 .048 1700000. 11391.  9705.  3146. 1.77 2.08 .5671 2.07 .1677 358.1 .2874 181.9    32600.
  4 .015 .013 1700000.  9403. 11993.  4500.  .63  .94 .1429  .79 .0668 161.3 .1252  81.9    16300.
  4 .001 .008 1700000. 50000. 50000. 50000. 5.49 5.80 .1094 6.18 .0935 186.7 .1576 100.9    48700.
  4 .001 .003 1700000. 50000. 50000. 50000. 1.82 2.13 .0369 2.04 .0448 105.6 .0866  56.6    24350.
  1 .060 .060  710000. 10818.  8446.  3077. 2.66 2.97 .8646 2.91 .3173 276.1 .5393 142.8    46000.
  1 .022 .019  710000.  8389.  9805.  3463.  .85 1.16 .2508 1.00 .1397 140.0 .2636  72.0    23000.
  4 .001 .008 1700000. 50000. 50000. 50000. 5.49 5.80 .1094 6.18 .0935 186.7 .1576 100.9    32000.
  4 .001 .003 1700000. 50000. 50000. 50000. 1.82 2.13 .0369 2.04 .0448 105.6 .0866  56.6    16000.
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| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 271 | 6 | 12 | 6.0 | 9.0 | 8.0 | | | 30000. | | 9000. | | | | 705000. | |
| 3 | .055 | .054 | 450000. | 14846. | 10194. | 4000. | 3.49 | 3.80 | .8660 | 3.66 | .3807 | 204.2 | .6444 | 109.2 | 5200. |
| 3 | .018 | .016 | 450000. | 12241. | 12397. | 5554. | 1.29 | 1.60 | .2344 | 1.41 | .1788 | 112.0 | .3434 | 59.4 | 2600. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.49 | 5.80 | .1094 | 6.18 | .0935 | 186.7 | .1576 | 100.9 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.82 | 2.13 | .0369 | 2.04 | .0448 | 105.6 | .0866 | 56.6 | 34400. |
| 1 | .070 | .070 | 710000. | 9844. | 7430. | 2472. | 2.40 | 2.71 | .9719 | 2.64 | .3316 | 290.0 | .5645 | 149.4 | 28000. |
| 1 | .029 | .025 | 710000. | 7261. | 8374. | 2202. | .68 | .99 | .3167 | .82 | .1467 | 147.3 | .2762 | 75.4 | 14000. |
| 2 | .070 | .070 | 230000. | 13946. | 8467. | 3267. | 3.95 | 4.26 | 1.1922 | 4.02 | .5723 | 152.4 | .9730 | 85.6 | 49200. |
| 2 | .026 | .026 | 230000. | 10525. | 9282. | 3042. | 1.25 | 1.56 | .4127 | 1.33 | .3039 | 95.9 | .5943 | 52.6 | 24600. |
| 2 | .060 | .060 | 230000. | 15367. | 9887. | 4050. | 4.26 | 4.57 | 1.0383 | 4.35 | .5378 | 141.9 | .9159 | 80.9 | 118800. |
| 2 | .024 | .023 | 230000. | 11027. | 10056. | 3740. | 1.37 | 1.68 | .3691 | 1.46 | .2968 | 93.4 | .5822 | 51.5 | 59400. |
| 3 | .050 | .050 | 450000. | 15603. | 10821. | 4420. | 3.64 | 3.95 | .8152 | 3.80 | .3711 | 198.5 | .6280 | 106.5 | 82700. |
| 3 | .019 | .017 | 450000. | 11723. | 11717. | 4711. | 1.20 | 1.51 | .2566 | 1.32 | .1821 | 114.2 | .3492 | 60.4 | 41350. |
| 4 | .042 | .042 | 1700000. | 12236. | 10655. | 3812. | 1.96 | 2.27 | .5169 | 2.27 | .1627 | 345.8 | .2784 | 176.0 | 32600. |
| 4 | .013 | .012 | 1700000. | 89800. | 11239. | 3797. | .51 | .82 | .1358 | .59 | .0468 | 110.2 | .0906 | 59.2 | 16300. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.49 | 5.80 | .1094 | 6.18 | .0935 | 186.7 | .1576 | 100.9 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.82 | 2.13 | .0369 | 2.04 | .0448 | 105.6 | .0866 | 56.6 | 24350. |
| 1 | .050 | .050 | 710000. | 11981. | 9893. | 4041. | 3.01 | 3.32 | .7435 | 3.29 | .3010 | 260.3 | .5105 | 135.3 | 46000. |
| 1 | .017 | .017 | 710000. | 8517. | 10243. | 4207. | .94 | 1.25 | .2263 | 1.09 | .1377 | 137.9 | .2602 | 71.0 | 23000. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.49 | 5.80 | .1094 | 6.18 | .0935 | 186.7 | .1576 | 100.9 | 89900. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.82 | 2.13 | .0369 | 2.04 | .0448 | 105.6 | .0866 | 56.6 | 44950. |
| 1 | .072 | .072 | 710000. | 9796. | 7218. | 2375. | 2.36 | 2.67 | .9927 | 2.59 | .3337 | 292.1 | .5683 | 150.4 | 99300. |
| 1 | .030 | .028 | 710000. | 7022. | 8084. | 1914. | .64 | .95 | .3399 | .77 | .1488 | 149.4 | .2799 | 76.4 | 49650. |
| 2 | .065 | .065 | 230000. | 14529. | 9191. | 3626. | 4.10 | 4.41 | 1.1154 | 4.18 | .5563 | 147.5 | .9464 | 83.4 | 35800. |
| 2 | .028 | .025 | 230000. | 10751. | 9631. | 3346. | 1.30 | 1.61 | .3921 | 1.39 | .3006 | 94.7 | .5887 | 52.1 | 17900. |
| 311 | 6 | 11 | 6.0 | 9.0 | 12.0 | | | 30000. | | 9000. | | | | 670000. | |
| 3 | .035 | .035 | 450000. | 19766. | 15386. | 7000. | 3.55 | 3.91 | .5034 | 3.69 | .3210 | 168.4 | .5431 | 92.7 | 5200. |
| 3 | .014 | .014 | 450000. | 12400. | 13392. | 6288. | 1.12 | 1.48 | .1801 | 1.22 | .1748 | 109.3 | .3365 | 58.2 | 2600. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.65 | 5.01 | .0929 | 5.13 | .0935 | 186.5 | .1575 | 100.9 | 68800. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.50 | 1.86 | .0303 | 1.65 | .0448 | 105.6 | .0865 | 56.6 | 34400. |
| 1 | .061 | .061 | 710000. | 11555. | 8960. | 2771. | 2.15 | 2.51 | .7748 | 2.32 | .3072 | 266.7 | .5215 | 138.3 | 28000. |
| 1 | .028 | .025 | 710000. | 7599. | 9120. | 2084. | .58 | .94 | .2840 | .69 | .1433 | 143.7 | .2701 | 73.7 | 14000. |
| 2 | .057 | .057 | 230000. | 16904. | 11012. | 3884. | 3.31 | 3.67 | .8422 | 3.36 | .5038 | 131.5 | .8621 | 76.3 | 32000. |
| 2 | .023 | .023 | 230000. | 11829. | 11125. | 3624. | 1.07 | 1.43 | .2962 | 1.14 | .2858 | 89.6 | .5636 | 49.9 | 16000. |
| 2 | .048 | .048 | 230000. | 18307. | 12718. | 4987. | 3.64 | 4.00 | .7206 | 3.70 | .4766 | 123.3 | .8210 | 72.6 | 137000. |
| 2 | .022 | .023 | 230000. | 11519. | 11114. | 3605. | 1.07 | 1.43 | .2980 | 1.14 | .2880 | 90.3 | .5672 | 50.2 | 68500. |
| 3 | .048 | .048 | 450000. | 17135. | 11893. | 4280. | 2.92 | 3.28 | .6774 | 3.02 | .3516 | 186.8 | .5950 | 101.2 | 81700. |
| 3 | .022 | .020 | 450000. | 10999. | 11309. | 3233. | .83 | 1.19 | .2592 | .92 | .1845 | 115.8 | .3534 | 61.2 | 40850. |
| 4 | .045 | .045 | 1700000. | 12766. | 10818. | 3263. | 1.60 | 1.96 | .4941 | 1.83 | .1604 | 341.2 | .2743 | 173.8 | 32600. |
| 4 | .020 | .019 | 1700000. | 8288. | 10815. | 2316. | .42 | .78 | .1871 | .54 | .0699 | 168.8 | .1308 | 85.5 | 16300. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.65 | 5.01 | .0929 | 5.13 | .0935 | 186.5 | .1575 | 100.9 | 48700. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.50 | 1.86 | .0303 | 1.65 | .0448 | 105.6 | .0865 | 56.6 | 24350. |
| 1 | .050 | .050 | 710000. | 12690. | 10374. | 3686. | 2.45 | 2.81 | .6623 | 2.63 | .2923 | 252.2 | .4955 | 131.5 | 46000. |
| 1 | .020 | .019 | 710000. | 8264. | 10127. | 3265. | .72 | 1.08 | .2234 | .83 | .1382 | 138.4 | .2609 | 71.2 | 23000. |
| 4 | .001 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.65 | 5.01 | .0929 | 5.13 | .0935 | 186.5 | .1575 | 100.9 | 89900. |
| 4 | .001 | .003 | 1700000. | 50000. | 50000. | 50000. | 1.50 | 1.86 | .0303 | 1.65 | .0448 | 105.6 | .0865 | 56.6 | 44950. |
| 1 | .065 | .065 | 710000. | 11246. | 8506. | 2531. | 2.06 | 2.42 | .8139 | 2.23 | .3120 | 271.5 | .5301 | 140.6 | 100100. |
| 1 | .030 | .029 | 710000. | 7424. | 8735. | 1684. | .52 | .88 | .3175 | .63 | .1456 | 146.0 | .2742 | 74.9 | 50050. |

# APPENDIX C

## ROADBED SOIL STRESS SENSITIVITY VALUES FOR AASHO ROAD TEST SINGLE AXLE SECTIONS

Table C.1 contains a summary of the stress sensitivity values determined for the 33 AASHO Road Test single axle load (Lane 1) sections considered in this study. Stress sensitivity (SSG) is an indicator of a material's resilient (elastic) behavior under different loads. A material which responds linearly to load has an SSG equal to zero. A material whose resilient modulus increases with increasing load will have a positive SSG and, conversely, a material whose modulus decreases with increasing load will have a negative SSG.

In this study, roadbed soil stress sensitivity is calculated as the slope of the line in a log-log plot of resilient (elastic) modulus, $E_{RS}$, versus deviator stress, $\sigma_d$. Thus, given two points derived from the deflection based materials characterization procedure described in Task 5 of Chapter 3, the slope can be calculated as follows:

$$SSG = \frac{\log (E_{RS})_1 - \log (E_{RS})_2}{\log (\sigma_d)_1 - \log (\sigma_d)_2}$$

As can be seen in Table C.1, insitu stress sensitivity values were determined for each season of each single axle section up until the time it failed. In cases where there was significant variation in deflection within a season, two values of SSG were generated.

Examination of the data indicates a considerable amount of variation in the in-situ SSG for the AASHO Road Test roadbed soil. However, there does seem to be an indication that the soil has an overall positive SSG, rather than the extreme negative value that was determined in laboratory resilient modulus tests under NCHRP Project 1-10B.

Table C.1. Stress sensitivity values determined from analysis of deflection measurements on single axle load lanes.

| | | 1958 | 1959 | | | | 1960 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Loop No. | AASHO Sect | Fall | Spring Thaw | Summer | Fall | Wint Unfr | Spr Thaw | Spr Thaw | Summer | Fall |
| 3 | 111 | .01 | -.07 | -.04 | .01 | -.11 | -.03 | .33 | | |
| | 155 | -.05 | -.19/-.39 | -.32/-.25 | -.80 | -.45 | .42 | .30 | | |
| 4 | 623 | -.24 | .70 | | | | | | | |
| | 601 | -.70 | .22 | .34 | .07 | -.09 | .71 | .47 | | |
| | 577 | .05 | .15 | .23/.24 | .45 | .13 | -1.02 | .17 | -.41 | |
| | 625 | .12 | .18 | .51 | .51 | .61 | .10 | .24 | .03 | |
| 5 | 419 | .60 | .97 | | | | | | | |
| | 487 | .32 | .71 | | | | | | | |
| | 471 | .50 | .30 | | | | | | | |
| | 455 | .59 | .50/.37 | | | | | | | |
| | 453 | .67 | .43 | | | | | | | |
| | 425 | .60 | .43 | .39 | -.13 | .05 | .01 | | | |
| | 417 | .28 | .38 | .01 | | | | | | |
| | 477 | .43 | .29 | .50 | .60 | .04 | .56 | .28 | .29 | .21 |
| | 469 | .20 | .04 | .32/.16 | .30 | .09 | .26 | | | |
| | 445 | .61 | .28 | .47 | .45 | .30 | .24 | .27 | .24 | |
| 6 | 303 | .12 | .92 | | | | | | | |
| | 323 | .30 | .73 | | | | | | | |
| | 253 | -.23 | .71 | .51/.49 | .35 | .53 | .80 | | | |
| | 321 | -.30 | .80 | | | | | | | |
| | 267 | -.14 | .15 | .26 | | | | | | |
| | 309 | .12 | .29 | .06/.26 | .44 | .54 | -.13 | .37 | .13/-.22 | .12 |
| | 259 | -.24 | .68/.61 | | | | | | | |
| | 307 | .01 | .38 | .28/.31 | .14 | .07 | .10 | .62 | | |
| | 305 | .25 | .22 | -.05 | | | | | | |
| | 327 | .90 | .33 | .17/.35 | .42 | .34 | .14 | .44 | .22 | |
| | 313 | .10 | .34 | .26/.28 | .12 | .07 | .70 | | | |
| | 331 | .53 | .44 | .37/.38 | .37 | .15 | .29 | | | |
| | 325 | -.33 | .41/.42 | | | | | | | |
| | 257 | -.43 | .25 | .36/.43 | .33 | .09 | .13 | .12 | .18 | |
| | 263 | -.59 | .21 | -.09/.27 | .17 | -.45 | -.13 | | | |
| | 271 | -.38 | .12 | .07/.08 | -.07 | .00 | -.04 | .21 | .08 | |
| | 311 | .11 | .29 | .07/.31 | .28 | .37 | .13 | .41 | | |

# APPENDIX D

## ROADBED SOIL STRESS SENSITIVITY VALUES FOR AASHO ROAD TEST TANDEM AXLE SECTIONS

Table D.1 contains a summary of the stress sensitivity values used for the 27 AASHO Road Test tandem axle load (Lane 2) sections considered in this study. Only the values for the Loop 3 sections were derived using the deflection based materials characterization technique described in Task 5 of Chapter 3. The roadbed soil stress sensitivity (SSG) values for sections in Loops 4, 5 and 6 were obtained from their counterparts in Lane 1. In case where the Lane 1 counterpart segments "failed" before the tandem axle section, an SSG value was selected based on values observed in other sections during the same season. These values are shown with an accuracy of only one place past the decimal.

Table D.1. Stress sensitivity values used for tandem axle load lanes.

| Loop No. | AASHO Sect | 1958 Fall | 1959 Spring Thaw | 1959 Summer | 1959 Fall | 1959 Wint Unfr | 1960 Spr Thaw | 1960 Spr Thaw | 1960 Summer | 1960 Fall |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 112 | -1.02 | .50 | .41/.03 | -.28 | .39 | .40 | | | |
| | 156 | -.18 | .41/.06 | -.11/.41 | -.05 | 1.07 | .41 | | | |
| 4 | 624 | -.24 | .70 | .3 | | | | | | |
| | 602 | -.70 | .22 | .34 | .07 | -.09 | .71 | | | |
| | 578 | .05 | .15 | .23/.24 | .45 | .13 | -1.02 | .17 | -.41 | |
| 5 | 420 | .60 | .96 | | | | | | | |
| | 488 | .32 | .71 | .3/.2 | .4 | .3 | .3 | | | |
| | 472 | .50 | .30 | | | | | | | |
| | 456 | .59 | .50 | | | | | | | |
| | 454 | .66 | .43 | .4 | | | | | | |
| | 426 | .60 | .43 | .39 | | | | | | |
| | 418 | .28 | .38 | .01 | | | | | | |
| | 470 | .20 | .04 | .32/.16 | .30 | .09 | | | | |
| | 446 | .61 | .28 | .47 | .45 | .30 | .24 | .27 | .24 | |
| 6 | 304 | .12 | .92 | .2 | | | | | | |
| | 324 | .30 | .73 | | | | | | | |
| | 254 | -.23 | .71 | .51/.49 | | | | | | |
| | 322 | -.30 | .80 | .5 | | | | | | |
| | 268 | -.14 | .15 | .26/.3 | | | | | | |
| | 260 | -.24 | .68 | .4 | | | | | | |
| | 308 | .01 | .38 | .28/.31 | .14 | .07 | .10 | | | |
| | 306 | .25 | .22 | -.05/.3 | .2 | .1 | .2 | .3 | | |
| | 328 | .90 | .33 | .17/.35 | .42 | .34 | .14 | .44 | | |
| | 314 | .10 | .34 | .26/.28 | .12 | .07 | .70 | .3 | | |
| | 332 | .53 | .44 | .37/.38 | | | | | | |
| | 326 | -.33 | .41 | .3 | | | | | | |
| | 272 | -.38 | .12 | .07/.08 | -.07 | .00 | -.04 | .21 | | |

# APPENDIX E
# TANDEM AXLE DATA BASE

This appendix contains the data base generated for the 27 AASHO Road Test tandem axle (Lane 2) sections considered in this study. The discussion provided in Appendix A for decoding the single axle data base also applies to the tandem axle data presented here. The only difference is that for each season within a section, the steering axle data is listed before the corresponding tandem axle data.

```
112 3 10       2.0    6.0    8.0          24000.    6000.                            500000.
  3 .000 .018  450000. 24048. 13751.  6877. 2.70 2.91 .3927 2.71 .3426 205.4 .6936 120.0     2600.
  3 .000 .035  450000. 23262. 13282.  5100. 3.64 3.85 .7124 3.93 .3678 211.8 .7113 123.1     5200.
  4 .000 .005 1700000. 50000. 50000. 50000. 3.87 4.08 .0778 4.06 .1189 276.8 .2330 152.4    32200.
  4 .000 .006 1700000. 50000. 50000. 50000. 5.73 5.94 .1125 6.31 .1264 280.0 .2360 154.3    64400.
  1 .000 .041  710000. 11748.  5911.  1652. 1.56 1.77 .9478 1.59 .4022 399.5 .7677 209.6    14100.
  1 .000 .071  710000. 13367.  6981.  2176. 2.89 3.101.3294 3.13 .4209 393.9 .7618 208.0    28200.
  2 .000 .032  230000. 19171.  8648.  2802. 2.07 2.28 .7401 2.06 .5084 149.71.0746  95.1    26700.
  2 .000 .050  230000. 20325. 10051.  3384. 3.41 3.621.0082 3.71 .4982 140.21.0272  90.9    53400.
  2 .000 .022  230000. 22778. 12206.  5456. 2.68 2.88 .4906 2.68 .4454 127.8 .9665  85.5    59900.
  2 .000 .034  230000. 23151. 13461.  5516. 3.97 4.18 .7138 4.30 .4469 123.6 .9447  83.6   119800.
  3 .000 .017  450000. 24334. 14278.  7399. 2.77 2.98 .3751 2.78 .3396 203.3 .6882 119.1    40850.
  3 .000 .029  450000. 24090. 15105.  6709. 4.01 4.22 .5941 4.32 .3563 204.7 .6927 119.9    81700.
  4 .000 .017 1700000. 16502. 12071.  5642. 2.11 2.31 .3746 2.19 .1952 467.5 .3694 241.5    16300.
  4 .000 .027 1700000. 19293. 14483.  6802. 3.54 3.75 .5264 3.95 .2083 467.0 .3710 242.6    32600.
  4 .000 .005 1700000. 50000. 50000. 50000. 3.87 4.08 .0778 4.06 .1189 276.8 .2330 152.4    24350.
  4 .000 .006 1700000. 50000. 50000. 50000. 5.73 5.94 .1125 6.31 .1264 280.0 .2360 154.3    48700.
  1 .000 .020  710000. 15916. 11189.  5435. 2.52 2.73 .4641 2.56 .3356 330.1 .6482 177.0    23000.
  1 .000 .031  710000. 17834. 13344.  6534. 4.07 4.28 .6221 4.43 .3427 318.2 .6304 172.1    46000.
  4 .000 .005 1700000. 50000. 50000. 50000. 3.87 4.08 .0778 4.06 .1189 276.8 .2330 152.4    10000.
  4 .000 .006 1700000. 50000. 50000. 50000. 5.73 5.94 .1125 6.31 .1264 280.0 .2360 154.3    20000.
156 3 11       3.0    6.0    8.0          24000.    6000.                            492000.
  3 .000 .020  450000. 16094. 10724.  4249. 1.83 2.05 .4311 1.87 .3043 188.4 .5930 102.6     2600.
  3 .000 .041  450000. 16739. 11017.  3935. 2.93 3.15 .7438 3.21 .3403 197.9 .6247 108.1     5200.
  4 .000 .003 1700000. 50000. 50000. 50000. 2.92 3.15 .0589 3.15 .0817 191.4 .1587 103.8    32200.
  4 .000 .005 1700000. 50000. 50000. 50000. 4.55 4.77 .0914 5.21 .0922 201.8 .1678 109.7    64400.
  1 .000 .022  710000. 10579.  8881.  3444. 1.56 1.79 .4565 1.66 .2579 257.1 .4900 133.8     5050.
  1 .000 .038  710000. 13003. 10682.  4324. 2.89 3.12 .6677 3.24 .2826 263.1 .5061 138.2    10100.
  1 .000 .027  710000.  9937.  7324.  2410. 1.33 1.56 .5573 1.42 .2690 268.6 .5098 139.2     9050.
  1 .000 .058  710000. 11256.  7826.  2485. 2.41 2.64 .9593 2.67 .3094 290.4 .5537 151.2    18100.
  2 .000 .027  230000. 15338.  8900.  2968. 1.79 2.02 .6048 1.81 .4547 139.6 .9182  81.2    26700.
  2 .000 .055  230000. 15371.  8821.  2829. 2.90 3.121.0269 3.16 .4995 145.0 .9537  84.4    53400.
  2 .000 .024  230000. 15326. 10035.  3873. 2.03 2.25 .5250 2.06 .4493 137.7 .9091  80.4    59900.
  2 .000 .037  230000. 17476. 11872.  4710. 3.39 3.62 .7260 3.74 .4541 130.4 .8808  77.9   119800.
  3 .000 .016  450000. 17455. 12548.  5894. 2.08 2.31 .3544 2.14 .2908 179.4 .5695  98.6    40850.
  3 .000 .031  450000. 18428. 13556.  5762. 3.29 3.52 .5755 3.64 .3188 184.4 .5889 101.9    81700.
  4 .000 .015 1700000. 11363. 10665.  4390. 1.27 1.49 .2923 1.41 .1330 320.3 .2499 163.4    16300.
  4 .000 .019 1700000. 16342. 16055.  9588. 3.00 3.23 .3131 3.49 .1418 318.0 .2509 164.0    32600.
  4 .000 .003 1700000. 50000. 50000. 50000. 2.92 3.15 .0589 3.15 .0817 191.4 .1587 103.8    24350.
  4 .000 .005 1700000. 50000. 50000. 50000. 4.55 4.77 .0914 5.21 .0922 201.8 .1678 109.7    48700.
  1 .000 .022  710000. 10579.  8881.  3444. 1.56 1.79 .4565 1.66 .2579 257.1 .4900 133.8    23000.
  1 .000 .038  710000. 13003. 10682.  4324. 2.89 3.12 .6677 3.24 .2826 263.1 .5061 138.2    46000.
  4 .000 .003 1700000. 50000. 50000. 50000. 2.92 3.15 .0589 3.15 .0817 191.4 .1587 103.8     6000.
  4 .000 .005 1700000. 50000. 50000. 50000. 4.55 4.77 .0914 5.21 .0922 201.8 .1678 109.7    12000.
624 4  4       3.0    6.0    8.0          32000.    9000.                            137000.
  3 .000 .030  450000. 17195. 10199.  3731. 2.55 2.77 .6831 2.58 .3688 227.5 .7220 125.0     2600.
  3 .000 .060  450000. 17068.  9974.  3444. 3.70 3.931.0716 4.04 .4047 233.7 .7394 128.0     5200.
  4 .000 .004 1700000. 50000. 50000. 50000. 3.85 4.07 .0776 4.15 .0946 221.3 .1844 120.5    32200.
  4 .000 .007 1700000. 50000. 50000. 50000. 6.01 6.23 .1208 6.90 .1085 235.3 .1965 128.5    64400.
  1 .000 .040  710000. 10157.  6386.  1926. 1.61 1.83 .8378 1.69 .3278 327.4 .6214 169.7    14100.
  1 .000 .069  710000. 13280.  8292.  2828. 3.31 3.541.1575 3.65 .3556 330.8 .6351 173.4    28200.
  2 .000 .047  230000. 13298.  6309.  1947. 2.06 2.281.0568 2.06 .5706 176.81.1403 100.9    19600.
  2 .000 .090  230000. 15122.  7050.  2200. 3.56 3.791.6140 3.87 .5978 172.51.1313 100.1    39200.
602 4  9       3.0    6.0   12.0          32000.    9000.                            569900.
  3 .000 .021  450000. 21551. 14688.  5879. 2.15 2.42 .3657 2.18 .3194 194.3 .6355 110.0     2600.
```

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | .000 | .043 | 450000. | 21076. | 14161. | 4683. | 3.11 | 3.39 | .6541 | 3.33 | .3475 | 197.8 | .6437 | 111.4 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.88 | 3.15 | .0579 | 3.04 | .0946 | 221.2 | .1843 | 120.5 | 34400. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.77 | 5.04 | .0956 | 5.35 | .1085 | 235.1 | .1964 | 128.4 | 68800. |
| 1 | .000 | .028 | 710000. | 13164. | 9672. | 2944. | 1.41 | 1.69 | .4820 | 1.47 | .2860 | 283.8 | .5464 | 149.2 | 14000. |
| 1 | .000 | .057 | 710000. | 15501. | 10665. | 3261. | 2.73 | 3.01 | .8181 | 2.93 | .3209 | 295.9 | .5745 | 156.9 | 28000. |
| 2 | .000 | .028 | 230000. | 18935. | 11648. | 3554. | 1.72 | 2.00 | .4852 | 1.75 | .4488 | 134.5 | .9310 | 82.4 | 84500. |
| 2 | .000 | .049 | 230000. | 22072. | 13345. | 4121. | 3.14 | 3.42 | .7534 | 3.38 | .4437 | 122.8 | .8812 | 77.9 | 169000. |
| 3 | .000 | .021 | 450000. | 19710. | 13391. | 4973. | 1.81 | 2.08 | .3645 | 1.84 | .3171 | 194.1 | .6266 | 108.4 | 40850. |
| 3 | .000 | .040 | 450000. | 22014. | 14894. | 5114. | 3.19 | 3.46 | .6138 | 3.41 | .3387 | 192.3 | .6294 | 108.9 | 81700. |
| 4 | .000 | .017 | 1700000. | 15725. | 12859. | 5031. | 1.40 | 1.67 | .2801 | 1.49 | .1472 | 353.3 | .2778 | 181.6 | 16300. |
| 4 | .000 | .038 | 1700000. | 17259. | 13604. | 4831. | 2.63 | 2.90 | .5297 | 2.87 | .1769 | 396.9 | .3132 | 204.8 | 32600. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.88 | 3.15 | .0579 | 3.04 | .0946 | 221.2 | .1843 | 120.5 | 24350. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.77 | 5.04 | .0956 | 5.35 | .1085 | 235.1 | .1964 | 128.4 | 48700. |
| 1 | .000 | .030 | 710000. | 12717. | 9198. | 2586. | 1.33 | 1.61 | .5179 | 1.39 | .2908 | 288.8 | .5549 | 151.5 | 23000. |
| 1 | .000 | .050 | 710000. | 16460. | 11626. | 3889. | 2.89 | 3.17 | .7279 | 3.10 | .3104 | 285.5 | .5564 | 151.9 | 46000. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.88 | 3.15 | .0579 | 3.04 | .0946 | 221.2 | .1843 | 120.5 | 44950. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.77 | 5.04 | .0956 | 5.35 | .1085 | 235.1 | .1964 | 128.4 | 89900. |
| 578 | 4 | 12 | | 4.0 | 6.0 | 8.0 | | 32000. | | 9000. | | | | 716000. | |
| 3 | .000 | .021 | 450000. | 15275. | 11874. | 5223. | 2.33 | 2.57 | .4473 | 2.43 | .2851 | 177.1 | .5531 | 95.7 | 2600. |
| 3 | .000 | .039 | 450000. | 17257. | 13255. | 5326. | 3.56 | 3.80 | .6632 | 3.95 | .3050 | 176.1 | .5552 | 96.1 | 5200. |
| 4 | .000 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.98 | 3.22 | .0602 | 3.28 | .0697 | 163.6 | .1351 | 88.3 | 34400. |
| 4 | .000 | .006 | 1700000. | 50000. | 50000. | 50000. | 4.82 | 5.06 | .0976 | 5.69 | .0835 | 181.3 | .1504 | 98.3 | 68800. |
| 1 | .000 | .025 | 710000. | 9727. | 8272. | 3016. | 1.43 | 1.67 | .4773 | 1.56 | .2261 | 226.0 | .4278 | 116.8 | 11900. |
| 1 | .000 | .056 | 710000. | 11716. | 9256. | 3247. | 2.77 | 3.01 | .8355 | 3.13 | .2687 | 253.0 | .4824 | 131.7 | 23800. |
| 2 | .000 | .032 | 230000. | 12795. | 8363. | 2926. | 1.97 | 2.21 | .6744 | 2.02 | .4387 | 136.9 | .8691 | 76.9 | 35500. |
| 2 | .000 | .062 | 230000. | 15124. | 9377. | 3216. | 3.46 | 3.70 | 1.0668 | 3.78 | .4769 | 137.8 | .8923 | 78.9 | 71000. |
| 2 | .000 | .026 | 230000. | 14287. | 10011. | 4013. | 2.23 | 2.47 | .5575 | 2.29 | .4124 | 127.7 | .8243 | 72.9 | 51200. |
| 2 | .000 | .049 | 230000. | 16977. | 11566. | 4413. | 3.79 | 4.03 | .8568 | 4.17 | .4408 | 126.0 | .8330 | 73.7 | 102400. |
| 3 | .000 | .021 | 450000. | 14298. | 11107. | 4554. | 1.96 | 2.20 | .4321 | 2.05 | .2735 | 170.4 | .5288 | 91.5 | 40850. |
| 3 | .000 | .038 | 450000. | 18276. | 13515. | 5604. | 3.61 | 3.85 | .6391 | 4.00 | .2985 | 172.1 | .5445 | 94.2 | 81700. |
| 4 | .000 | .018 | 1700000. | 10585. | 9940. | 3690. | 1.06 | 1.30 | .2920 | 1.23 | .1137 | 274.1 | .2131 | 139.4 | 16300. |
| 4 | .000 | .042 | 1700000. | 13024. | 11492. | 3964. | 2.24 | 2.48 | .5518 | 2.64 | .1393 | 321.5 | .2513 | 164.3 | 32600. |
| 4 | .000 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.98 | 3.22 | .0602 | 3.28 | .0697 | 163.6 | .1351 | 88.3 | 24350. |
| 4 | .000 | .006 | 1700000. | 50000. | 50000. | 50000. | 4.82 | 5.06 | .0976 | 5.69 | .0835 | 181.3 | .1504 | 98.3 | 48700. |
| 1 | .000 | .016 | 710000. | 12383. | 11823. | 6380. | 1.98 | 2.22 | .3127 | 2.16 | .2032 | 202.1 | .3870 | 105.7 | 23000. |
| 1 | .000 | .043 | 710000. | 12639. | 11341. | 4643. | 3.12 | 3.36 | .6635 | 3.56 | .2544 | 237.6 | .4556 | 124.4 | 46000. |
| 4 | .000 | .003 | 1700000. | 50000. | 50000. | 50000. | 2.98 | 3.22 | .0602 | 3.28 | .0697 | 163.6 | .1351 | 88.3 | 44950. |
| 4 | .000 | .006 | 1700000. | 50000. | 50000. | 50000. | 4.82 | 5.06 | .0976 | 5.69 | .0835 | 181.3 | .1504 | 98.3 | 89900. |
| 1 | .000 | .028 | 710000. | 9254. | 7606. | 2563. | 1.32 | 1.56 | .5205 | 1.45 | .2313 | 231.5 | .4373 | 119.4 | 49650. |
| 1 | .000 | .063 | 710000. | 11138. | 8422. | 2788. | 2.62 | 2.86 | .9214 | 2.97 | .2763 | 261.2 | .4966 | 135.6 | 99300. |
| 2 | .000 | .026 | 230000. | 15013. | 10210. | 3871. | 2.17 | 2.41 | .5617 | 2.22 | .4050 | 125.2 | .8119 | 71.8 | 23300. |
| 2 | .000 | .060 | 230000. | 14937. | 9882. | 3382. | 3.51 | 3.75 | 1.0321 | 3.85 | .4757 | 137.4 | .8898 | 78.7 | 46600. |
| 420 | 5 | 3 | | 3.0 | 6.0 | 8.0 | | 40000. | | 9000. | | | | 76000. | |
| 3 | .000 | .033 | 450000. | 15905. | 9248. | 3235. | 2.42 | 2.65 | .7504 | 2.46 | .3843 | 237.8 | .7492 | 129.7 | 2600. |
| 3 | .000 | .056 | 450000. | 21952. | 12687. | 4825. | 4.96 | 5.18 | 1.0275 | 5.42 | .3948 | 223.3 | .7283 | 126.0 | 5200. |
| 4 | .000 | .005 | 1700000. | 50000. | 50000. | 50000. | 4.75 | 4.98 | .0958 | 5.14 | .1051 | 245.3 | .2052 | 134.1 | 32200. |
| 4 | .000 | .009 | 1700000. | 50000. | 50000. | 50000. | 7.44 | 7.66 | .1497 | 8.56 | .1224 | 262.8 | .2204 | 144.1 | 64400. |
| 1 | .000 | .067 | 710000. | 8561. | 4787. | 1258. | 1.67 | 1.90 | 1.3367 | 1.76 | .4098 | 410.4 | .7741 | 211.4 | 3200. |
| 1 | .000 | .079 | 710000. | 14759. | 8843. | 3114. | 4.21 | 4.44 | 1.3378 | 4.63 | .3926 | 362.4 | .6998 | 191.1 | 6400. |
| 488 | 5 | 9 | | 3.0 | 6.0 | 12.0 | | 40000. | | 9000. | | | | 458000. | |
| 3 | .000 | .026 | 450000. | 18758. | 12325. | 3998. | 1.85 | 2.13 | .4644 | 1.88 | .3444 | 211.2 | .6791 | 117.5 | 2600. |
| 3 | .000 | .050 | 450000. | 24712. | 14935. | 4935. | 3.83 | 4.11 | .7634 | 4.09 | .3585 | 200.7 | .6678 | 115.6 | 5200. |
| 4 | .000 | .005 | 1700000. | 50000. | 50000. | 50000. | 3.57 | 3.84 | .0717 | 3.77 | .1050 | 245.2 | .2051 | 134.1 | 32200. |
| 4 | .000 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.92 | 6.20 | .1187 | 6.65 | .1223 | 262.6 | .2203 | 144.0 | 64400. |
| 1 | .000 | .040 | 710000. | 12351. | 8693. | 2273. | 1.57 | 1.84 | .6934 | 1.63 | .3354 | 333.1 | .6400 | 174.8 | 14100. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .000 | .059 | 710000. | 18159. | 12147. | 4085. | 3.61 | 3.88 | .8643 | 3.86 | .3412 | 311.0 | .6106 | 166.7 | 28200. |
| 2 | .000 | .035 | 230000. | 18872. | 11461. | 3415. | 2.11 | 2.38 | .6180 | 2.13 | .4852 | 144.8 | 1.0108 | 89.4 | 26700. |
| 2 | .000 | .060 | 230000. | 24088. | 13653. | 4143. | 3.84 | 4.11 | .9152 | 4.14 | .4543 | 122.6 | .9094 | 80.4 | 53400. |
| 2 | .000 | .032 | 230000. | 19627. | 12296. | 4021. | 2.26 | 2.53 | .5615 | 2.28 | .4716 | 140.1 | .9878 | 87.4 | 59900. |
| 2 | .000 | .055 | 230000. | 24695. | 14450. | 4539. | 3.94 | 4.22 | .8584 | 4.25 | .4442 | 119.4 | .8936 | 79.1 | 119800. |
| 3 | .000 | .027 | 450000. | 19210. | 13075. | 4663. | 2.20 | 2.48 | .4726 | 2.23 | .3544 | 216.7 | .7011 | 121.3 | 40850. |
| 3 | .000 | .043 | 450000. | 26290. | 16697. | 6074. | 4.08 | 4.35 | .6615 | 4.36 | .3422 | 190.5 | .6412 | 111.0 | 81700. |
| 4 | .000 | .020 | 1700000. | 15176. | 12913. | 5396. | 1.82 | 2.09 | .3390 | 1.93 | .1694 | 406.5 | .3198 | 209.1 | 16300. |
| 4 | .000 | .037 | 1700000. | 21555. | 16425. | 6688. | 3.60 | 3.87 | .5244 | 3.91 | .1899 | 419.4 | .3335 | 218.0 | 32600. |
| 4 | .000 | .005 | 1700000. | 50000. | 50000. | 50000. | 3.57 | 3.84 | .0717 | 3.77 | .1050 | 245.2 | .2051 | 134.1 | 24350. |
| 4 | .000 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.92 | 6.20 | .1187 | 6.65 | .1223 | 262.6 | .2203 | 144.0 | 48700. |
| 1 | .000 | .030 | 710000. | 13669. | 10487. | 3610. | 1.93 | 2.21 | .5369 | 1.99 | .3159 | 312.9 | .6051 | 165.2 | 12000. |
| 1 | .000 | .055 | 710000. | 18540. | 12783. | 4431. | 3.70 | 3.97 | .8173 | 3.96 | .3357 | 305.5 | .6012 | 164.2 | 24000. |
| 472 | 5 | 3 | 3.0 | 9.0 | 8.0 | | | 40000. | | 9000. | | | | 85300. | |
| 3 | .000 | .035 | 450000. | 15243. | 7916. | 2542. | 1.70 | 1.96 | .6671 | 1.70 | .3790 | 234.3 | .7398 | 128.0 | 2600. |
| 3 | .000 | .065 | 450000. | 20198. | 9895. | 3679. | 3.81 | 4.07 | 1.0155 | 4.02 | .3979 | 225.2 | .7329 | 126.8 | 5200. |
| 4 | .000 | .005 | 1700000. | 50000. | 50000. | 50000. | 3.78 | 4.05 | .0762 | 4.03 | .1049 | 244.8 | .2048 | 133.9 | 32200. |
| 4 | .000 | .009 | 1700000. | 50000. | 50000. | 50000. | 6.18 | 6.44 | .1245 | 7.03 | .1221 | 262.0 | .2199 | 143.8 | 64400. |
| 1 | .000 | .058 | 710000. | 9426. | 5310. | 1361. | 1.39 | 1.65 | 1.0211 | 1.43 | .3753 | 374.6 | .7117 | 194.4 | 7850. |
| 1 | .000 | .121 | 710000. | 11334. | 5494. | 1716. | 3.00 | 3.27 | 1.6994 | 3.19 | .4327 | 402.8 | .7705 | 210.4 | 15700. |
| 456 | 5 | 3 | 4.0 | 6.0 | 8.0 | | | 40000. | | 9000. | | | | 92900. | |
| 3 | .000 | .037 | 450000. | 11383. | 7543. | 2227. | 1.61 | 1.85 | .7280 | 1.70 | .3311 | 207.9 | .6340 | 109.7 | 2600. |
| 3 | .000 | .067 | 450000. | 16411. | 10117. | 3558. | 3.88 | 4.12 | 1.0738 | 4.27 | .3750 | 217.5 | .6798 | 117.7 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 3.69 | 3.93 | .0745 | 4.07 | .0790 | 185.2 | .1534 | 100.3 | 32200. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.99 | 6.23 | .1211 | 7.07 | .0962 | 207.4 | .1725 | 112.8 | 64400. |
| 1 | .000 | .057 | 710000. | 7264. | 5317. | 1222. | 1.15 | 1.39 | .9491 | 1.28 | .3007 | 302.0 | .5658 | 154.5 | 11650. |
| 1 | .000 | .107 | 710000. | 9921. | 6476. | 1913. | 2.86 | 3.10 | 1.4580 | 3.25 | .3560 | 333.4 | .6303 | 172.1 | 23300. |
| 454 | 5 | 4 | 4.0 | 6.0 | 8.0 | | | 40000. | | 9000. | | | | 151200. | |
| 3 | .000 | .035 | 450000. | 11598. | 7812. | 2356. | 1.65 | 1.89 | .7056 | 1.74 | .3278 | 205.7 | .6281 | 108.7 | 2600. |
| 3 | .000 | .061 | 450000. | 17252. | 11065. | 4026. | 4.03 | 4.27 | .9867 | 4.43 | .3633 | 209.9 | .6595 | 114.1 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 3.69 | 3.93 | .0745 | 4.07 | .0790 | 185.2 | .1534 | 100.3 | 32200. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.99 | 6.23 | .1211 | 7.07 | .0962 | 207.4 | .1725 | 112.8 | 64400. |
| 1 | .000 | .048 | 710000. | 7897. | 6033. | 1547. | 1.29 | 1.53 | .8445 | 1.43 | .2896 | 290.5 | .5458 | 149.1 | 14100. |
| 1 | .000 | .094 | 710000. | 10769. | 7152. | 2229. | 3.02 | 3.26 | 1.3225 | 3.42 | .3431 | 320.2 | .6072 | 165.8 | 28200. |
| 2 | .000 | .047 | 230000. | 11582. | 7102. | 2171. | 2.17 | 2.41 | 1.0016 | 2.22 | .5246 | 164.5 | 1.0334 | 91.4 | 26700. |
| 2 | .000 | .085 | 230000. | 15111. | 8595. | 2860. | 4.13 | 4.37 | 1.4298 | 4.51 | .5515 | 158.7 | 1.0272 | 90.9 | 53400. |
| 426 | 5 | 4 | 4.0 | 6.0 | 12.0 | | | 40000. | | 9000. | | | | 182000. | |
| 3 | .000 | .026 | 450000. | 14570. | 11180. | 3387. | 1.45 | 1.74 | .4286 | 1.51 | .2892 | 179.9 | .5602 | 97.0 | 2600. |
| 3 | .000 | .044 | 450000. | 21426. | 15045. | 5446. | 3.53 | 3.82 | .6325 | 3.79 | .3157 | 179.1 | .5779 | 100.0 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.88 | 3.17 | .0580 | 3.10 | .0789 | 185.1 | .1533 | 100.3 | 32200. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.99 | 5.28 | .0988 | 5.65 | .0961 | 207.2 | .1724 | 112.7 | 64400. |
| 1 | .000 | .033 | 710000. | 10128. | 8787. | 2384. | 1.25 | 1.55 | .5306 | 1.35 | .2557 | 255.3 | .4848 | 132.4 | 14100. |
| 1 | .000 | .063 | 710000. | 14357. | 10612. | 3361. | 2.88 | 3.17 | .8287 | 3.13 | .2930 | 270.0 | .5200 | 142.0 | 28200. |
| 2 | .000 | .038 | 230000. | 14306. | 9639. | 2474. | 1.60 | 1.89 | .6504 | 1.65 | .4607 | 142.4 | .9232 | 81.7 | 42100. |
| 2 | .000 | .069 | 230000. | 18874. | 11281. | 3263. | 3.29 | 3.58 | .9856 | 3.53 | .4715 | 132.5 | .8947 | 79.1 | 84200. |
| 418 | 5 | 4 | 4.0 | 9.0 | 8.0 | | | 40000. | | 9000. | | | | 123000. | |
| 3 | .000 | .029 | 450000. | 12783. | 8809. | 2834. | 1.46 | 1.73 | .5155 | 1.51 | .3034 | 189.4 | .5850 | 101.3 | 2600. |
| 3 | .000 | .064 | 450000. | 16436. | 9674. | 3460. | 3.29 | 3.57 | .9257 | 3.51 | .3585 | 206.7 | .6508 | 112.6 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 3.03 | 3.30 | .0610 | 3.28 | .0789 | 184.9 | .1532 | 100.1 | 32200. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.18 | 5.46 | .1030 | 5.93 | .0960 | 206.9 | .1721 | 112.5 | 64400. |
| 1 | .000 | .051 | 710000. | 7887. | 5859. | 1317. | 1.01 | 1.29 | .7762 | 1.11 | .2828 | 283.4 | .5335 | 145.7 | 14100. |
| 1 | .000 | .105 | 710000. | 10009. | 6124. | 1818. | 2.49 | 2.77 | 1.3227 | 2.73 | .3428 | 319.9 | .6067 | 165.7 | 28200. |
| 2 | .000 | .051 | 230000. | 11489. | 6236. | 1686. | 1.52 | 1.79 | .9006 | 1.53 | .5106 | 159.7 | 1.0093 | 89.3 | 12600. |
| 2 | .000 | .121 | 230000. | 12164. | 5612. | 1702. | 2.99 | 3.26 | 1.7056 | 3.16 | .6004 | 174.6 | 1.1082 | 98.0 | 25200. |
| 470 | 5 | 7 | 5.0 | 6.0 | 8.0 | | | 40000. | | 9000. | | | | 373000. | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | .000 | .024 | 450000. | 11556. | 9798. | 3620. | 1.57 | 1.82 | .4364 | 1.69 | .2422 | 152.1 | .4639 | 80.3 | 2600. |
| 3 | .000 | .055 | 450000. | 15542. | 11331. | 4160. | 3.43 | 3.69 | .8079 | 3.83 | .3038 | 176.3 | .5472 | 94.7 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.93 | 3.19 | .0594 | 3.29 | .0610 | 143.4 | .1181 | 77.2 | 32200. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.97 | 5.23 | .0993 | 5.92 | .0769 | 165.6 | .1372 | 89.7 | 64400. |
| 1 | .000 | .030 | 710000. | 8180. | 7967. | 2515. | 1.21 | 1.46 | .4875 | 1.38 | .2052 | 205.8 | .3870 | 105.7 | 14100. |
| 1 | .000 | .076 | 710000. | 10205. | 8361. | 2594. | 2.54 | 2.80 | .9553 | 2.96 | .2621 | 246.4 | .4664 | 127.4 | 28200. |
| 2 | .000 | .043 | 230000. | 9958. | 7188. | 2087. | 1.72 | 1.98 | .8291 | 1.80 | .4379 | 138.7 | .8524 | 75.4 | 26700. |
| 2 | .000 | .085 | 230000. | 12788. | 8163. | 2648. | 3.51 | 3.76 | 1.2981 | 3.85 | .4933 | 144.8 | .9102 | 80.5 | 53400. |
| 2 | .000 | .035 | 230000. | 11106. | 8414. | 2887. | 2.00 | 2.25 | .6943 | 2.08 | .4133 | 130.2 | .8101 | 71.7 | 59900. |
| 2 | .000 | .073 | 230000. | 14195. | 9287. | 3219. | 3.72 | 3.98 | 1.1362 | 4.09 | .4656 | 135.6 | .8633 | 76.4 | 119800. |
| 3 | .000 | .023 | 450000. | 12312. | 10972. | 4451. | 1.91 | 2.17 | .4331 | 2.06 | .2515 | 157.5 | .4831 | 83.6 | 40850. |
| 3 | .000 | .044 | 450000. | 17141. | 13451. | 5522. | 3.77 | 4.03 | .6707 | 4.22 | .2859 | 164.8 | .5169 | 89.5 | 81700. |
| 4 | .000 | .018 | 1700000. | 9352. | 10285. | 3739. | .95 | 1.20 | .2584 | 1.15 | .0985 | 237.7 | .1845 | 120.6 | 10150. |
| 4 | .000 | .047 | 1700000. | 12517. | 11547. | 4017. | 2.17 | 2.43 | .5282 | 2.65 | .1283 | 293.5 | .2290 | 149.8 | 20300. |
| 446 5 11 | | | 5.0 | 6.0 | 12.0 | | | 40000. | | 9000. | | | | 764000. | |
| 3 | .000 | .022 | 450000. | 12563. | 11246. | 3530. | 1.21 | 1.52 | .3456 | 1.30 | .2310 | 144.6 | .4442 | 76.9 | 2600. |
| 3 | .000 | .040 | 450000. | 18936. | 15129. | 5832. | 3.17 | 3.48 | .5282 | 3.45 | .2686 | 153.8 | .4879 | 84.4 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.35 | 2.66 | .0475 | 2.57 | .0610 | 143.4 | .1180 | 77.2 | 32200. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.24 | 4.55 | .0831 | 4.85 | .0769 | 165.5 | .1371 | 89.6 | 64400. |
| 1 | .000 | .027 | 710000. | 8973. | 9288. | 2764. | 1.05 | 1.36 | .3842 | 1.18 | .1949 | 195.0 | .3684 | 100.6 | 14100. |
| 1 | .000 | .058 | 710000. | 12602. | 10672. | 3433. | 2.43 | 2.74 | .6839 | 2.71 | .2369 | 219.9 | .4205 | 114.8 | 28200. |
| 2 | .000 | .031 | 230000. | 12709. | 10330. | 3017. | 1.51 | 1.81 | .5019 | 1.57 | .3817 | 119.1 | .7560 | 66.9 | 86600. |
| 2 | .000 | .053 | 230000. | 17895. | 12887. | 4298. | 3.24 | 3.55 | .7341 | 3.49 | .4001 | 113.5 | .7529 | 66.6 | 173200. |
| 3 | .000 | .020 | 450000. | 13514. | 12714. | 5243. | 1.62 | 1.92 | .3107 | 1.72 | .2376 | 148.2 | .4589 | 79.4 | 40850. |
| 3 | .000 | .034 | 450000. | 20121. | 16873. | 7347. | 3.42 | 3.73 | .4530 | 3.73 | .2583 | 147.3 | .4710 | 81.5 | 81700. |
| 4 | .000 | .016 | 1700000. | 9967. | 11525. | 4229. | .88 | 1.18 | .2113 | 1.04 | .0950 | 229.0 | .1781 | 116.5 | 16300. |
| 4 | .000 | .036 | 1700000. | 14898. | 14207. | 5428. | 2.20 | 2.50 | .3910 | 2.54 | .1183 | 267.5 | .2099 | 137.3 | 32600. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.35 | 2.66 | .0475 | 2.57 | .0610 | 143.4 | .1180 | 77.2 | 24350. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.24 | 4.55 | .0831 | 4.85 | .0769 | 165.5 | .1371 | 89.6 | 48700. |
| 1 | .000 | .019 | 710000. | 9939. | 10894. | 4738. | 1.36 | 1.66 | .2898 | 1.50 | .1849 | 184.5 | .3505 | 95.7 | 23000. |
| 1 | .000 | .039 | 710000. | 14454. | 13663. | 5685. | 2.90 | 3.21 | .4942 | 3.23 | .2189 | 201.0 | .3881 | 106.0 | 46000. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.35 | 2.66 | .0475 | 2.57 | .0610 | 143.4 | .1180 | 77.2 | 44950. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.24 | 4.55 | .0831 | 4.85 | .0769 | 165.5 | .1371 | 89.6 | 89900. |
| 1 | .000 | .028 | 710000. | 8867. | 9106. | 2591. | 1.02 | 1.32 | .3969 | 1.14 | .1961 | 196.2 | .3706 | 101.2 | 49650. |
| 1 | .000 | .061 | 710000. | 12348. | 10299. | 3207. | 2.37 | 2.68 | .7140 | 2.65 | .2396 | 222.7 | .4254 | 116.2 | 99300. |
| 2 | .000 | .028 | 230000. | 13375. | 11154. | 3731. | 1.66 | 1.97 | .4470 | 1.73 | .3712 | 115.5 | .7383 | 65.3 | 47400. |
| 2 | .000 | .052 | 230000. | 18127. | 13155. | 4393. | 3.26 | 3.56 | .7218 | 3.51 | .3970 | 112.4 | .7478 | 66.1 | 94800. |
| 304 6 4 | | | 4.0 | 6.0 | 8.0 | | | 48000. | | 12000. | | | | 114000. | |
| 3 | .000 | .023 | 450000. | 18121. | 14248. | 6908. | 3.39 | 3.63 | .4934 | 3.54 | .3088 | 190.3 | .6054 | 104.8 | 2600. |
| 3 | .000 | .045 | 450000. | 22898. | 16540. | 7321. | 5.70 | 5.94 | .7743 | 6.31 | .3519 | 192.3 | .6258 | 108.3 | 5200. |
| 4 | .000 | .005 | 1700000. | 50000. | 50000. | 50000. | 4.38 | 4.62 | .0885 | 4.84 | .0870 | 203.8 | .1693 | 110.7 | 32200. |
| 4 | .000 | .009 | 1700000. | 50000. | 50000. | 50000. | 7.14 | 7.38 | .1443 | 8.44 | .1117 | 230.6 | .1923 | 125.8 | 64400. |
| 1 | .000 | .041 | 710000. | 10424. | 7562. | 2580. | 2.00 | 2.24 | .7806 | 2.15 | .2966 | 296.3 | .5617 | 153.4 | 14100. |
| 1 | .000 | .055 | 710000. | 16561. | 12886. | 5565. | 4.87 | 5.11 | .8636 | 5.48 | .3223 | 284.3 | .5523 | 150.8 | 28200. |
| 2 | .000 | .048 | 230000. | 13752. | 7942. | 2706. | 2.81 | 3.05 | 1.0402 | 2.85 | .5313 | 165.0 | 1.0588 | 93.7 | 8100. |
| 2 | .000 | .097 | 230000. | 16157. | 8928. | 3010. | 4.97 | 5.21 | 1.6344 | 5.42 | .6025 | 167.8 | 1.0990 | 97.2 | 16200. |
| 324 6 3 | | | 4.0 | 6.0 | 12.0 | | | 48000. | | 12000. | | | | 88300. | |
| 3 | .000 | .028 | 450000. | 17666. | 12907. | 4447. | 2.12 | 2.41 | .4791 | 2.19 | .3140 | 193.8 | .6144 | 106.3 | 2600. |
| 3 | .000 | .053 | 450000. | 22946. | 15247. | 5339. | 4.14 | 4.43 | .7557 | 4.44 | .3522 | 192.4 | .6261 | 108.4 | 5200. |
| 4 | .000 | .005 | 1700000. | 50000. | 50000. | 50000. | 3.43 | 3.72 | .0690 | 3.70 | .0870 | 203.7 | .1692 | 110.6 | 32200. |
| 4 | .000 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.96 | 6.25 | .1179 | 6.75 | .1116 | 230.3 | .1922 | 125.7 | 64400. |
| 1 | .000 | .052 | 710000. | 10065. | 7104. | 1535. | 1.21 | 1.50 | .7961 | 1.31 | .3003 | 300.2 | .5684 | 155.2 | 9350. |
| 1 | .000 | .085 | 710000. | 14495. | 9618. | 2871. | 3.25 | 3.54 | 1.0945 | 3.54 | .3499 | 311.6 | .5995 | 163.7 | 18700. |
| 254 6 5 | | | 4.0 | 6.0 | 16.0 | | | 48000. | | 12000. | | | | 217000. | |
| 3 | .000 | .025 | 450000. | 18683. | 14434. | 4709. | 1.67 | 2.01 | .3553 | 1.72 | .3005 | 184.7 | .5909 | 102.3 | 2600. |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | .000 | .060 | 450000. | 21827. | 14965. | 4178. | 3.08 | 3.42 | .7120 | 3.27 | .3564 | 194.4 | .6309 | 109.2 | 5200. |
| 4 | .000 | .005 | 1700000. | 50000. | 50000. | 50000. | 2.73 | 3.07 | .0549 | 2.90 | .0869 | 203.6 | .1691 | 110.6 | 32200. |
| 4 | .000 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.01 | 5.35 | .0976 | 5.52 | .1116 | 230.2 | .1921 | 125.6 | 64400. |
| 1 | .000 | .030 | 710000. | 13261. | 11418. | 3291. | 1.36 | 1.71 | .4168 | 1.44 | .2569 | 255.0 | .4908 | 134.0 | 14100. |
| 1 | .000 | .048 | 710000. | 18869. | 15214. | 5697. | 3.37 | 3.71 | .5696 | 3.60 | .2947 | 257.1 | .5056 | 138.1 | 28200. |
| 2 | .000 | .038 | 230000. | 17842. | 12045. | 2720. | 1.43 | 1.77 | .5271 | 1.48 | .4409 | 133.6 | .9037 | 79.9 | 26700. |
| 2 | .000 | .066 | 230000. | 23326. | 14520. | 3854. | 3.19 | 3.53 | .8017 | 3.40 | .4452 | 119.6 | .8557 | 75.7 | 53400. |
| 2 | .000 | .029 | 230000. | 19483. | 14310. | 4470. | 1.80 | 2.14 | .4025 | 1.84 | .4152 | 124.6 | .8605 | 76.1 | 32900. |
| 2 | .000 | .047 | 230000. | 25843. | 17995. | 6148. | 3.73 | 4.07 | .5894 | 3.98 | .4072 | 108.2 | .8006 | 70.8 | 65800. |
| 322 | 6 | 4 | 4.0 | 9.0 | 8.0 | | | 48000. | | 12000. | | | | 119000. | |
| 3 | .000 | .026 | 450000. | 16285. | 11803. | 5295. | 2.50 | 2.78 | .4739 | 2.57 | .3185 | 196.8 | .6221 | 107.7 | 2600. |
| 3 | .000 | .062 | 450000. | 18641. | 11775. | 4572. | 4.26 | 4.54 | .9092 | 4.56 | .3852 | 211.9 | .6777 | 117.3 | 5200. |
| 4 | .000 | .005 | 1700000. | 50000. | 50000. | 50000. | 3.60 | 3.88 | .0727 | 3.92 | .0869 | 203.4 | .1690 | 110.5 | 32200. |
| 4 | .000 | .009 | 1700000. | 50000. | 50000. | 50000. | 6.18 | 6.46 | .1229 | 7.08 | .1114 | 229.9 | .1919 | 125.5 | 64400. |
| 1 | .000 | .046 | 710000. | 9681. | 6613. | 1980. | 1.49 | 1.77 | .7574 | 1.58 | .2976 | 297.4 | .5635 | 153.9 | 14100. |
| 1 | .000 | .069 | 710000. | 14497. | 9854. | 3886. | 3.82 | 4.10 | .9540 | 4.15 | .3372 | 298.8 | .5773 | 157.6 | 28200. |
| 2 | .000 | .046 | 230000. | 14122. | 7558. | 2510. | 2.13 | 2.40 | .8474 | 2.13 | .5027 | 155.0 | 1.0098 | 89.3 | 10600. |
| 2 | .000 | .081 | 230000. | 18205. | 9334. | 3451. | 4.29 | 4.57 | 1.2167 | 4.55 | .5243 | 144.0 | .9783 | 86.5 | 21200. |
| 268 | 6 | 5 | 4.0 | 9.0 | 12.0 | | | 48000. | | 12000. | | | | 233000. | |
| 3 | .000 | .026 | 450000. | 17065. | 12476. | 4568. | 1.79 | 2.12 | .3922 | 1.83 | .3098 | 190.9 | .6069 | 105.0 | 2600. |
| 3 | .000 | .061 | 450000. | 19760. | 12696. | 4242. | 3.35 | 3.68 | .7624 | 3.53 | .3685 | 201.7 | .6504 | 112.6 | 5200. |
| 4 | .000 | .005 | 1700000. | 50000. | 50000. | 50000. | 2.86 | 3.19 | .0576 | 3.05 | .0868 | 203.3 | .1689 | 110.4 | 32200. |
| 4 | .000 | .009 | 1700000. | 50000. | 50000. | 50000. | 5.19 | 5.52 | .1015 | 5.77 | .1114 | 229.8 | .1917 | 125.4 | 64400. |
| 1 | .000 | .038 | 710000. | 11138. | 8650. | 2310. | 1.25 | 1.58 | .5453 | 1.32 | .2754 | 274.3 | .5236 | 143.0 | 14100. |
| 1 | .000 | .089 | 710000. | 13813. | 8613. | 2556. | 2.75 | 3.08 | 1.0337 | 2.94 | .3461 | 307.8 | .5929 | 161.9 | 28200. |
| 2 | .000 | .038 | 230000. | 16320. | 10015. | 2870. | 1.63 | 1.96 | .5686 | 1.65 | .4558 | 138.7 | .9294 | 82.2 | 26700. |
| 2 | .000 | .076 | 230000. | 20123. | 10869. | 3388. | 3.34 | 3.67 | .9561 | 3.52 | .4817 | 130.8 | .9119 | 80.7 | 53400. |
| 2 | .000 | .034 | 230000. | 17196. | 11159. | 3644. | 1.81 | 2.13 | .4964 | 1.83 | .4410 | 133.6 | .9043 | 80.0 | 40900. |
| 2 | .000 | .062 | 230000. | 21827. | 12712. | 4385. | 3.62 | 3.94 | .8002 | 3.82 | .4525 | 122.0 | .8683 | 76.8 | 81800. |
| 260 | 6 | 4 | 5.0 | 6.0 | 8.0 | | | 48000. | | 12000. | | | | 100000. | |
| 3 | .000 | .027 | 450000. | 13396. | 10951. | 4388. | 2.27 | 2.53 | .5216 | 2.42 | .2780 | 173.8 | .5353 | 92.7 | 2600. |
| 3 | .000 | .069 | 450000. | 15465. | 11014. | 3870. | 3.99 | 4.25 | 1.0085 | 4.46 | .3590 | 201.8 | .6265 | 108.4 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 3.49 | 3.74 | .0706 | 3.92 | .0681 | 159.9 | .1320 | 86.3 | 32200. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.93 | 6.19 | .1185 | 7.07 | .0899 | 186.5 | .1548 | 101.2 | 64400. |
| 1 | .000 | .049 | 710000. | 7564. | 6218. | 1548. | 1.14 | 1.39 | .7443 | 1.30 | .2488 | 249.9 | .4681 | 127.8 | 14100. |
| 1 | .000 | .083 | 710000. | 11367. | 8559. | 2890. | 3.18 | 3.44 | 1.0718 | 3.67 | .2997 | 274.2 | .5207 | 142.2 | 28200. |
| 2 | .000 | .055 | 230000. | 10194. | 6326. | 1880. | 1.98 | 2.24 | 1.0589 | 2.06 | .4958 | 157.1 | .9649 | 85.4 | 1100. |
| 2 | .000 | .108 | 230000. | 12514. | 7699. | 2448. | 4.08 | 4.34 | 1.6326 | 4.49 | .5875 | 166.4 | 1.0435 | 92.3 | 2200. |
| 308 | 6 | 10 | 5.0 | 6.0 | 12.0 | | | 48000. | | 12000. | | | | 505000. | |
| 3 | .000 | .025 | 450000. | 14894. | 12558. | 4502. | 1.79 | 2.09 | .3993 | 1.88 | .2624 | 163.3 | .5081 | 87.9 | 2600. |
| 3 | .000 | .057 | 450000. | 18230. | 13681. | 4528. | 3.46 | 3.77 | .7406 | 3.76 | .3248 | 179.9 | .5684 | 98.4 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.80 | 3.11 | .0566 | 3.07 | .0680 | 159.8 | .1319 | 86.2 | 34400. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.06 | 5.37 | .0993 | 5.80 | .0898 | 186.3 | .1547 | 101.1 | 68800. |
| 1 | .000 | .030 | 710000. | 10228. | 9680. | 2975. | 1.30 | 1.61 | .4426 | 1.43 | .2155 | 215.3 | .4083 | 111.5 | 11900. |
| 1 | .000 | .062 | 710000. | 14119. | 11510. | 3944. | 3.05 | 3.36 | .7462 | 3.39 | .2680 | 241.0 | .4632 | 126.5 | 23800. |
| 2 | .000 | .034 | 230000. | 14538. | 11000. | 3399. | 1.88 | 2.19 | .5547 | 1.94 | .4024 | 124.6 | .8043 | 71.1 | 26700. |
| 2 | .000 | .067 | 230000. | 18720. | 12578. | 4036. | 3.76 | 4.07 | .9063 | 4.05 | .4542 | 124.4 | .8312 | 73.5 | 53400. |
| 2 | .000 | .029 | 230000. | 15596. | 12423. | 4471. | 2.11 | 2.42 | .4741 | 2.18 | .3855 | 118.7 | .7758 | 68.6 | 59900. |
| 2 | .000 | .053 | 230000. | 20380. | 14819. | 5399. | 4.12 | 4.43 | .7444 | 4.44 | .4255 | 115.4 | .7871 | 69.6 | 119800. |
| 3 | .000 | .025 | 450000. | 14983. | 12633. | 4529. | 1.79 | 2.10 | .3976 | 1.89 | .2618 | 162.9 | .5071 | 87.8 | 40850. |
| 3 | .000 | .053 | 450000. | 19408. | 14281. | 4946. | 3.56 | 3.87 | .6971 | 3.86 | .3163 | 174.7 | .5547 | 96.0 | 81700. |
| 4 | .000 | .022 | 1700000. | 10669. | 11031. | 3326. | .94 | 1.25 | .2875 | 1.10 | .1100 | 265.1 | .2062 | 134.8 | 16300. |
| 4 | .000 | .059 | 1700000. | 13837. | 11654. | 3489. | 2.21 | 2.52 | .6123 | 2.58 | .1483 | 332.6 | .2601 | 170.0 | 32600. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.80 | 3.11 | .0566 | 3.07 | .0680 | 159.8 | .1319 | 86.2 | 24350. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.06 | 5.37 | .0993 | 5.80 | .0898 | 186.3 | .1547 | 101.1 | 48700. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .000 | .023 | 710000. | 11122. | 11330. | 4718. | 1.62 | 1.93 | .3472 | 1.77 | .2049 | 204.3 | .3894 | 106.3 | 23000. |
| 1 | .000 | .051 | 710000. | 14832. | 13125. | 5022. | 3.32 | 3.62 | .6381 | 3.68 | .2582 | 230.5 | .4453 | 121.6 | 46000. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.80 | 3.11 | .0566 | 3.07 | .0680 | 159.8 | .1319 | 86.2 | 12500. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.06 | 5.37 | .0993 | 5.80 | .0898 | 186.3 | .1547 | 101.1 | 25000. |
| 306 | 6 | 11 | 5.0 | 6.0 | 12.0 | | | 48000. | 12000. | | | | | 601000. | |
| 3 | .000 | .021 | 450000. | 15922. | 14010. | 5876. | 2.01 | 2.31 | .3432 | 2.11 | .2530 | 157.0 | .4918 | 85.1 | 2600. |
| 3 | .000 | .042 | 450000. | 21299. | 16835. | 6840. | 3.96 | 4.26 | .5621 | 4.30 | .2976 | 163.0 | .5240 | 90.7 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.80 | 3.11 | .0566 | 3.07 | .0680 | 159.8 | .1319 | 86.2 | 34400. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.06 | 5.37 | .0993 | 5.80 | .0898 | 186.3 | .1547 | 101.1 | 68800. |
| 1 | .000 | .030 | 710000. | 10179. | 9634. | 2961. | 1.30 | 1.61 | .4439 | 1.43 | .2158 | 215.6 | .4088 | 111.6 | 11900. |
| 1 | .000 | .068 | 710000. | 13428. | 10722. | 3442. | 2.91 | 3.21 | .8143 | 3.23 | .2748 | 248.1 | .4755 | 129.9 | 23800. |
| 2 | .000 | .034 | 230000. | 14311. | 10828. | 3346. | 1.87 | 2.18 | .5614 | 1.93 | .4053 | 125.7 | .8091 | 71.6 | 26700. |
| 2 | .000 | .079 | 230000. | 16433. | 11029. | 3251. | 3.54 | 3.84 | 1.0566 | 3.81 | .4901 | 135.4 | .8864 | 78.4 | 53400. |
| 2 | .000 | .029 | 230000. | 15582. | 12413. | 4467. | 2.11 | 2.42 | .4744 | 2.18 | .3857 | 118.8 | .7761 | 68.7 | 59900. |
| 2 | .000 | .054 | 230000. | 20554. | 14782. | 5348. | 4.10 | 4.41 | .7479 | 4.42 | .4242 | 115.0 | .7852 | 69.5 | 119800. |
| 3 | .000 | .023 | 450000. | 15350. | 13145. | 4983. | 1.87 | 2.17 | .3768 | 1.97 | .2584 | 160.6 | .5011 | 86.7 | 40850. |
| 3 | .000 | .048 | 450000. | 20069. | 15255. | 5637. | 3.72 | 4.03 | .6398 | 4.03 | .3090 | 170.1 | .5426 | 93.9 | 81700. |
| 4 | .000 | .021 | 1700000. | 10842. | 11260. | 3574. | .98 | 1.28 | .2775 | 1.14 | .1092 | 263.1 | .2048 | 133.9 | 16300. |
| 4 | .000 | .055 | 1700000. | 14335. | 12244. | 3835. | 2.30 | 2.60 | .5782 | 2.67 | .1458 | 326.1 | .2552 | 166.9 | 32600. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.80 | 3.11 | .0566 | 3.07 | .0680 | 159.8 | .1319 | 86.2 | 24350. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.06 | 5.37 | .0993 | 5.80 | .0898 | 186.3 | .1547 | 101.1 | 48700. |
| 1 | .000 | .021 | 710000. | 11514. | 11999. | 5552. | 1.74 | 2.05 | .3171 | 1.91 | .2012 | 200.3 | .3827 | 104.5 | 23000. |
| 1 | .000 | .043 | 710000. | 16091. | 14715. | 6312. | 3.58 | 3.88 | .5485 | 3.97 | .2480 | 220.1 | .4274 | 116.7 | 46000. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.80 | 3.11 | .0566 | 3.07 | .0680 | 159.8 | .1319 | 86.2 | 44950. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.06 | 5.37 | .0993 | 5.80 | .0898 | 186.3 | .1547 | 101.1 | 89900. |
| 1 | .000 | .037 | 710000. | 9379. | 8425. | 2103. | 1.10 | 1.40 | .5276 | 1.22 | .2250 | 225.2 | .4254 | 116.2 | 15550. |
| 1 | .000 | .085 | 710000. | 12307. | 9110. | 2623. | 2.64 | 2.94 | .9688 | 2.95 | .2891 | 263.2 | .5018 | 137.0 | 31100. |
| 328 | 6 | 11 | 5.0 | 6.0 | 16.0 | | | 48000. | 12000. | | | | | 575000. | |
| 3 | .000 | .023 | 450000. | 16391. | 14232. | 4623. | 1.42 | 1.78 | .3088 | 1.49 | .2494 | 154.5 | .4855 | 84.0 | 2600. |
| 3 | .000 | .031 | 450000. | 23947. | 20296. | 9677. | 3.69 | 4.05 | .3677 | 3.95 | .2744 | 148.4 | .4863 | 84.2 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.29 | 2.65 | .0461 | 2.47 | .0680 | 159.8 | .1318 | 86.2 | 34400. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.35 | 4.71 | .0842 | 4.85 | .0898 | 186.2 | .1546 | 101.1 | 68800. |
| 1 | .000 | .029 | 710000. | 10850. | 10510. | 2815. | 1.05 | 1.40 | .3748 | 1.14 | .2084 | 207.9 | .3957 | 108.0 | 11900. |
| 1 | .000 | .063 | 710000. | 14678. | 11953. | 3545. | 2.50 | 2.85 | .6751 | 2.72 | .2620 | 234.5 | .4521 | 123.5 | 23800. |
| 2 | .000 | .032 | 230000. | 15560. | 12229. | 3213. | 1.39 | 1.75 | .4345 | 1.45 | .3838 | 118.2 | .7728 | 68.4 | 26700. |
| 2 | .000 | .067 | 230000. | 19920. | 13515. | 3572. | 2.88 | 3.23 | .7772 | 3.08 | .4321 | 117.3 | .7957 | 70.4 | 53400. |
| 2 | .000 | .036 | 230000. | 15096. | 11543. | 2674. | 1.27 | 1.63 | .4779 | 1.33 | .3912 | 120.8 | .7852 | 69.5 | 59900. |
| 2 | .000 | .070 | 230000. | 19531. | 13006. | 3387. | 2.84 | 3.19 | .8075 | 3.03 | .4386 | 119.3 | .8056 | 71.3 | 119800. |
| 3 | .000 | .019 | 450000. | 17043. | 15559. | 6608. | 1.68 | 2.03 | .2546 | 1.75 | .2427 | 150.0 | .4738 | 82.0 | 40850. |
| 3 | .000 | .034 | 450000. | 23622. | 19717. | 8699. | 3.56 | 3.91 | .3941 | 3.80 | .2772 | 150.2 | .4909 | 85.0 | 81700. |
| 4 | .000 | .019 | 1700000. | 11698. | 12526. | 3926. | .89 | 1.24 | .2290 | 1.01 | .1051 | 253.2 | .1975 | 129.1 | 16300. |
| 4 | .000 | .043 | 1700000. | 16549. | 14844. | 5074. | 2.27 | 2.62 | .4287 | 2.55 | .1355 | 298.6 | .2350 | 153.7 | 32600. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.29 | 2.65 | .0461 | 2.47 | .0680 | 159.8 | .1318 | 86.2 | 24350. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.35 | 4.71 | .0842 | 4.85 | .0898 | 186.2 | .1546 | 101.1 | 48700. |
| 1 | .000 | .022 | 710000. | 11621. | 12065. | 4690. | 1.34 | 1.69 | .2871 | 1.44 | .1996 | 198.7 | .3799 | 103.8 | 23000. |
| 1 | .000 | .048 | 710000. | 15864. | 14222. | 5141. | 2.85 | 3.21 | .5316 | 3.10 | .2487 | 220.6 | .4283 | 117.0 | 46000. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.29 | 2.65 | .0461 | 2.47 | .0680 | 159.8 | .1318 | 86.2 | 44950. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.35 | 4.71 | .0842 | 4.85 | .0898 | 186.2 | .1546 | 101.1 | 89900. |
| 1 | .000 | .027 | 710000. | 11012. | 10872. | 3171. | 1.11 | 1.47 | .3527 | 1.21 | .2063 | 205.7 | .3919 | 107.0 | 2550. |
| 1 | .000 | .054 | 710000. | 15397. | 13132. | 4379. | 2.70 | 3.05 | .5903 | 2.93 | .2543 | 226.4 | .4383 | 119.7 | 5100. |
| 314 | 6 | 11 | 5.0 | 9.0 | 8.0 | | | 48000. | 12000. | | | | | 594000. | |
| 3 | .000 | .021 | 450000. | 15063. | 13261. | 6604. | 2.25 | 2.55 | .3430 | 2.38 | .2555 | 158.7 | .4961 | 85.9 | 2600. |
| 3 | .000 | .042 | 450000. | 19319. | 15083. | 6978. | 4.22 | 4.52 | .5894 | 4.60 | .3065 | 168.3 | .5379 | 93.1 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.93 | 3.23 | .0593 | 3.24 | .0680 | 159.7 | .1318 | 86.2 | 32200. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.23 | 5.52 | .1029 | 6.05 | .0897 | 186.0 | .1545 | 101.0 | 64400. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .000 | .031 | 710000. | 9334. | 8696. | 2928. | 1.37 | 1.66 | .4724 | 1.51 | .2210 | 221.0 | .4180 | 114.1 | 14100. |
| 1 | .000 | .066 | 710000. | 12539. | 9899. | 3749. | 3.15 | 3.44 | .8117 | 3.51 | .2770 | 250.1 | .4789 | 130.8 | 28200. |
| 2 | .000 | .034 | 230000. | 13379. | 9478. | 3509. | 2.08 | 2.38 | .5955 | 2.13 | .4133 | 128.5 | .8230 | 72.8 | 26700. |
| 2 | .000 | .068 | 230000. | 16797. | 10615. | 4103. | 4.07 | 4.36 | .9665 | 4.36 | .4720 | 129.8 | .8587 | 76.0 | 53400. |
| 2 | .000 | .029 | 230000. | 14384. | 10923. | 4589. | 2.33 | 2.62 | .5082 | 2.39 | .3963 | 122.5 | .7940 | 70.2 | 59900. |
| 2 | .000 | .055 | 230000. | 18542. | 12641. | 5405. | 4.42 | 4.71 | .7991 | 4.75 | .4418 | 120.4 | .8120 | 71.8 | 119800. |
| 3 | .000 | .023 | 450000. | 14510. | 12339. | 5573. | 2.10 | 2.39 | .3791 | 2.21 | .2609 | 162.3 | .5055 | 87.5 | 40850. |
| 3 | .000 | .047 | 450000. | 18572. | 13798. | 5975. | 4.02 | 4.32 | .6544 | 4.37 | .3146 | 173.4 | .5512 | 95.4 | 81700. |
| 4 | .000 | .018 | 1700000. | 10815. | 11611. | 4705. | 1.16 | 1.45 | .2500 | 1.35 | .1077 | 259.5 | .2020 | 132.1 | 16300. |
| 4 | .000 | .046 | 1700000. | 14096. | 12674. | 4926. | 2.62 | 2.91 | .5136 | 3.05 | .1425 | 316.8 | .2483 | 162.3 | 32600. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.93 | 3.23 | .0593 | 3.24 | .0680 | 159.7 | .1318 | 86.2 | 24350. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.23 | 5.52 | .1029 | 6.05 | .0897 | 186.0 | .1545 | 101.0 | 48700. |
| 1 | .000 | .023 | 710000. | 10618. | 10697. | 4671. | 1.70 | 1.99 | .3667 | 1.87 | .2081 | 207.6 | .3951 | 107.9 | 23000. |
| 1 | .000 | .037 | 710000. | 15736. | 14790. | 8140. | 4.06 | 4.35 | .4846 | 4.57 | .2454 | 217.1 | .4221 | 115.3 | 46000. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.93 | 3.23 | .0593 | 3.24 | .0680 | 159.7 | .1318 | 86.2 | 44950. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 5.23 | 5.52 | .1029 | 6.05 | .0897 | 186.0 | .1545 | 101.0 | 89900. |
| 1 | .000 | .039 | 710000. | 8504. | 7433. | 2067. | 1.15 | 1.45 | .5647 | 1.28 | .2309 | 231.3 | .4358 | 119.0 | 12050. |
| 1 | .000 | .087 | 710000. | 10944. | 7853. | 2587. | 2.76 | 3.06 | 1.0305 | 3.09 | .2967 | 271.0 | .5151 | 140.7 | 24100. |
| 332 | 6 | 5 | | 5.0 | 9.0 | 12.0 | | 48000. | | 12000. | | | | 270000. | |
| 3 | .000 | .023 | 450000. | 15218. | 12967. | 4815. | 1.55 | 1.90 | .3240 | 1.63 | .2547 | 158.1 | .4947 | 85.6 | 2600. |
| 3 | .000 | .040 | 450000. | 20837. | 16127. | 7009. | 3.51 | 3.85 | .4828 | 3.75 | .2935 | 160.1 | .5165 | 89.4 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.39 | 2.73 | .0481 | 2.59 | .0679 | 159.6 | .1317 | 86.1 | 32200. |
| 4 | .000 | .008 | 1700000. | 50000. | 50000. | 50000. | 4.49 | 4.83 | .0870 | 5.04 | .0897 | 185.9 | .1544 | 100.9 | 64400. |
| 1 | .000 | .030 | 710000. | 9986. | 9545. | 2733. | 1.09 | 1.43 | .4026 | 1.19 | .2137 | 213.4 | .4050 | 110.6 | 14100. |
| 1 | .000 | .062 | 710000. | 13716. | 10968. | 3802. | 2.70 | 3.05 | .6820 | 2.94 | .2651 | 237.6 | .4575 | 124.9 | 28200. |
| 2 | .000 | .031 | 230000. | 14778. | 11252. | 3683. | 1.61 | 1.95 | .4382 | 1.66 | .3887 | 119.8 | .7811 | 69.1 | 26700. |
| 2 | .000 | .057 | 230000. | 19370. | 13021. | 4690. | 3.41 | 3.75 | .7023 | 3.61 | .4273 | 115.8 | .7888 | 69.8 | 53400. |
| 2 | .000 | .027 | 230000. | 15520. | 12445. | 4785. | 1.80 | 2.15 | .3781 | 1.85 | .3776 | 116.0 | .7625 | 67.5 | 59400. |
| 2 | .000 | .047 | 230000. | 20521. | 14888. | 6103. | 3.71 | 4.06 | .5890 | 3.95 | .4097 | 110.3 | .7622 | 67.4 | 118800. |
| 326 | 6 | 4 | | 6.0 | 6.0 | 8.0 | | 48000. | | 12000. | | | | 120000. | |
| 3 | .000 | .020 | 450000. | 12895. | 12512. | 5894. | 2.08 | 2.35 | .3566 | 2.28 | .2184 | 136.6 | .4200 | 72.7 | 2600. |
| 3 | .000 | .053 | 450000. | 15214. | 12950. | 4972. | 3.70 | 3.97 | .7252 | 4.20 | .2869 | 161.9 | .5025 | 87.0 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.84 | 3.11 | .0576 | 3.23 | .0544 | 128.1 | .1052 | 68.8 | 32200. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 5.02 | 5.29 | .0994 | 6.03 | .0729 | 152.4 | .1262 | 82.5 | 64400. |
| 1 | .000 | .031 | 710000. | 8021. | 8283. | 2536. | 1.11 | 1.38 | .4462 | 1.30 | .1823 | 182.9 | .3434 | 93.8 | 14100. |
| 1 | .000 | .065 | 710000. | 11233. | 9902. | 3533. | 2.81 | 3.09 | .7750 | 3.32 | .2334 | 215.6 | .4096 | 111.8 | 28200. |
| 2 | .000 | .050 | 230000. | 9167. | 6556. | 1829. | 1.58 | 1.85 | .8708 | 1.68 | .4137 | 131.8 | .7995 | 70.7 | 11100. |
| 2 | .000 | .109 | 230000. | 10926. | 7332. | 2249. | 3.43 | 3.70 | 1.4821 | 3.81 | .5201 | 149.3 | .9200 | 81.4 | 22200. |
| 272 | 6 | 11 | | 6.0 | 9.0 | 8.0 | | 48000. | | 12000. | | | | 618000. | |
| 3 | .000 | .021 | 450000. | 12463. | 11906. | 5110. | 1.67 | 1.98 | .3292 | 1.81 | .2188 | 136.9 | .4207 | 72.8 | 2600. |
| 3 | .000 | .059 | 450000. | 14225. | 11454. | 4156. | 3.10 | 3.41 | .7211 | 3.43 | .2900 | 163.7 | .5073 | 87.8 | 5200. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.42 | 2.73 | .0491 | 2.71 | .0543 | 127.9 | .1051 | 68.7 | 32200. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.49 | 4.80 | .0877 | 5.25 | .0727 | 152.0 | .1259 | 82.3 | 64400. |
| 1 | .000 | .025 | 710000. | 8687. | 9492. | 3377. | 1.14 | 1.45 | .3432 | 1.31 | .1731 | 173.4 | .3269 | 89.3 | 15200. |
| 1 | .000 | .062 | 710000. | 11265. | 10055. | 3659. | 2.61 | 2.92 | .6895 | 3.00 | .2274 | 208.9 | .3979 | 108.7 | 30400. |
| 2 | .000 | .034 | 230000. | 11356. | 8980. | 3010. | 1.66 | 1.96 | .5525 | 1.73 | .3612 | 113.6 | .7092 | 62.7 | 25600. |
| 2 | .000 | .079 | 230000. | 13529. | 9024. | 3145. | 3.34 | 3.65 | 1.0274 | 3.60 | .4503 | 126.2 | .8029 | 71.0 | 51200. |
| 2 | .000 | .029 | 230000. | 12332. | 10420. | 4092. | 1.89 | 2.20 | .4652 | 1.98 | .3454 | 108.1 | .6824 | 60.4 | 59900. |
| 2 | .000 | .062 | 230000. | 15224. | 11073. | 4290. | 3.69 | 4.00 | .8336 | 3.99 | .4200 | 116.3 | .7532 | 66.6 | 119800. |
| 3 | .000 | .020 | 450000. | 12854. | 12455. | 5651. | 1.74 | 2.05 | .3110 | 1.89 | .2158 | 134.9 | .4155 | 71.9 | 40850. |
| 3 | .000 | .048 | 450000. | 15700. | 13232. | 5435. | 3.40 | 3.71 | .6052 | 3.76 | .2760 | 154.4 | .4827 | 83.5 | 81700. |
| 4 | .000 | .016 | 1700000. | 9826. | 11831. | 4652. | .86 | 1.17 | .1891 | 1.06 | .0835 | 201.5 | .1565 | 102.4 | 16300. |
| 4 | .000 | .044 | 1700000. | 12274. | 12648. | 4665. | 2.06 | 2.37 | .4297 | 2.51 | .1149 | 261.3 | .2043 | 133.5 | 32600. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.42 | 2.73 | .0491 | 2.71 | .0543 | 127.9 | .1051 | 68.7 | 24350. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.49 | 4.80 | .0877 | 5.25 | .0727 | 152.0 | .1259 | 82.3 | 48700. |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .000 | .021 | 710000. | 9202. | 10442. | 4500. | 1.31 | 1.62 | .2955 | 1.50 | .1681 | 168.1 | .3179 | 86.8 | 23000. |
| 1 | .000 | .054 | 710000. | 11470. | 11105. | 4382. | 2.79 | 3.10 | .6151 | 3.21 | .2222 | 203.1 | .3877 | 105.9 | 46000. |
| 4 | .000 | .004 | 1700000. | 50000. | 50000. | 50000. | 2.42 | 2.73 | .0491 | 2.71 | .0543 | 127.9 | .1051 | 68.7 | 44950. |
| 4 | .000 | .007 | 1700000. | 50000. | 50000. | 50000. | 4.49 | 4.80 | .0877 | 5.25 | .0727 | 152.0 | .1259 | 82.3 | 89900. |
| 1 | .000 | .029 | 710000. | 8235. | 8695. | 2635. | 1.01 | 1.32 | .3886 | 1.16 | .1777 | 178.2 | .3352 | 91.5 | 24050. |
| 1 | .000 | .071 | 710000. | 10643. | 9079. | 3071. | 2.45 | 2.76 | .7692 | 2.81 | .2342 | 216.5 | .4111 | 112.3 | 48100. |

# APPENDIX F

# SUMMARY OF ARE INC MECHANISTIC LOAD EQUIVALENCE FACTORS

CONTENTS OF FILE ARE.EQF    AXLE SET TYPE: Single axle, single tires
SURFACE THICKNESS: 0.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0572 | .0134 | .0047 |
| 2 | 12000. | 75. | 4. | .0572 | .0134 | .0047 |
| 3 | 20000. | 75. | 4. | .0573 | .0134 | .0047 |
| 4 | 4000. | 110. | 4. | .0706 | .0138 | .0046 |
| 5 | 12000. | 110. | 4. | .0705 | .0138 | .0046 |
| 6 | 20000. | 110. | 4. | .0706 | .0138 | .0046 |
| 7 | 4000. | 145. | 4. | .0787 | .0139 | .0046 |
| 8 | 12000. | 145. | 4. | .0786 | .0139 | .0046 |
| 9 | 20000. | 145. | 4. | .0787 | .0139 | .0046 |
| 10 | 4000. | 75. | 10. | 1.1998 | .4940 | .2180 |
| 11 | 12000. | 75. | 10. | 1.1997 | .4940 | .2180 |
| 12 | 20000. | 75. | 10. | 1.1999 | .4940 | .2180 |
| 13 | 4000. | 110. | 10. | 1.8745 | .5871 | .2322 |
| 14 | 12000. | 110. | 10. | 1.8742 | .5872 | .2322 |
| 15 | 20000. | 110. | 10. | 1.8746 | .5872 | .2321 |
| 16 | 4000. | 145. | 10. | 2.4018 | .6396 | .2359 |
| 17 | 12000. | 145. | 10. | 2.4015 | .6397 | .2360 |
| 18 | 20000. | 145. | 10. | 2.4021 | .6397 | .2359 |
| 19 | 4000. | 75. | 18. | 5.6072 | 4.0385 | 2.1907 |
| 20 | 12000. | 75. | 18. | 5.6065 | 4.0388 | 2.1910 |
| 21 | 20000. | 75. | 18. | 5.6077 | 4.0389 | 2.1906 |
| 22 | 4000. | 110. | 18. | 11.0434 | 5.4143 | 2.5499 |
| 23 | 12000. | 110. | 18. | 11.0420 | 5.4146 | 2.5502 |
| 24 | 20000. | 110. | 18. | 11.0444 | 5.4148 | 2.5498 |
| 25 | 4000. | 145. | 18. | 16.3016 | 6.3461 | 2.7404 |
| 26 | 12000. | 145. | 18. | 16.2996 | 6.3465 | 2.7408 |
| 27 | 20000. | 145. | 18. | 16.3031 | 6.3468 | 2.7403 |

CONTENTS OF FILE ARE.EQF      AXLE SET TYPE: Single axle, single tires
SURFACE THICKNESS: 3.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0057 | .0075 | .0087 |
| 2 | 12000. | 75. | 4. | .0243 | .0336 | .0387 |
| 3 | 20000. | 75. | 4. | .0533 | .0748 | .0849 |
| 4 | 4000. | 110. | 4. | .0145 | .0199 | .0237 |
| 5 | 12000. | 110. | 4. | .0830 | .1198 | .1404 |
| 6 | 20000. | 110. | 4. | .2163 | .3169 | .3640 |
| 7 | 4000. | 145. | 4. | .0256 | .0363 | .0441 |
| 8 | 12000. | 145. | 4. | .1748 | .2585 | .3058 |
| 9 | 20000. | 145. | 4. | .5025 | .7522 | .8696 |
| 10 | 4000. | 75. | 10. | .3143 | .3582 | .3875 |
| 11 | 12000. | 75. | 10. | .5050 | .5795 | .6206 |
| 12 | 20000. | 75. | 10. | .6067 | .6951 | .7370 |
| 13 | 4000. | 110. | 10. | 1.1503 | 1.4001 | 1.5687 |
| 14 | 12000. | 110. | 10. | 2.9176 | 3.6845 | 4.1029 |
| 15 | 20000. | 110. | 10. | 4.6694 | 5.9532 | 6.5540 |
| 16 | 4000. | 145. | 10. | 2.6854 | 3.3955 | 3.8837 |
| 17 | 12000. | 145. | 10. | 9.0513 | 12.0412 | 13.6810 |
| 18 | 20000. | 145. | 10. | 17.2642 | 23.2856 | 26.1037 |
| 19 | 4000. | 75. | 18. | 2.6410 | 2.6089 | 2.6115 |
| 20 | 12000. | 75. | 18. | 1.8094 | 1.6702 | 1.6234 |
| 21 | 20000. | 75. | 18. | 1.2639 | 1.1195 | 1.0729 |
| 22 | 4000. | 110. | 18. | 12.1649 | 13.2739 | 14.0289 |
| 23 | 12000. | 110. | 18. | 14.8410 | 15.9646 | 16.6286 |
| 24 | 20000. | 110. | 18. | 14.9743 | 15.9235 | 16.4174 |
| 25 | 4000. | 145. | 18. | 33.2393 | 38.4042 | 41.8467 |
| 26 | 12000. | 145. | 18. | 58.4867 | 68.4934 | 73.9737 |
| 27 | 20000. | 145. | 18. | 74.4180 | 87.2329 | 93.2695 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Single axle, single tires
SURFACE THICKNESS: 6.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0005 | .0006 | .0007 |
| 2 | 12000. | 75. | 4. | .0014 | .0017 | .0020 |
| 3 | 20000. | 75. | 4. | .0022 | .0028 | .0032 |
| 4 | 4000. | 110. | 4. | .0006 | .0008 | .0009 |
| 5 | 12000. | 110. | 4. | .0021 | .0027 | .0032 |
| 6 | 20000. | 110. | 4. | .0036 | .0048 | .0056 |
| 7 | 4000. | 145. | 4. | .0008 | .0010 | .0012 |
| 8 | 12000. | 145. | 4. | .0026 | .0035 | .0042 |
| 9 | 20000. | 145. | 4. | .0047 | .0064 | .0075 |
| 10 | 4000. | 75. | 10. | .1202 | .1320 | .1424 |
| 11 | 12000. | 75. | 10. | .2210 | .2506 | .2709 |
| 12 | 20000. | 75. | 10. | .2809 | .3242 | .3515 |
| 13 | 4000. | 110. | 10. | .2323 | .2668 | .2980 |
| 14 | 12000. | 110. | 10. | .5384 | .6370 | .7070 |
| 15 | 20000. | 110. | 10. | .7675 | .9305 | 1.0347 |
| 16 | 4000. | 145. | 10. | .3346 | .3986 | .4564 |
| 17 | 12000. | 145. | 10. | .8971 | 1.0935 | 1.2359 |
| 18 | 20000. | 145. | 10. | 1.3720 | 1.7120 | 1.9321 |
| 19 | 4000. | 75. | 18. | 2.5279 | 2.6256 | 2.7030 |
| 20 | 12000. | 75. | 18. | 3.0895 | 3.1944 | 3.2688 |
| 21 | 20000. | 75. | 18. | 3.1103 | 3.1910 | 3.2524 |
| 22 | 4000. | 110. | 18. | 6.4311 | 6.9233 | 7.3430 |
| 23 | 12000. | 110. | 18. | 10.3380 | 11.4097 | 12.1346 |
| 24 | 20000. | 110. | 18. | 12.2216 | 13.6371 | 14.5247 |
| 25 | 4000. | 145. | 18. | 11.3235 | 12.5331 | 13.6050 |
| 26 | 12000. | 145. | 18. | 21.7864 | 24.9098 | 27.0708 |
| 27 | 20000. | 145. | 18. | 28.3352 | 33.0511 | 36.0227 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Single axle, dual tires
SURFACE THICKNESS: 0.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0044 | .0018 | .0018 |
| 2 | 12000. | 75. | 4. | .0044 | .0018 | .0018 |
| 3 | 20000. | 75. | 4. | .0044 | .0018 | .0018 |
| 4 | 4000. | 110. | 4. | .0048 | .0019 | .0018 |
| 5 | 12000. | 110. | 4. | .0048 | .0019 | .0018 |
| 6 | 20000. | 110. | 4. | .0048 | .0019 | .0018 |
| 7 | 4000. | 145. | 4. | .0050 | .0019 | .0018 |
| 8 | 12000. | 145. | 4. | .0050 | .0019 | .0018 |
| 9 | 20000. | 145. | 4. | .0050 | .0019 | .0018 |
| 10 | 4000. | 75. | 10. | .1403 | .0876 | .0867 |
| 11 | 12000. | 75. | 10. | .1403 | .0876 | .0867 |
| 12 | 20000. | 75. | 10. | .1403 | .0876 | .0867 |
| 13 | 4000. | 110. | 10. | .1789 | .0904 | .0891 |
| 14 | 12000. | 110. | 10. | .1789 | .0904 | .0891 |
| 15 | 20000. | 110. | 10. | .1789 | .0904 | .0891 |
| 16 | 4000. | 145. | 10. | .2039 | .0918 | .0904 |
| 17 | 12000. | 145. | 10. | .2038 | .0918 | .0904 |
| 18 | 20000. | 145. | 10. | .2039 | .0918 | .0904 |
| 19 | 4000. | 75. | 18. | 1.0000 | 1.0000 | .9999 |
| 20 | 12000. | 75. | 18. | .9999 | 1.0000 | 1.0000 |
| 21 | 20000. | 75. | 18. | 1.0001 | 1.0001 | .9999 |
| 22 | 4000. | 110. | 18. | 1.4728 | 1.0600 | 1.0514 |
| 23 | 12000. | 110. | 18. | 1.4726 | 1.0601 | 1.0515 |
| 24 | 20000. | 110. | 18. | 1.4730 | 1.0601 | 1.0514 |
| 25 | 4000. | 145. | 18. | 1.8281 | 1.0916 | 1.0791 |
| 26 | 12000. | 145. | 18. | 1.8278 | 1.0917 | 1.0792 |
| 27 | 20000. | 145. | 18. | 1.8282 | 1.0917 | 1.0790 |
| 28 | 4000. | 75. | 30. | 4.3940 | 7.8361 | 8.0148 |
| 29 | 12000. | 75. | 30. | 4.3935 | 7.8366 | 8.0158 |
| 30 | 20000. | 75. | 30. | 4.3944 | 7.8370 | 8.0144 |
| 31 | 4000. | 110. | 30. | 7.6224 | 8.6779 | 8.7125 |
| 32 | 12000. | 110. | 30. | 7.6215 | 8.6784 | 8.7136 |
| 33 | 20000. | 110. | 30. | 7.6231 | 8.6788 | 8.7121 |
| 34 | 4000. | 145. | 30. | 10.4815 | 9.1322 | 9.0977 |
| 35 | 12000. | 145. | 30. | 10.4802 | 9.1328 | 9.0988 |
| 36 | 20000. | 145. | 30. | 10.4825 | 9.1332 | 9.0972 |
| 37 | 4000. | 75. | 50. | 22.0705 | 55.6762 | 59.8567 |
| 38 | 12000. | 75. | 50. | 22.0677 | 55.6797 | 59.8639 |
| 39 | 20000. | 75. | 50. | 22.0725 | 55.6823 | 59.8538 |
| 40 | 4000. | 110. | 50. | 31.5971 | 66.6981 | 68.8502 |
| 41 | 12000. | 110. | 50. | 31.5931 | 66.7021 | 68.8585 |
| 42 | 20000. | 110. | 50. | 31.6000 | 66.7053 | 68.8468 |
| 43 | 4000. | 145. | 50. | 49.1950 | 72.9529 | 73.9789 |
| 44 | 12000. | 145. | 50. | 49.1887 | 72.9574 | 73.9879 |
| 45 | 20000. | 145. | 50. | 49.1995 | 72.9608 | 73.9753 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Single axle, dual tires
SURFACE THICKNESS: 3.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0004 | .0005 | .0006 |
| 2 | 12000. | 75. | 4. | .0017 | .0023 | .0026 |
| 3 | 20000. | 75. | 4. | .0042 | .0057 | .0064 |
| 4 | 4000. | 110. | 4. | .0007 | .0009 | .0011 |
| 5 | 12000. | 110. | 4. | .0037 | .0052 | .0060 |
| 6 | 20000. | 110. | 4. | .0102 | .0144 | .0163 |
| 7 | 4000. | 145. | 4. | .0009 | .0013 | .0015 |
| 8 | 12000. | 145. | 4. | .0058 | .0083 | .0096 |
| 9 | 20000. | 145. | 4. | .0169 | .0244 | .0278 |
| 10 | 4000. | 75. | 10. | .0582 | .0644 | .0683 |
| 11 | 12000. | 75. | 10. | .1157 | .1352 | .1446 |
| 12 | 20000. | 75. | 10. | .1794 | .2145 | .2290 |
| 13 | 4000. | 110. | 10. | .1407 | .1647 | .1801 |
| 14 | 12000. | 110. | 10. | .4033 | .5050 | .5555 |
| 15 | 20000. | 110. | 10. | .7805 | 1.0047 | 1.0990 |
| 16 | 4000. | 145. | 10. | .2454 | .2988 | .3338 |
| 17 | 12000. | 145. | 10. | .8799 | 1.1447 | 1.2790 |
| 18 | 20000. | 145. | 10. | 1.9380 | 2.5921 | 2.8710 |
| 19 | 4000. | 75. | 18. | .9999 | 1.0000 | 1.0000 |
| 20 | 12000. | 75. | 18. | .9999 | 1.0001 | 1.0000 |
| 21 | 20000. | 75. | 18. | .9999 | 1.0001 | .9998 |
| 22 | 4000. | 110. | 18. | 2.8428 | 3.0490 | 3.1721 |
| 23 | 12000. | 110. | 18. | 4.5276 | 5.0502 | 5.2950 |
| 24 | 20000. | 110. | 18. | 6.1090 | 6.9337 | 7.2658 |
| 25 | 4000. | 145. | 18. | 5.6841 | 6.3636 | 6.7844 |
| 26 | 12000. | 145. | 18. | 12.1663 | 14.4268 | 15.5174 |
| 27 | 20000. | 145. | 18. | 19.7405 | 23.9814 | 25.7315 |
| 28 | 4000. | 75. | 30. | 19.0543 | 17.0015 | 15.9922 |
| 29 | 12000. | 75. | 30. | 9.3619 | 7.6416 | 6.9729 |
| 30 | 20000. | 75. | 30. | 5.9371 | 4.6355 | 4.1955 |
| 31 | 4000. | 110. | 30. | 31.9022 | 31.0658 | 30.5956 |
| 32 | 12000. | 110. | 30. | 26.9385 | 25.7982 | 25.2954 |
| 33 | 20000. | 110. | 30. | 24.1128 | 22.8957 | 22.4261 |
| 34 | 4000. | 145. | 30. | 69.8816 | 71.9363 | 73.1172 |
| 35 | 12000. | 145. | 30. | 84.3226 | 88.2967 | 90.0965 |
| 36 | 20000. | 145. | 30. | 95.2656 | 100.5637 | 102.6190 |
| 37 | 4000. | 75. | 50. | 278.4919 | 229.8350 | 206.0408 |
| 38 | 12000. | 75. | 50. | 97.0122 | 70.4466 | 60.4970 |
| 39 | 20000. | 75. | 50. | 50.7524 | 34.4326 | 29.2275 |
| 40 | 4000. | 110. | 50. | 703.4823 | 619.1404 | 577.4562 |
| 41 | 12000. | 110. | 50. | 327.2975 | 262.1705 | 236.9475 |
| 42 | 20000. | 110. | 50. | 202.3232 | 154.6423 | 138.6527 |
| 43 | 4000. | 145. | 50. | 1089.8980 | 984.7924 | 933.6120 |
| 44 | 12000. | 145. | 50. | 560.3387 | 464.8528 | 427.7284 |
| 45 | 20000. | 145. | 50. | 361.6348 | 287.3463 | 262.1188 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Single axle, dual tires
SURFACE THICKNESS: 6.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0000 | .0000 | .0000 |
| 2 | 12000. | 75. | 4. | .0001 | .0001 | .0001 |
| 3 | 20000. | 75. | 4. | .0001 | .0001 | .0001 |
| 4 | 4000. | 110. | 4. | .0000 | .0001 | .0001 |
| 5 | 12000. | 110. | 4. | .0001 | .0001 | .0001 |
| 6 | 20000. | 110. | 4. | .0001 | .0001 | .0002 |
| 7 | 4000. | 145. | 4. | .0001 | .0001 | .0001 |
| 8 | 12000. | 145. | 4. | .0001 | .0001 | .0001 |
| 9 | 20000. | 145. | 4. | .0001 | .0002 | .0002 |
| 10 | 4000. | 75. | 10. | .0203 | .0218 | .0232 |
| 11 | 12000. | 75. | 10. | .0312 | .0333 | .0348 |
| 12 | 20000. | 75. | 10. | .0366 | .0394 | .0411 |
| 13 | 4000. | 110. | 10. | .0269 | .0301 | .0327 |
| 14 | 12000. | 110. | 10. | .0475 | .0530 | .0567 |
| 15 | 20000. | 110. | 10. | .0604 | .0680 | .0723 |
| 16 | 4000. | 145. | 10. | .0317 | .0361 | .0395 |
| 17 | 12000. | 145. | 10. | .0593 | .0683 | .0742 |
| 18 | 20000. | 145. | 10. | .0791 | .0917 | .0989 |
| 19 | 4000. | 75. | 18. | 1.0000 | 1.0000 | 1.0000 |
| 20 | 12000. | 75. | 18. | 1.0001 | .9999 | .9999 |
| 21 | 20000. | 75. | 18. | .9997 | 1.0001 | .9999 |
| 22 | 4000. | 110. | 18. | 1.3749 | 1.4482 | 1.5146 |
| 23 | 12000. | 110. | 18. | 1.9255 | 2.0105 | 2.0672 |
| 24 | 20000. | 110. | 18. | 2.1456 | 2.2596 | 2.3236 |
| 25 | 4000. | 145. | 18. | 1.7666 | 1.9181 | 2.0476 |
| 26 | 12000. | 145. | 18. | 2.8026 | 3.0182 | 3.1623 |
| 27 | 20000. | 145. | 18. | 3.3399 | 3.6300 | 3.7964 |
| 28 | 4000. | 75. | 30. | 29.8532 | 29.2611 | 28.8179 |
| 29 | 12000. | 75. | 30. | 25.8550 | 24.2780 | 23.3992 |
| 30 | 20000. | 75. | 30. | 21.5430 | 19.6593 | 18.7574 |
| 31 | 4000. | 110. | 30. | 42.2364 | 42.0698 | 41.9422 |
| 32 | 12000. | 110. | 30. | 40.0801 | 38.6256 | 37.8447 |
| 33 | 20000. | 110. | 30. | 35.1200 | 33.6902 | 33.3052 |
| 34 | 4000. | 145. | 30. | 50.3630 | 50.5607 | 51.4764 |
| 35 | 12000. | 145. | 30. | 60.5648 | 61.6068 | 62.3000 |
| 36 | 20000. | 145. | 30. | 63.2897 | 64.6849 | 65.4380 |
| 37 | 4000. | 75. | 50. | 656.7026 | 624.7160 | 600.9060 |
| 38 | 12000. | 75. | 50. | 464.4071 | 410.7268 | 381.1671 |
| 39 | 20000. | 75. | 50. | 343.5912 | 290.5050 | 265.1522 |
| 40 | 4000. | 110. | 50. | 1184.9360 | 1153.1240 | 1129.4750 |
| 41 | 12000. | 110. | 50. | 984.6438 | 913.7089 | 874.0429 |
| 42 | 20000. | 110. | 50. | 801.5163 | 720.8344 | 682.0047 |
| 43 | 4000. | 145. | 50. | 1601.4830 | 1580.8940 | 1565.3830 |
| 44 | 12000. | 145. | 50. | 1444.4520 | 1372.1200 | 1332.1810 |
| 45 | 20000. | 145. | 50. | 1231.0350 | 1139.4150 | 1096.0340 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Triple axle
SURFACE THICKNESS: 6.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0000 | .0000 | .0000 |
| 2 | 12000. | 75. | 4. | .0001 | .0001 | .0001 |
| 3 | 20000. | 75. | 4. | .0004 | .0004 | .0004 |
| 4 | 4000. | 110. | 4. | .0000 | .0000 | .0000 |
| 5 | 12000. | 110. | 4. | .0001 | .0001 | .0001 |
| 6 | 20000. | 110. | 4. | .0004 | .0004 | .0005 |
| 7 | 4000. | 145. | 4. | .0000 | .0000 | .0000 |
| 8 | 12000. | 145. | 4. | .0001 | .0001 | .0001 |
| 9 | 20000. | 145. | 4. | .0004 | .0002 | .0005 |
| 10 | 4000. | 75. | 10. | .0013 | .0021 | .0027 |
| 11 | 12000. | 75. | 10. | .0134 | .0220 | .0288 |
| 12 | 20000. | 75. | 10. | .0457 | .0740 | .0945 |
| 13 | 4000. | 110. | 10. | .0015 | .0021 | .0027 |
| 14 | 12000. | 110. | 10. | .0127 | .0208 | .0271 |
| 15 | 20000. | 110. | 10. | .0433 | .0713 | .0908 |
| 16 | 4000. | 145. | 10. | .0017 | .0024 | .0029 |
| 17 | 12000. | 145. | 10. | .0128 | .0204 | .0262 |
| 18 | 20000. | 145. | 10. | .0415 | .0677 | .0861 |
| 19 | 4000. | 75. | 18. | .0903 | .1272 | .1592 |
| 20 | 12000. | 75. | 18. | .5516 | .7926 | .9816 |
| 21 | 20000. | 75. | 18. | 1.4172 | 2.0268 | 2.4565 |
| 22 | 4000. | 110. | 18. | .0829 | .1116 | .1348 |
| 23 | 12000. | 110. | 18. | .4657 | .6980 | .8779 |
| 24 | 20000. | 110. | 18. | 1.2945 | 1.9505 | 2.4070 |
| 25 | 4000. | 145. | 18. | .1049 | .1408 | .1698 |
| 26 | 12000. | 145. | 18. | .6073 | .8908 | 1.1005 |
| 27 | 20000. | 145. | 18. | 1.6282 | 2.4300 | 2.9723 |
| 28 | 4000. | 75. | 30. | .2574 | .4020 | .5598 |
| 29 | 12000. | 75. | 30. | 3.8640 | 6.3134 | 8.4338 |
| 30 | 20000. | 75. | 30. | 13.2972 | 21.2525 | 27.1490 |
| 31 | 4000. | 110. | 30. | .2318 | .3679 | .5118 |
| 32 | 12000. | 110. | 30. | 2.9576 | 4.7780 | 6.3283 |
| 33 | 20000. | 110. | 30. | 10.2451 | 16.7087 | 21.6989 |
| 34 | 4000. | 145. | 30. | .2120 | .3406 | .4785 |
| 35 | 12000. | 145. | 30. | 3.3240 | 5.7155 | 7.7995 |
| 36 | 20000. | 145. | 30. | 13.9434 | 24.1978 | 31.9326 |
| 37 | 4000. | 75. | 50. | 6.1938 | 8.4012 | 10.4338 |
| 38 | 12000. | 75. | 50. | 37.3319 | 51.6079 | 62.6559 |
| 39 | 20000. | 75. | 50. | 92.6352 | 128.0472 | 152.3259 |
| 40 | 4000. | 110. | 50. | 10.1434 | 13.8962 | 17.3704 |
| 41 | 12000. | 110. | 50. | 71.8230 | 103.2867 | 128.0332 |
| 42 | 20000. | 110. | 50. | 207.9424 | 296.8741 | 353.9282 |
| 43 | 4000. | 145. | 50. | 15.9908 | 22.8506 | 28.5917 |
| 44 | 12000. | 145. | 50. | 96.0793 | 134.7679 | 165.2304 |
| 45 | 20000. | 145. | 50. | 244.7442 | 345.0066 | 415.2554 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Triple axle
SURFACE THICKNESS: 3.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0000 | .0001 | .0001 |
| 2 | 12000. | 75. | 4. | .0013 | .0023 | .0028 |
| 3 | 20000. | 75. | 4. | .0089 | .0152 | .0186 |
| 4 | 4000. | 110. | 4. | .0001 | .0001 | .0001 |
| 5 | 12000. | 110. | 4. | .0013 | .0022 | .0028 |
| 6 | 20000. | 110. | 4. | .0087 | .0152 | .0186 |
| 7 | 4000. | 145. | 4. | .0000 | .0001 | .0001 |
| 8 | 12000. | 145. | 4. | .0013 | .0021 | .0027 |
| 9 | 20000. | 145. | 4. | .0085 | .0146 | .0180 |
| 10 | 4000. | 75. | 10. | .0058 | .0095 | .0124 |
| 11 | 12000. | 75. | 10. | .1516 | .2590 | .3232 |
| 12 | 20000. | 75. | 10. | 1.0009 | 1.7263 | 2.0805 |
| 13 | 4000. | 110. | 10. | .0069 | .0117 | .0155 |
| 14 | 12000. | 110. | 10. | .1950 | .3332 | .4169 |
| 15 | 20000. | 110. | 10. | 1.3145 | 2.2485 | 2.7086 |
| 16 | 4000. | 145. | 10. | .0075 | .0130 | .0173 |
| 17 | 12000. | 145. | 10. | .2138 | .3681 | .4622 |
| 18 | 20000. | 145. | 10. | 1.4473 | 2.4680 | 2.9780 |
| 19 | 4000. | 75. | 18. | .0898 | .1313 | .1634 |
| 20 | 12000. | 75. | 18. | 1.3296 | 2.0893 | 2.5251 |
| 21 | 20000. | 75. | 18. | 6.6329 | 10.6098 | 12.4818 |
| 22 | 4000. | 110. | 18. | .1172 | .1821 | .2328 |
| 23 | 12000. | 110. | 18. | 2.2560 | 3.6435 | 4.4514 |
| 24 | 20000. | 110. | 18. | 12.5495 | 20.4177 | 24.1657 |
| 25 | 4000. | 145. | 18. | .1464 | .2330 | .3005 |
| 26 | 12000. | 145. | 18. | 3.0375 | 4.9640 | 6.0986 |
| 27 | 20000. | 145. | 18. | 17.7404 | 29.1066 | 34.5775 |
| 28 | 4000. | 75. | 30. | .6557 | .9860 | 1.2395 |
| 29 | 12000. | 75. | 30. | 7.5510 | 11.0701 | 13.0238 |
| 30 | 20000. | 75. | 30. | 29.6766 | 44.2578 | 50.9161 |
| 31 | 4000. | 110. | 30. | .6750 | 1.0899 | 1.4154 |
| 32 | 12000. | 110. | 30. | 13.1666 | 20.8978 | 25.2829 |
| 33 | 20000. | 110. | 30. | 64.3776 | 101.7747 | 119.2124 |
| 34 | 4000. | 145. | 30. | 1.2388 | 2.0289 | 2.6431 |
| 35 | 12000. | 145. | 30. | 24.8183 | 38.9352 | 46.8968 |
| 36 | 20000. | 145. | 30. | 121.1161 | 189.8578 | 221.8589 |
| 37 | 4000. | 75. | 50. | 2.8043 | 3.7149 | 4.3829 |
| 38 | 12000. | 75. | 50. | 19.0622 | 25.3689 | 28.6240 |
| 39 | 20000. | 75. | 50. | 56.4509 | 80.3763 | 90.6557 |
| 40 | 4000. | 110. | 50. | 8.4041 | 11.3306 | 13.5255 |
| 41 | 12000. | 110. | 50. | 72.5919 | 103.4700 | 120.4135 |
| 42 | 20000. | 110. | 50. | 267.2357 | 388.6187 | 442.8723 |
| 43 | 4000. | 145. | 50. | 10.9190 | 15.2729 | 18.5683 |
| 44 | 12000. | 145. | 50. | 119.3716 | 177.9727 | 210.8484 |
| 45 | 20000. | 145. | 50. | 500.7688 | 762.0837 | 882.4536 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Triple axle
SURFACE THICKNESS: 0.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0001 | .0002 | .0004 |
| 2 | 12000. | 75. | 4. | .0008 | .0013 | .0027 |
| 3 | 20000. | 75. | 4. | .0020 | .0029 | .0064 |
| 4 | 4000. | 110. | 4. | .0001 | .0002 | .0005 |
| 5 | 12000. | 110. | 4. | .0008 | .0012 | .0027 |
| 6 | 20000. | 110. | 4. | .0019 | .0028 | .0064 |
| 7 | 4000. | 145. | 4. | .0001 | .0002 | .0005 |
| 8 | 12000. | 145. | 4. | .0007 | .0012 | .0027 |
| 9 | 20000. | 145. | 4. | .0018 | .0028 | .0064 |
| 10 | 4000. | 75. | 10. | .0028 | .0037 | .0079 |
| 11 | 12000. | 75. | 10. | .0186 | .0245 | .0530 |
| 12 | 20000. | 75. | 10. | .0449 | .0589 | .1271 |
| 13 | 4000. | 110. | 10. | .0027 | .0037 | .0080 |
| 14 | 12000. | 110. | 10. | .0180 | .0243 | .0527 |
| 15 | 20000. | 110. | 10. | .0434 | .0584 | .1269 |
| 16 | 4000. | 145. | 10. | .0026 | .0037 | .0080 |
| 17 | 12000. | 145. | 10. | .0174 | .0242 | .0527 |
| 18 | 20000. | 145. | 10. | .0419 | .0583 | .1268 |
| 19 | 4000. | 75. | 18. | .0140 | .0231 | .0501 |
| 20 | 12000. | 75. | 18. | .0924 | .1529 | .3317 |
| 21 | 20000. | 75. | 18. | .2227 | .3678 | .7978 |
| 22 | 4000. | 110. | 18. | .0148 | .0233 | .0504 |
| 23 | 12000. | 110. | 18. | .0976 | .1538 | .3338 |
| 24 | 20000. | 110. | 18. | .2350 | .3704 | .8035 |
| 25 | 4000. | 145. | 18. | .0151 | .0234 | .0507 |
| 26 | 12000. | 145. | 18. | .0997 | .1544 | .3349 |
| 27 | 20000. | 145. | 18. | .2401 | .3717 | .8063 |
| 28 | 4000. | 75. | 30. | .0515 | .1113 | .2409 |
| 29 | 12000. | 75. | 30. | .3409 | .7360 | 1.5941 |
| 30 | 20000. | 75. | 30. | .8210 | 1.7720 | 3.8371 |
| 31 | 4000. | 110. | 30. | .0606 | .1123 | .2432 |
| 32 | 12000. | 110. | 30. | .4012 | .7434 | 1.6093 |
| 33 | 20000. | 110. | 30. | .9660 | 1.7900 | 3.8735 |
| 34 | 4000. | 145. | 30. | .0654 | .1128 | .2442 |
| 35 | 12000. | 145. | 30. | .4325 | .7467 | 1.6164 |
| 36 | 20000. | 145. | 30. | 1.0414 | 1.7976 | 3.8911 |
| 37 | 4000. | 75. | 50. | .1584 | .3876 | .8492 |
| 38 | 12000. | 75. | 50. | 1.0482 | 2.5652 | 5.6201 |
| 39 | 20000. | 75. | 50. | 2.5241 | 6.1761 | 13.5280 |
| 40 | 4000. | 110. | 50. | .1874 | .3996 | .8716 |
| 41 | 12000. | 110. | 50. | 1.2401 | 2.6443 | 5.7680 |
| 42 | 20000. | 110. | 50. | 2.9863 | 6.3666 | 13.8844 |
| 43 | 4000. | 145. | 50. | .2082 | .4059 | .8835 |
| 44 | 12000. | 145. | 50. | 1.3772 | 2.6860 | 5.8467 |
| 45 | 20000. | 145. | 50. | 3.3164 | 6.4670 | 14.0742 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Tandem axle
SURFACE THICKNESS: 6.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0000 | .0000 | .0000 |
| 2 | 12000. | 75. | 4. | .0001 | .0001 | .0001 |
| 3 | 20000. | 75. | 4. | .0002 | .0002 | .0002 |
| 4 | 4000. | 110. | 4. | .0000 | .0000 | .0000 |
| 5 | 12000. | 110. | 4. | .0001 | .0001 | .0001 |
| 6 | 20000. | 110. | 4. | .0002 | .0002 | .0003 |
| 7 | 4000. | 145. | 4. | .0000 | .0000 | .0000 |
| 8 | 12000. | 145. | 4. | .0001 | .0001 | .0001 |
| 9 | 20000. | 145. | 4. | .0002 | .0002 | .0003 |
| 10 | 4000. | 75. | 10. | .0037 | .0048 | .0056 |
| 11 | 12000. | 75. | 10. | .0145 | .0192 | .0225 |
| 12 | 20000. | 75. | 10. | .0290 | .0383 | .0442 |
| 13 | 4000. | 110. | 10. | .0045 | .0057 | .0067 |
| 14 | 12000. | 110. | 10. | .0174 | .0235 | .0278 |
| 15 | 20000. | 110. | 10. | .0362 | .0493 | .0575 |
| 16 | 4000. | 145. | 10. | .0052 | .0066 | .0076 |
| 17 | 12000. | 145. | 10. | .0195 | .0264 | .0312 |
| 18 | 20000. | 145. | 10. | .0405 | .0559 | .0654 |
| 19 | 4000. | 75. | 18. | .0989 | .1229 | .1439 |
| 20 | 12000. | 75. | 18. | .3453 | .4320 | .4937 |
| 21 | 20000. | 75. | 18. | .6327 | .7954 | .8975 |
| 22 | 4000. | 110. | 18. | .1246 | .1594 | .1898 |
| 23 | 12000. | 110. | 18. | .4810 | .6234 | .7258 |
| 24 | 20000. | 110. | 18. | .9350 | 1.2151 | 1.3925 |
| 25 | 4000. | 145. | 18. | .1442 | .1865 | .2216 |
| 26 | 12000. | 145. | 18. | .5704 | .7577 | .8913 |
| 27 | 20000. | 145. | 18. | 1.1496 | 1.5289 | 1.7695 |
| 28 | 4000. | 75. | 30. | 1.4801 | 1.7586 | 1.9963 |
| 29 | 12000. | 75. | 30. | 4.2644 | 5.1100 | 5.6913 |
| 30 | 20000. | 75. | 30. | 7.0715 | 8.4986 | 9.3659 |
| 31 | 4000. | 110. | 30. | 2.1139 | 2.5958 | 3.0177 |
| 32 | 12000. | 110. | 30. | 7.0676 | 8.7425 | 9.9278 |
| 33 | 20000. | 110. | 30. | 12.6537 | 15.7392 | 17.6627 |
| 34 | 4000. | 145. | 30. | 2.5611 | 3.2236 | 3.8005 |
| 35 | 12000. | 145. | 30. | 9.3549 | 11.8611 | 13.6565 |
| 36 | 20000. | 145. | 30. | 17.5745 | 22.3721 | 25.3998 |
| 37 | 4000. | 75. | 50. | 24.2185 | 28.0133 | 30.9883 |
| 38 | 12000. | 75. | 50. | 54.3905 | 61.9884 | 67.0768 |
| 39 | 20000. | 75. | 50. | 76.3698 | 85.1160 | 90.4116 |
| 40 | 4000. | 110. | 50. | 31.4373 | 36.7135 | 40.8886 |
| 41 | 12000. | 110. | 50. | 82.0802 | 97.3111 | 107.6587 |
| 42 | 20000. | 110. | 50. | 132.1818 | 156.7759 | 171.5635 |
| 43 | 4000. | 145. | 50. | 40.4505 | 48.6728 | 55.7744 |
| 44 | 12000. | 145. | 50. | 123.9050 | 150.3218 | 168.6958 |
| 45 | 20000. | 145. | 50. | 211.9985 | 258.3732 | 286.8695 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Tandem axle
SURFACE THICKNESS: 3.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0001 | .0002 | .0002 |
| 2 | 12000. | 75. | 4. | .0015 | .0023 | .0027 |
| 3 | 20000. | 75. | 4. | .0061 | .0093 | .0109 |
| 4 | 4000. | 110. | 4. | .0002 | .0003 | .0003 |
| 5 | 12000. | 110. | 4. | .0022 | .0034 | .0041 |
| 6 | 20000. | 110. | 4. | .0094 | .0148 | .0174 |
| 7 | 4000. | 145. | 4. | .0002 | .0003 | .0004 |
| 8 | 12000. | 145. | 4. | .0027 | .0042 | .0051 |
| 9 | 20000. | 145. | 4. | .0120 | .0189 | .0224 |
| 10 | 4000. | 75. | 10. | .0131 | .0177 | .0209 |
| 11 | 12000. | 75. | 10. | .0961 | .1364 | .1579 |
| 12 | 20000. | 75. | 10. | .3129 | .4522 | .5143 |
| 13 | 4000. | 110. | 10. | .0222 | .0313 | .0378 |
| 14 | 12000. | 110. | 10. | .2014 | .2953 | .3468 |
| 15 | 20000. | 110. | 10. | .7334 | 1.0910 | 1.2536 |
| 16 | 4000. | 145. | 10. | .0305 | .0443 | .0541 |
| 17 | 12000. | 145. | 10. | .3100 | .4646 | .5506 |
| 18 | 20000. | 145. | 10. | 1.2023 | 1.8183 | 2.1031 |
| 19 | 4000. | 75. | 18. | .1733 | .2189 | .2499 |
| 20 | 12000. | 75. | 18. | .8470 | 1.1193 | 1.2593 |
| 21 | 20000. | 75. | 18. | 2.1596 | 2.9045 | 3.2250 |
| 22 | 4000. | 110. | 18. | .3539 | .4667 | .5452 |
| 23 | 12000. | 110. | 18. | 2.2837 | 3.1711 | 3.6406 |
| 24 | 20000. | 110. | 18. | 6.9019 | 9.7723 | 11.0393 |
| 25 | 4000. | 145. | 18. | .5517 | .7507 | .8911 |
| 26 | 12000. | 145. | 18. | 4.2266 | 6.0347 | 7.0084 |
| 27 | 20000. | 145. | 18. | 14.0828 | 20.4771 | 23.3390 |
| 28 | 4000. | 75. | 30. | 1.3437 | 1.5916 | 1.7535 |
| 29 | 12000. | 75. | 30. | 4.1707 | 5.0110 | 5.4172 |
| 30 | 20000. | 75. | 30. | 8.0000 | 9.6843 | 10.3523 |
| 31 | 4000. | 110. | 30. | 3.1351 | 3.9028 | 4.4183 |
| 32 | 12000. | 110. | 30. | 13.8033 | 17.8749 | 19.9447 |
| 33 | 20000. | 110. | 30. | 33.0919 | 43.5497 | 47.9951 |
| 34 | 4000. | 145. | 30. | 5.4387 | 6.9871 | 8.0480 |
| 35 | 12000. | 145. | 30. | 29.7472 | 40.1431 | 45.5532 |
| 36 | 20000. | 145. | 30. | 81.4321 | 111.9795 | 125.2762 |
| 37 | 4000. | 75. | 50. | 11.9589 | 12.7398 | 13.2949 |
| 38 | 12000. | 75. | 50. | 18.2244 | 18.1163 | 18.0205 |
| 39 | 20000. | 75. | 50. | 22.0562 | 22.7259 | 22.7699 |
| 40 | 4000. | 110. | 50. | 23.4746 | 27.2934 | 29.7677 |
| 41 | 12000. | 110. | 50. | 63.9394 | 74.5521 | 79.5477 |
| 42 | 20000. | 110. | 50. | 112.9138 | 132.0625 | 139.3171 |
| 43 | 4000. | 145. | 50. | 44.2626 | 53.5052 | 59.6059 |
| 44 | 12000. | 145. | 50. | 158.6049 | 196.7098 | 215.5634 |
| 45 | 20000. | 145. | 50. | 331.9489 | 416.3932 | 451.0707 |

CONTENTS OF FILE ARE.EQF

AXLE SET TYPE: Tandem axle
SURFACE THICKNESS: 0.0 inches

| INDEX | ROADBED SOIL MODULUS (psi) | TIRE PRESS. (psi) | AXLE WEIGHT (kips) | ----EQUIVALENCE FACTORS--- BS/SUB THICK. 8 in. | BS/SUB THICK. 14 in. | BS/SUB THICK. 20 in. |
|---|---|---|---|---|---|---|
| 1 | 4000. | 75. | 4. | .0008 | .0006 | .0008 |
| 2 | 12000. | 75. | 4. | .0019 | .0015 | .0022 |
| 3 | 20000. | 75. | 4. | .0030 | .0023 | .0034 |
| 4 | 4000. | 110. | 4. | .0008 | .0006 | .0009 |
| 5 | 12000. | 110. | 4. | .0019 | .0015 | .0022 |
| 6 | 20000. | 110. | 4. | .0030 | .0023 | .0034 |
| 7 | 4000. | 145. | 4. | .0007 | .0006 | .0009 |
| 8 | 12000. | 145. | 4. | .0019 | .0015 | .0022 |
| 9 | 20000. | 145. | 4. | .0030 | .0023 | .0034 |
| 10 | 4000. | 75. | 10. | .0146 | .0130 | .0190 |
| 11 | 12000. | 75. | 10. | .0377 | .0335 | .0490 |
| 12 | 20000. | 75. | 10. | .0585 | .0519 | .0759 |
| 13 | 4000. | 110. | 10. | .0162 | .0132 | .0192 |
| 14 | 12000. | 110. | 10. | .0416 | .0339 | .0495 |
| 15 | 20000. | 110. | 10. | .0645 | .0526 | .0768 |
| 16 | 4000. | 145. | 10. | .0169 | .0133 | .0194 |
| 17 | 12000. | 145. | 10. | .0434 | .0341 | .0498 |
| 18 | 20000. | 145. | 10. | .0674 | .0529 | .0773 |
| 19 | 4000. | 75. | 18. | .0851 | .0942 | .1381 |
| 20 | 12000. | 75. | 18. | .2188 | .2422 | .3552 |
| 21 | 20000. | 75. | 18. | .3396 | .3758 | .5511 |
| 22 | 4000. | 110. | 18. | .1017 | .0963 | .1409 |
| 23 | 12000. | 110. | 18. | .2616 | .2477 | .3625 |
| 24 | 20000. | 110. | 18. | .4059 | .3844 | .5624 |
| 25 | 4000. | 145. | 18. | .1118 | .0974 | .1424 |
| 26 | 12000. | 145. | 18. | .2875 | .2506 | .3663 |
| 27 | 20000. | 145. | 18. | .4462 | .3888 | .5683 |
| 28 | 4000. | 75. | 30. | .3459 | .5145 | .7593 |
| 29 | 12000. | 75. | 30. | .8897 | 1.3236 | 1.9535 |
| 30 | 20000. | 75. | 30. | 1.3808 | 2.0539 | 3.0306 |
| 31 | 4000. | 110. | 30. | .4535 | .5349 | .7854 |
| 32 | 12000. | 110. | 30. | 1.1665 | 1.3761 | 2.0205 |
| 33 | 20000. | 110. | 30. | 1.8104 | 2.1353 | 3.1346 |
| 34 | 4000. | 145. | 30. | .5268 | .5455 | .7992 |
| 35 | 12000. | 145. | 30. | 1.3550 | 1.4034 | 2.0561 |
| 36 | 20000. | 145. | 30. | 2.1029 | 2.1776 | 3.1898 |
| 37 | 4000. | 75. | 50. | 1.2002 | 2.7121 | 4.0596 |
| 38 | 12000. | 75. | 50. | 3.0869 | 6.9769 | 10.4438 |
| 39 | 20000. | 75. | 50. | 4.7908 | 10.8261 | 16.2022 |
| 40 | 4000. | 110. | 50. | 1.7789 | 2.9024 | 4.2941 |
| 41 | 12000. | 110. | 50. | 4.5752 | 7.4663 | 11.0472 |
| 42 | 20000. | 110. | 50. | 7.1007 | 11.5856 | 17.1383 |
| 43 | 4000. | 145. | 50. | 2.2258 | 3.0028 | 4.4208 |
| 44 | 12000. | 145. | 50. | 5.7247 | 7.7245 | 11.3732 |
| 45 | 20000. | 145. | 50. | 8.8845 | 11.9862 | 17.6441 |

# APPENDIX G

# DEVELOPMENT OF EXTENDED AASHTO COMPATIBLE FACTORS

Because the mechanistically derived load equivalence factors were not compatible with the AASHTO Guide equivalence factors presently being used by Arizona DOT, it was necessary to conduct additional research that would result in a set of load equivalence factors that were both compatible with those in the AASHTO Guide and capable of considering the effects of increased tire pressures. This appendix describes the process through which the new factors were developed and presents the summary data tables that are now used by the FEDESAL and WIMESAL programs for 18-kip ESAL traffic projection. It should be understood that these alternate factors are not meant to replace the recommended set of mechanistic load equivalence factors. They are, instead, meant to be interim values that can be used by ADOT until some experience and confidence in the mechanistic factors can be achieved.

## DEVELOPMENT PROCESS

As indicated previously, there were only two criteria for developing the separate set of extended load equivalence factors. One was that they be compatible with those in the current AASHTO Guide. The second was that they must account for the effects of higher tire pressures. To satisfy these criteria, it was necessary to adopt an approach that would relate a given AASHTO load equivalence factor to the maximum asphalt concrete tensile strain generated (due to the specific load considered) in a given flexible pavement structure. With this approach, it was then possible to estimate load equivalence factors for other conditions (i.e., higher tire pressures) simply by determining the effect of the new condition on tensile strain.

Following is a discussion of the steps that were taken to develop the extended AASHTO factors:

Step 1 - Determine Average Material Properties for AASHO Road Test Sections

The development approach involved the use of the AASHO Road Test material property data that was generated and used to develop the mechanistic damage models (see Chapter 3). For this purpose, however, it was necessary to translate the seasonal values for each layer into average or effective values that were representative of year-round conditions. This was accomplished through an iterative back-calculation process using the ELSYM5 program. The objective of the back-calculation process was to find for each Road Test section, the set of elastic layer properties that produced the same "effective year-round tensile strains" that were used in developing the tensile strain based damage model. As before, the fall season was chosen as the average season and it was still necessary that the properties chosen for the base and subbase still satisfy NCHRP Project 1-10B bulk stress criteria. Tables G.1 and G.2 present the results of this step for the single and tandem axle sections, respectively. (Note: Since the fall season was chosen, the asphalt concrete surface modulus, E1, was 450,000 psi in all cases.)

Step 2 - Develop Average Material Property Relationships

After average material properties were identified for each Road Test section, it was then necessary to develop material property relationships that could be used to estimate the average properties of any actual or hypothetical pavement cross section in the AASHO Road Test environment. This was accomplished through simple linear regression analysis. Tables G.3 and G.4 summarize the results of these regression analyses for the single and tandem axle sections, respectively. Note that since a pavement's overall thickness had an effect on the properties of the underlying layers, a new term referred to as the subgrade cover factor (D3ST) was created and allowed to enter the equation. It basically represents the equivalent thickness of the subbase layer in shielding the roadbed soil from freeze-thaw effects and is calculated as follows:

Table G.1. Average (year-round) properties for AASHO Road Test single axle load sections.

| Section No. | Axle Load (kips) | Layer Thicknesses (in) D1 | D2 | D3 | Layer Moduli (psi) E4 | E3 | E2 |
|---|---|---|---|---|---|---|---|
| 111 | 12 | 2 | 6 | 8 | 3000 | 8911 | 18638 |
| 155 | 12 | 3 | 6 | 8 | 2500 | 7807 | 13618 |
| 623 | 18 | 3 | 6 | 8 | 2500 | 7388 | 15040 |
| 601 | 18 | 3 | 6 | 12 | 4000 | 12508 | 20672 |
| 577 | 18 | 4 | 6 | 8 | 3500 | 9584 | 14806 |
| 625 | 18 | 4 | 6 | 12 | 3500 | 11188 | 16800 |
| 419 | 22.4 | 3 | 6 | 8 | 2500 | 7280 | 15511 |
| 487 | 22.4 | 3 | 6 | 12 | 2500 | 9354 | 18946 |
| 471 | 22.4 | 3 | 9 | 8 | 2000 | 5766 | 14611 |
| 455 | 22.4 | 4 | 6 | 8 | 2000 | 6189 | 11504 |
| 453 | 22.4 | 4 | 6 | 8 | 2500 | 7260 | 13350 |
| 425 | 22.4 | 4 | 6 | 12 | 4500 | 12970 | 19787 |
| 417 | 22.4 | 4 | 9 | 8 | 2500 | 7106 | 13914 |
| 477 | 22.4 | 4 | 9 | 12 | 6000 | 14279 | 21697 |
| 469 | 22.4 | 5 | 6 | 8 | 4500 | 11215 | 15649 |
| 445 | 22.4 | 5 | 6 | 12 | 4500 | 12549 | 17538 |
| 303 | 30 | 4 | 6 | 8 | 3000 | 8314 | 15499 |
| 323 | 30 | 4 | 6 | 12 | 2000 | 7316 | 14968 |
| 253 | 30 | 4 | 6 | 16 | 5500 | 16510 | 25024 |
| 321 | 30 | 4 | 9 | 8 | 2000 | 5663 | 12781 |
| 267 | 30 | 4 | 9 | 12 | 2000 | 6981 | 15606 |
| 309 | 30 | 4 | 9 | 16 | 5000 | 14688 | 24132 |
| 259 | 30 | 5 | 6 | 8 | 3000 | 8452 | 13595 |
| 307 | 30 | 5 | 6 | 12 | 5500 | 14346 | 20633 |
| 305 | 30 | 5 | 6 | 12 | 3000 | 10078 | 15767 |
| 327 | 30 | 5 | 6 | 16 | 4500 | 14329 | 20528 |
| 313 | 30 | 5 | 9 | 8 | 5000 | 11588 | 18219 |
| 331 | 30 | 5 | 9 | 12 | 6500 | 14991 | 21697 |
| 325 | 30 | 6 | 6 | 8 | 2500 | 7614 | 11135 |
| 257 | 30 | 6 | 6 | 12 | 4500 | 12555 | 17016 |
| 263 | 30 | 6 | 9 | 8 | 4500 | 10936 | 15743 |
| 271 | 30 | 6 | 9 | 8 | 4500 | 10936 | 15743 |
| 311 | 30 | 6 | 9 | 12 | 4500 | 12294 | 17266 |

Table G.2. Average (year-round) material properties for AASHO Road Test tandem axle load sections.

| Section No. | Axle Load (kips) | Layer Thicknesses (in) | | | Layer Moduli (psi) | | |
|---|---|---|---|---|---|---|---|
| | | D1 | D2 | D3 | E4 | E3 | E2 |
| 112 | 24 | 2 | 6 | 8 | 4000 | 11344 | 20968 |
| 156 | 24 | 3 | 6 | 8 | 4000 | 10823 | 17028 |
| 624 | 32 | 3 | 6 | 8 | 2500 | 8002 | 15227 |
| 602 | 32 | 3 | 6 | 12 | 4500 | 13569 | 21148 |
| 578 | 32 | 4 | 6 | 8 | 4000 | 10891 | 15970 |
| 420 | 40 | 3 | 6 | 8 | 3000 | 9093 | 17558 |
| 488 | 40 | 3 | 6 | 12 | 5500 | 15482 | 24363 |
| 472 | 40 | 3 | 9 | 8 | 1500 | 6128 | 12375 |
| 456 | 40 | 4 | 6 | 8 | 2000 | 6692 | 12047 |
| 454 | 40 | 4 | 6 | 8 | 3000 | 9200 | 14821 |
| 426 | 40 | 4 | 6 | 12 | 4000 | 12637 | 19676 |
| 418 | 40 | 4 | 9 | 8 | 2000 | 6561 | 12659 |
| 470 | 40 | 5 | 6 | 8 | 3500 | 10263 | 13931 |
| 446 | 40 | 5 | 6 | 12 | 4500 | 13005 | 17502 |
| 304 | 48 | 4 | 6 | 8 | 4500 | 12249 | 18383 |
| 324 | 48 | 4 | 6 | 12 | 3000 | 10829 | 17893 |
| 254 | 48 | 4 | 6 | 16 | 7000 | 18281 | 25558 |
| 322 | 48 | 4 | 9 | 8 | 4000 | 10831 | 17984 |
| 268 | 48 | 4 | 9 | 12 | 4500 | 12756 | 21012 |
| 260 | 48 | 5 | 6 | 8 | 3500 | 10291 | 14716 |
| 308 | 48 | 5 | 6 | 12 | 5500 | 14776 | 19745 |
| 306 | 48 | 5 | 6 | 12 | 5000 | 13978 | 19196 |
| 328 | 48 | 5 | 6 | 16 | 5000 | 15079 | 20550 |
| 314 | 48 | 5 | 9 | 8 | 5500 | 13005 | 18310 |
| 332 | 48 | 5 | 9 | 12 | 5500 | 14210 | 19608 |
| 326 | 48 | 6 | 6 | 8 | 2500 | 8377 | 11433 |
| 272 | 48 | 6 | 9 | 8 | 4000 | 10952 | 14774 |

Table G.3. Material property prediction relationships for AASHO Road Test single axle sections.

Form of Equation:

$$E = b_0 + b_1*D3ST + b_2*P$$

where: D3ST = subgrade cover factor (inches)
P = single axle load (kips)
E = predicted layer modulus (psi)

| Layer | Dependent Variable | Coefficients | | | |
|---|---|---|---|---|---|
| | | $b_0$ | $b_1$ | $b_2$ | $r^2$ |
| Roadbed Soil | $E_4$ | -1868 | +292.8 | -60.8 | 0.448 |
| Subbase | $E_3$ | -3665 | +791.9 | -202.4 | 0.559 |
| Base | $E_2$ | +3587 | +857.2 | -289.9 | 0.479 |

Table G.4. Material property prediction relationships for AASHO Road Test tandem axle sections.

Form of Equation:

$$E = b_0 + b_1 * D3ST + b_2 * P$$

where: D3ST = subgrade cover factor (inches)
P = tandem axle load (kips)
E = predicted layer modulus (psi)

| Layer | Dependent Variable | Coefficients | | | $r^2$ |
|---|---|---|---|---|---|
| | | $b_0$ | $b_1$ | $b_2$ | |
| Roadbed Soil | $E_4$ | -1142 | +220.9 | - | 0.320 |
| Subbase | $E_3$ | -539 | +712.5 | -108.4 | 0.408 |
| Base | $E_2$ | 8694 | +729.8 | -193.5 | 0.237 |

$D3ST = (1.4*D1) + (1.1*D2) + D3$

Note: D1, D2 and D3 represent the respective thicknesses of surface, base and subbase.

Step 3 - Calculate Tensile Strains, Predicted AASHTO Traffic for Road Test Sections and Develop Interrelationship

Tables G.5 and G.6 present the calculated maximum asphalt concrete tensile strains and predicted AASHTO traffic for the AASHO Road Test single and tandem axle load sections, respectively. The asphalt concrete tensile strains were calculated using the ELSYM5 program for the actual primary axle load on each section and the material properties derived from the relationships developed in step 2. The predicted AASHTO traffic ($W_t$) values for each section were generated using the standard AASHTO performance algorithm where: 1) SN was assumed to be 5.0, 2) terminal serviceability was set equal to 2.5, and 3) axle load ($L_1$) and number of axles ($L_2$) were varied according to section load variables. The regression analyses between AASHTO traffic and AC tensile strain resulted in the following relationships.

Single Axles:

$$\log(W_t) = -6.678 - 3.626*\log(strain)$$

$$r^2 = 0.928$$

Tandem Axles:

$$\log(W_t) = -5.670 - 3.264*\log(strain)$$

$$r^2 = 0.828$$

Table G.5. Data used to develop single axle prediction relationship.

| AASHO Section No. | Axle Load (kips) | Layer Thicknesses (in.) D1 | D2 | D3 | D3ST (in.) | Layer Moduli (psi) E2 | E3 | E4 | Tensile Strain $(10^{-3})$ | AASHO Structural Number | AASHO Load Applications |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 111 | 12.0 | 2 | 6 | 8 | 17.4 | 15024 | 7686 | 2497 | .4920 | 2.60 | 358960 |
| 155 | 12.0 | 3 | 6 | 8 | 18.8 | 16224 | 8794 | 2907 | .3637 | 3.04 | 892083 |
| 623 | 18.0 | 3 | 6 | 8 | 18.8 | 14484 | 7580 | 2542 | .4957 | 3.04 | 204240 |
| 601 | 18.0 | 3 | 6 | 12 | 22.8 | 17913 | 10748 | 3714 | .4184 | 3.48 | 463393 |
| 577 | 18.0 | 4 | 6 | 8 | 20.2 | 15685 | 8689 | 2952 | .3828 | 3.48 | 463393 |
| 625 | 18.0 | 4 | 6 | 12 | 24.2 | 19113 | 11856 | 4123 | .3304 | 3.92 | 968752 |
| 419 | 22.4 | 3 | 6 | 8 | 18.8 | 13209 | 6689 | 2275 | .6055 | 3.04 | 87688 |
| 487 | 22.4 | 3 | 6 | 12 | 22.8 | 16638 | 9857 | 3446 | .4926 | 3.48 | 205139 |
| 471 | 22.4 | 3 | 9 | 8 | 22.1 | 16038 | 9303 | 3241 | .4856 | 3.46 | 197852 |
| 455 | 22.4 | 4 | 6 | 8 | 20.2 | 14409 | 7798 | 2685 | .4766 | 3.48 | 205139 |
| 453 | 22.4 | 4 | 6 | 8 | 20.2 | 14409 | 7798 | 2685 | .4766 | 3.48 | 205139 |
| 425 | 22.4 | 4 | 6 | 12 | 24.2 | 17838 | 10966 | 3856 | .4016 | 3.92 | 433099 |
| 417 | 22.4 | 4 | 9 | 8 | 23.5 | 17238 | 10411 | 3651 | .3977 | 3.90 | 419387 |
| 477 | 22.4 | 4 | 9 | 12 | 27.5 | 20667 | 13579 | 4822 | .3486 | 4.34 | 825158 |
| 469 | 22.4 | 5 | 6 | 8 | 21.6 | 15609 | 8907 | 3095 | .3782 | 3.92 | 433099 |
| 445 | 22.4 | 5 | 6 | 12 | 25.6 | 19038 | 12074 | 4266 | .3264 | 4.36 | 849779 |
| 303 | 30.0 | 4 | 6 | 8 | 20.2 | 12206 | 6260 | 2223 | .6692 | 3.48 | 63903 |
| 323 | 30.0 | 4 | 6 | 12 | 24.2 | 15635 | 9427 | 3394 | .5505 | 3.92 | 140983 |
| 253 | 30.0 | 4 | 6 | 16 | 28.2 | 19063 | 12595 | 4565 | .4758 | 4.36 | 284173 |
| 321 | 30.0 | 4 | 9 | 8 | 23.5 | 15035 | 8873 | 3189 | .5462 | 3.90 | 136289 |
| 267 | 30.0 | 4 | 9 | 12 | 27.5 | 18463 | 12041 | 4360 | .4713 | 4.34 | 275726 |
| 309 | 30.0 | 4 | 9 | 16 | 31.5 | 21892 | 15208 | 5531 | .4193 | 4.78 | 519001 |
| 259 | 30.0 | 5 | 6 | 8 | 21.6 | 13406 | 7368 | 2633 | .5232 | 3.92 | 140983 |
| 307 | 30.0 | 5 | 6 | 12 | 25.6 | 16835 | 10536 | 3804 | .4437 | 4.36 | 284173 |
| 305 | 30.0 | 5 | 6 | 12 | 25.6 | 16835 | 10536 | 3804 | .4437 | 4.36 | 284173 |
| 327 | 20.0 | 5 | 6 | 16 | 29.6 | 20263 | 13704 | 4975 | .3909 | 4.80 | 533381 |
| 313 | 30.0 | 5 | 9 | 8 | 24.9 | 16235 | 9982 | 3599 | .4417 | 4.34 | 275726 |
| 331 | 30.0 | 5 | 9 | 12 | 28.9 | 19663 | 13149 | 4770 | .3883 | 4.78 | 519001 |
| 325 | 30.0 | 6 | 6 | 8 | 23.0 | 14606 | 8477 | 3042 | .4180 | 4.36 | 284173 |
| 257 | 30.0 | 6 | 6 | 12 | 27.0 | 18035 | 11645 | 4214 | .3624 | 4.80 | 533381 |
| 263 | 30.0 | 6 | 9 | 8 | 26.3 | 17435 | 11090 | 4009 | .3615 | 4.78 | 519001 |
| 271 | 30.0 | 6 | 9 | 8 | 26.3 | 17435 | 11090 | 4009 | .3615 | 4.78 | 519001 |
| 311 | 30.0 | 6 | 9 | 12 | 30.3 | 20863 | 14258 | 5180 | .3223 | 5.22 | 925116 |

Table G.6. Data used to develop tandem axle prediction relationship.

| AASHO Section No. | Axle Load (kips) | Layer Thicknesses (in.) D1 | D2 | D3 | D3ST (in.) | Layer Moduli (psi) E2 | E3 | E4 | Tensile Strain ($10^{-3}$) | AASHO Structural Number | AASHO Load Applications |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 112 | 24.0 | 2 | 6 | 8 | 17.4 | 16748 | 9257 | 2702 | .4537 | 2.60 | 261140 |
| 156 | 24.0 | 3 | 6 | 8 | 18.8 | 17770 | 10255 | 3011 | .3384 | 3.04 | 648982 |
| 624 | 32.0 | 3 | 6 | 8 | 18.8 | 16222 | 9387 | 3011 | .4173 | 3.04 | 229565 |
| 602 | 32.0 | 3 | 6 | 12 | 22.8 | 19141 | 12237 | 3895 | .3688 | 3.48 | 517836 |
| 578 | 32.0 | 4 | 6 | 8 | 20.2 | 17244 | 10385 | 3320 | .3198 | 3.48 | 517836 |
| 420 | 40.0 | 3 | 6 | 8 | 18.8 | 14674 | 8520 | 3011 | .4975 | 3.04 | 99559 |
| 488 | 40.0 | 3 | 6 | 12 | 22.8 | 17593 | 11370 | 3895 | .4331 | 3.48 | 228683 |
| 472 | 40.0 | 3 | 9 | 8 | 22.1 | 17082 | 10871 | 3740 | .4286 | 3.46 | 220704 |
| 456 | 40.0 | 4 | 6 | 8 | 20.2 | 15696 | 9518 | 3320 | .3840 | 3.48 | 228683 |
| 454 | 40.0 | 4 | 6 | 8 | 20.2 | 15696 | 9518 | 3320 | .3840 | 3.48 | 228683 |
| 426 | 40.0 | 4 | 6 | 12 | 24.2 | 18615 | 12369 | 4204 | .3417 | 3.92 | 478595 |
| 418 | 40.0 | 4 | 9 | 8 | 23.5 | 18104 | 11869 | 4049 | .3391 | 3.90 | 463516 |
| 470 | 40.0 | 5 | 6 | 8 | 21.6 | 16718 | 10515 | 3630 | .3034 | 3.92 | 478595 |
| 446 | 40.0 | 5 | 6 | 12 | 25.6 | 19637 | 13365 | 4513 | .2728 | 4.36 | 940686 |
| 304 | 48.0 | 4 | 6 | 8 | 20.2 | 14148 | 8651 | 3320 | .4676 | 3.48 | 114349 |
| 324 | 48.0 | 4 | 6 | 12 | 24.2 | 17067 | 11501 | 4204 | .4109 | 3.92 | 243479 |
| 254 | 48.0 | 4 | 6 | 16 | 28.2 | 19986 | 14351 | 5087 | .3697 | 4.36 | 479007 |
| 322 | 48.0 | 4 | 9 | 8 | 23.5 | 16556 | 11002 | 4049 | .4081 | 3.90 | 235707 |
| 268 | 48.0 | 4 | 9 | 12 | 27.5 | 19475 | 13852 | 4933 | .3670 | 4.34 | 465132 |
| 260 | 48.0 | 5 | 6 | 8 | 21.6 | 15170 | 9648 | 3630 | .3673 | 3.92 | 243479 |
| 308 | 48.0 | 5 | 6 | 12 | 25.6 | 18089 | 12498 | 4513 | .3294 | 4.36 | 479007 |
| 306 | 48.0 | 5 | 6 | 12 | 25.6 | 18089 | 12498 | 4513 | .3294 | 4.36 | 479007 |
| 328 | 48.0 | 5 | 6 | 16 | 29.6 | 21008 | 15348 | 5397 | .3009 | 4.80 | 891221 |
| 314 | 48.0 | 5 | 9 | 8 | 24.9 | 17578 | 11999 | 4359 | .3281 | 4.34 | 465132 |
| 332 | 48.0 | 5 | 9 | 12 | 28.9 | 20497 | 14849 | 5242 | .2994 | 4.78 | 867243 |
| 326 | 48.0 | 6 | 6 | 8 | 23.0 | 16191 | 10646 | 3939 | .2938 | 4.36 | 479007 |
| 272 | 48.0 | 6 | 9 | 8 | 26.3 | 18600 | 12997 | 4658 | .2664 | 4.78 | 867243 |

These equations, when used in conjunction with the average material property relationships (developed in step 2) and ELSYM5 should provide axle load traffic estimates that are compatible with those generated by the AASHTO performance algorithm.

Step 4 - Select Pavement Cross Section

To generate the needed tensile strains, it was necessary to select a standard pavement cross section. Since FHWA and ADOT both normally develop their load equivalence factors for highway pavements using a structural number (SN) of 5.0, we chose a structure that provides the same SN:

$D_1 = 7.5$ inches $(a_1 = 0.44)$
$D_2 = 6.0$ inches $(a_2 = 0.14)$
$D_3 = 8.0$ inches $(a_3 = 0.11)$

Step 5 - Develop Extended Equivalence Factors Using AASHTO Compatible Prediction Relationships

Table G.7 summarizes the results obtained from using the prediction relationships generated in step 3 and the pavement structure selected in step 4 to generate 18-kip single axle load equivalence factors for varying axle configurations, axle loads and tire pressures. The load equivalence factors were calculated by taking the ratio of the $W_t$ obtained from the single axle prediction relationship for a standard 18-kip (75 psi) single axle load to that obtained for any other configuration, load and tire pressure.

Step 6 - Calibrate Extended Equivalence Factors

Due to the lack-of-fit in the prediction relationships developed in step 3, there is a small amount of discrepancy between extended equivalence factors and the standard AASHTO factors in the region where they overlap. It is very likely, that had we chosen a different SN or layer combination upon which to develop the extended factors, there might

Table G.7. Summary of extended AASHTO compatible load equivalence factors (LEF) for the three primary axle configurations.

| Axle Load (kips) | Roadbed Soil Modulus (psi) | Subbase Modulus (psi) | Base Modulus (psi) | Tire Pressure: 75 psi Strain ($10^{-3}$) | 75 psi LEF | 110 psi Strain ($10^{-3}$) | 110 psi LEF | 145 psi Strain ($10^{-3}$) | 145 psi LEF |
|---|---|---|---|---|---|---|---|---|---|
| **Single Axle - Single Tire Data** | | | | | | | | | |
| 2.00 | 5360. | 15807. | 24523. | .0312 | .00166 | .0323 | .00188 | .0331 | .00206 |
| 5.00 | 5177. | 15200. | 23654. | .0714 | .03349 | .0748 | .03962 | .0770 | .04398 |
| 8.00 | 4995. | 14593. | 22784. | .1071 | .14560 | .1142 | .18366 | .1184 | .20954 |
| 10.00 | 4873. | 14188. | 22204. | .1289 | .28505 | .1390 | .37413 | .1450 | .43620 |
| 14.00 | 4630. | 13378. | 21044. | .1691 | .76113 | .1856 | 1.06852 | .1958 | 1.29713 |
| 17.00 | 4448. | 12771. | 20175. | .1970 | 1.32469 | .2187 | 1.93598 | .2324 | 2.41271 |
| 18.00 | 4387. | 12569. | 19885. | .2060 | 1.55801 | .2294 | 2.30371 | .2443 | 2.89390 |
| 18.25 | 4372. | 12518. | 19812. | .2082 | 1.62017 | .2321 | 2.40234 | .2473 | 3.02361 |
| 19.25 | 4311. | 12316. | 19522. | .2171 | 1.88481 | .2427 | 2.82486 | .2591 | 3.58199 |
| 21.00 | 4205. | 11962. | 19015. | .2324 | 2.41311 | .2611 | 3.67880 | .2797 | 4.72177 |
| 23.00 | 4083. | 11557. | 18435. | .2496 | 3.12827 | .2817 | 4.85103 | .3029 | 6.30485 |
| 25.00 | 3961. | 11152. | 17856. | .2667 | 3.97662 | .3022 | 6.25823 | .3259 | 8.22536 |
| 28.00 | 3779. | 10545. | 16986. | .2922 | 5.53815 | .3328 | 8.87739 | .3603 | 11.83837 |
| 32.50 | 3505. | 9634. | 15681. | .3308 | 8.68277 | .3789 | 14.20693 | .4122 | 19.27529 |
| **Single Axle - Dual Tire Data** | | | | | | | | | |
| 2.00 | 5360. | 15807. | 24523. | .0220 | .00047 | .0226 | .00051 | .0230 | .00055 |
| 5.00 | 5177. | 15200. | 23654. | .0523 | .01078 | .0537 | .01189 | .0547 | .01275 |
| 8.00 | 4995. | 14593. | 22784. | .0817 | .05447 | .0843 | .06092 | .0860 | .06551 |
| 10.00 | 4873. | 14188. | 22204. | .1010 | .11738 | .1045 | .13303 | .1067 | .14371 |
| 14.00 | 4630. | 13378. | 21044. | .1413 | .39727 | .1448 | .43456 | .1485 | .47529 |
| 17.00 | 4448. | 12771. | 20175. | .1720 | .81007 | .1765 | .88962 | .1800 | .95528 |
| 18.00 | 4387. | 12569. | 19885. | .1823 | 1.00000 | .1873 | 1.10494 | .1906 | 1.17489 |
| 18.25 | 4372. | 12518. | 19812. | .1848 | 1.05222 | .1900 | 1.16323 | .1932 | 1.23518 |
| 19.25 | 4311. | 12316. | 19522. | .1952 | 1.28156 | .2009 | 1.42421 | .2040 | 1.50362 |
| 21.00 | 4205. | 11962. | 19015. | .2133 | 1.76978 | .2202 | 1.98473 | .2238 | 2.10524 |
| 23.00 | 4083. | 11557. | 18435. | .2343 | 2.48492 | .2425 | 2.81525 | .2468 | 3.00205 |
| 25.00 | 3961. | 11152. | 17656. | .2554 | 3.39896 | .2651 | 3.88935 | .2702 | 4.16910 |
| 28.00 | 3779. | 10545. | 16986. | .2876 | 5.22504 | .2997 | 6.06616 | .3061 | 6.55229 |
| 32.50 | 3505. | 9634. | 15681. | .3371 | 9.29261 | .3532 | 11.01304 | .3619 | 12.02699 |
| **Tandem Axle - Dual Tire Data** | | | | | | | | | |
| 3.00 | 4403. | 17020. | 26431. | .0156 | .00073 | .0160 | .00079 | .0164 | .00085 |
| 9.00 | 4403. | 16369. | 25270. | .0438 | .02109 | .0451 | .02325 | .0460 | .02481 |
| 15.00 | 4403. | 15719. | 24109. | .0706 | .10009 | .0731 | .11210 | .0748 | .12084 |
| 21.00 | 4403. | 15069. | 22948. | .0965 | .27831 | .1004 | .31697 | .1030 | .34367 |
| 27.00 | 4403. | 14418. | 21787. | .1229 | .61300 | .1276 | .69121 | .1310 | .75473 |
| 31.00 | 4403. | 13985. | 21013. | .1410 | .95924 | .1455 | 1.06244 | .1498 | 1.16777 |
| 32.25 | 4403. | 13849. | 20772. | .1467 | 1.09039 | .1511 | 1.20176 | .1556 | 1.32345 |
| 33.25 | 4403. | 13741. | 20578. | .1512 | 1.20386 | .1556 | 1.32187 | .1603 | 1.45799 |
| 35.00 | 4403. | 13551. | 20239. | .1591 | 1.42171 | .1638 | 1.56434 | .1695 | 1.71596 |
| 37.00 | 4403. | 13334. | 19852. | .1681 | 1.70252 | .1734 | 1.88350 | .1779 | 2.04808 |
| 39.00 | 4403. | 13117. | 19465. | .1772 | 2.01972 | .1830 | 2.24652 | .1873 | 2.42293 |
| 41.00 | 4403. | 12901. | 19078. | .1862 | 2.37585 | .1927 | 2.65688 | .1967 | 2.84366 |
| 43.00 | 4493. | 12684. | 18691. | .1952 | 2.77355 | .2024 | 3.11827 | .2062 | 3.31356 |
| 45.00 | 4403. | 12467. | 18304. | .2043 | 3.21552 | .2121 | 3.63448 | .2162 | 3.87023 |
| 48.00 | 4403. | 12142. | 17724. | .2179 | 3.96765 | .2267 | 4.52030 | .2314 | 4.83331 |
| 52.50 | 4403. | 11654. | 16853. | .2383 | 5.31591 | .2489 | 6.12799 | .2545 | 6.59250 |

have been a more precise agreement. Nevertheless, the agreement between them is close enough such that the extended factors may be used as a basis to extend the actual AASHTO factors. Table G.8 shows the results of taking ratios of the extended equivalence factors for different tire pressures and using them to extend the actual AASHTO factors. These extended AASHTO factors are what were ultimately incorporated into the WIMESAL and FEDESAL programs (i.e., filename: AASHTO.EQF).

REMARKS

Since some "calibration" was required in Step 6 to derive "precisely" compatible extended AASHTO equivalence factors for higher tire pressures, there is some suggestion that this could have been done from the start using the original mechanistic load equivalence factors as a basis. (In other words, the ratios of mechanistic load equivalence factors between tire pressures could have been used to directly adjust the original AASHTO load equivalence factors). This option was thoroughly examined and it was eliminated because of the fact that the mechanistic factors were much more sensitive to load and tire pressure. Had the mechanistic factors been used to account for higher tire pressures, there would have been an uneven treatment of tire pressure versus axle load. In other words, higher tire pressures would have been found to be proportionately much more detrimental to pavements than axle load. Using the approach that was actually followed, however, changes in tire pressure will have the same effect on load equivalence factors as changes in axle load, if they both produce the same change in asphalt concrete tensile strain.

Table G.8. Final set of extended AASHTO compatible flexible pavement load equivalence factors for the three primary load configurations.

| Axle Set Type | Weight Interval Index | Lower Weight Limit | Upper Weight Limit | Rigid Equivalence Factor | Flexible Equivalence Factors For Tire Pressures of | | |
|---|---|---|---|---|---|---|---|
| | | | | | 75 psi | 110 psi | 145 psi |
| **Single Axle - Single Tire Factors** | | | | | | | |
| 1 | 1 | 0000.0 | 2999.0 | 0.0002 | 0.00166 | 0.00188 | 0.00226 |
| 1 | 2 | 3000.0 | 6999.0 | 0.0050 | 0.03349 | 0.03960 | 0.04390 |
| 1 | 3 | 7000.0 | 7999.0 | 0.0260 | 0.14560 | 0.18400 | 0.21000 |
| 1 | 4 | 8000.0 | 11999.0 | 0.0820 | 0.28510 | 0.37400 | 0.43600 |
| 1 | 5 | 12000.0 | 15999.0 | 0.3410 | 0.76113 | 1.06900 | 1.29700 |
| 1 | 6 | 16000.0 | 18000.0 | 0.7830 | 1.32469 | 1.93600 | 2.41300 |
| 1 | 7 | 18001.0 | 18500.0 | 1.0650 | 1.62017 | 2.40200 | 3.02400 |
| 1 | 8 | 18501.0 | 20000.0 | 1.3360 | 1.88481 | 2.82500 | 3.58200 |
| 1 | 9 | 20001.0 | 21999.0 | 1.9260 | 2.41311 | 3.67900 | 4.72200 |
| 1 | 10 | 22000.0 | 23999.0 | 2.8180 | 3.12827 | 4.85100 | 6.30500 |
| 1 | 11 | 24000.0 | 25999.0 | 3.9760 | 3.97662 | 6.25800 | 8.22500 |
| 1 | 12 | 26000.0 | 29999.0 | 6.2890 | 5.53815 | 8.87700 | 11.83800 |
| 1 | 13 | 30000.0 | 999999.0 | 11.3950 | 8.68277 | 14.20700 | 19.27500 |
| **Single Axle - Dual Tire Factors** | | | | | | | |
| 2 | 1 | 0000.0 | 2999.0 | 0.0002 | 0.000182 | 0.000197 | 0.000212 |
| 2 | 2 | 3000.0 | 6999.0 | 0.0050 | 0.005610 | 0.00553 | 0.00593 |
| 2 | 3 | 7000.0 | 7999.0 | 0.0260 | 0.034300 | 0.03840 | 0.04130 |
| 2 | 4 | 8000.0 | 11999.0 | 0.0820 | 0.087700 | 0.09940 | 0.10700 |
| 2 | 5 | 12000.0 | 15999.0 | 0.3410 | 0.360200 | 0.39400 | 0.43100 |
| 2 | 6 | 16000.0 | 18000.0 | 0.7830 | 0.796000 | 0.87400 | 0.93900 |
| 2 | 7 | 18001.0 | 18500.0 | 1.0650 | 1.060000 | 1.16800 | 1.24100 |
| 2 | 8 | 18501.0 | 20000.0 | 1.3360 | 1.3070 | 1.44900 | 1.53000 |
| 2 | 9 | 20001.0 | 21999.0 | 1.9260 | 1.8260 | 2.04900 | 2.17300 |
| 2 | 10 | 22000.0 | 23999.0 | 2.8180 | 2.5630 | 2.92800 | 3.12200 |
| 2 | 11 | 24000.0 | 25999.0 | 3.9760 | 3.5330 | 4.04500 | 4.33500 |
| 2 | 12 | 26000.0 | 29999.0 | 6.2890 | 5.3890 | 6.26000 | 6.76200 |
| 2 | 13 | 30000.0 | 999999.0 | 11.3950 | 9.4320 | 11.16800 | 12.19676 |
| **Tandem Axle - Dual Tire Factors** | | | | | | | |
| 3 | 1 | 000.0 | 5999.0 | 0.0100 | 0.000105 | 0.000113 | 0.000122 |
| 3 | 2 | 6000.0 | 11999.0 | 0.0100 | 0.004550 | 0.00502 | 0.00535 |
| 3 | 3 | 12000.0 | 17999.0 | 0.0620 | 0.036000 | 0.04040 | 0.04350 |
| 3 | 4 | 18000.0 | 23999.0 | 0.2530 | 0.1480 | 0.16900 | 0.18300 |
| 3 | 5 | 24000.0 | 29999.0 | 0.7290 | 0.4260 | 0.48000 | 0.52500 |
| 3 | 6 | 30000.0 | 32000.0 | 1.3050 | 0.7530 | 0.83400 | 0.91700 |
| 3 | 7 | 32001.0 | 32500.0 | 1.5420 | 0.8440 | 0.97500 | 1.07400 |
| 3 | 8 | 32501.0 | 33999.0 | 1.7510 | 1.0010 | 1.09900 | 1.21300 |
| 3 | 9 | 34000.0 | 35999.0 | 2.1650 | 1.2300 | 1.35400 | 1.48500 |
| 3 | 10 | 36000.0 | 37999.0 | 2.7210 | 1.5330 | 1.69700 | 1.84500 |
| 3 | 11 | 38000.0 | 39999.0 | 3.3730 | 1.8860 | 2.09000 | 2.26300 |
| 3 | 12 | 40000.0 | 41999.0 | 4.1290 | 2.2900 | 2.56100 | 2.74100 |
| 3 | 13 | 42000.0 | 43999.0 | 4.9970 | 2.7500 | 3.09300 | 3.28600 |
| 3 | 14 | 44000.0 | 45999.0 | 5.9870 | 3.2700 | 3.69700 | 3.93700 |
| 3 | 15 | 46000.0 | 49999.0 | 7.7250 | 4.1700 | 4.75400 | 5.08300 |
| 3 | 16 | 50000.0 | 9999999.0 | 10.1600 | 5.8300 | 6.72400 | 7.23300 |

# APPENDIX H

# PROGRAMS FEDESAL AND WINESAL SENSITIVITY TEST OUTPUT

Legend

| | | |
|---|---|---|
| Ers | - | Roadbed Soil Modulus |
| J | - | Structure Thickness Index |
| LT | - | Light Truck |
| MT | - | Medium Truck |
| TS | - | Tractor Semi-Trailer |
| TT | - | Truck and Trailer |
| TST | - | Tractor Semi-Trailer and Trailer |

| Ers psi | Tire Press. psi | J | LT | MT | TS | TT | TST |
|---|---|---|---|---|---|---|---|
| | | | 18KESAL PER 1000 TRUCKS | | | | |
| 1000 | 75 | 1 | 114 | 2555 | 26228 | 1861 | 2447 |
| 1000 | 110 | 1 | 154 | 4805 | 54893 | 2908 | 3596 |
| 1000 | 145 | 1 | 182 | 6928 | 83473 | 3753 | 4479 |
| 1000 | 170 | 1 | 194 | 8369 | 103835 | 4234 | 4948 |
| 4000 | 75 | 1 | 114 | 2555 | 26224 | 1979 | 2461 |
| 4000 | 110 | 1 | 154 | 4804 | 54886 | 3062 | 3613 |
| 4000 | 145 | 1 | 182 | 6927 | 83462 | 3932 | 4498 |
| 4000 | 170 | 1 | 194 | 8368 | 103821 | 4423 | 4968 |
| 12000 | 75 | 1 | 114 | 2555 | 26221 | 2274 | 2497 |
| 12000 | 110 | 1 | 154 | 4803 | 54879 | 3447 | 3657 |
| 12000 | 145 | 1 | 181 | 6926 | 83451 | 4379 | 4547 |
| 12000 | 170 | 1 | 194 | 8367 | 103807 | 4897 | 5018 |
| 20000 | 75 | 1 | 114 | 2555 | 26227 | 2541 | 2530 |
| 20000 | 110 | 1 | 154 | 4804 | 54891 | 3796 | 3698 |
| 20000 | 145 | 1 | 182 | 6928 | 83469 | 4784 | 4593 |
| 20000 | 170 | 1 | 194 | 8369 | 103829 | 5326 | 5066 |
| 40000 | 75 | 1 | 115 | 2561 | 26286 | 3085 | 2600 |
| 40000 | 110 | 1 | 155 | 4815 | 55006 | 4510 | 3787 |
| 40000 | 145 | 1 | 183 | 6943 | 83636 | 5614 | 4696 |
| 40000 | 170 | 1 | 196 | 8386 | 104032 | 6206 | 5174 |
| 1000 | 75 | 2 | 34 | 1672 | 21355 | 1280 | 1634 |
| 1000 | 110 | 2 | 37 | 2209 | 29138 | 1447 | 1788 |
| 1000 | 145 | 2 | 39 | 2569 | 34481 | 1545 | 1874 |
| 1000 | 170 | 2 | 39 | 2717 | 36804 | 1574 | 1893 |
| 4000 | 75 | 2 | 34 | 1672 | 21356 | 1456 | 1652 |
| 4000 | 110 | 2 | 37 | 2209 | 29138 | 1630 | 1806 |
| 4000 | 145 | 2 | 39 | 2569 | 34482 | 1732 | 1892 |
| 4000 | 170 | 2 | 39 | 2717 | 36806 | 1761 | 1912 |
| 12000 | 75 | 2 | 34 | 1672 | 21358 | 1895 | 1695 |
| 12000 | 110 | 2 | 37 | 2209 | 29139 | 2087 | 1851 |
| 12000 | 145 | 2 | 39 | 2569 | 34484 | 2198 | 1938 |
| 12000 | 170 | 2 | 39 | 2718 | 36809 | 2228 | 1957 |
| 20000 | 75 | 2 | 34 | 1672 | 21358 | 2291 | 1735 |
| 20000 | 110 | 2 | 37 | 2209 | 29141 | 2499 | 1892 |
| 20000 | 145 | 2 | 39 | 2569 | 34485 | 2618 | 1979 |
| 20000 | 170 | 2 | 39 | 2718 | 36811 | 2650 | 1998 |
| 40000 | 75 | 2 | 34 | 1672 | 21354 | 3095 | 1816 |
| 40000 | 110 | 2 | 37 | 2209 | 29144 | 3334 | 1973 |
| 40000 | 145 | 2 | 39 | 2569 | 34490 | 3470 | 2061 |
| 40000 | 170 | 2 | 39 | 2718 | 36813 | 3505 | 2081 |
| 1000 | 75 | 3 | 13 | 886 | 11921 | 1048 | 1388 |
| 1000 | 110 | 3 | 14 | 1022 | 14022 | 1111 | 1460 |
| 1000 | 145 | 3 | 14 | 1093 | 15163 | 1142 | 1495 |
| 1000 | 170 | 3 | 14 | 1103 | 15391 | 1144 | 1498 |
| 4000 | 75 | 3 | 13 | 886 | 11922 | 1308 | 1414 |
| 4000 | 110 | 3 | 14 | 1022 | 14024 | 1380 | 1486 |
| 4000 | 145 | 3 | 14 | 1093 | 15165 | 1415 | 1522 |
| 4000 | 170 | 3 | 14 | 1104 | 15392 | 1419 | 1525 |

| Ers psi | Tire Press. psi | J | LT | 18KESAL PER 1000 TRUCKS MT | TS | TT | TST |
|---|---|---|---|---|---|---|---|
| 12000 | 75 | 3 | 13 | 886 | 11924 | 1956 | 1478 |
| 12000 | 110 | 3 | 14 | 1022 | 14026 | 2051 | 1552 |
| 12000 | 145 | 3 | 14 | 1093 | 15167 | 2098 | 1588 |
| 12000 | 170 | 3 | 14 | 1104 | 15394 | 2104 | 1591 |
| 20000 | 75 | 3 | 13 | 886 | 11922 | 2540 | 1536 |
| 20000 | 110 | 3 | 14 | 1022 | 14024 | 2656 | 1611 |
| 20000 | 145 | 3 | 14 | 1093 | 15164 | 2714 | 1648 |
| 20000 | 170 | 3 | 14 | 1104 | 15391 | 2722 | 1651 |
| 40000 | 75 | 3 | 13 | 884 | 11897 | 3723 | 1652 |
| 40000 | 110 | 3 | 14 | 1020 | 14004 | 3880 | 1729 |
| 40000 | 145 | 3 | 14 | 1091 | 15140 | 3960 | 1766 |
| 40000 | 170 | 3 | 14 | 1101 | 15359 | 3970 | 1769 |
| 1000 | 75 | 4 | 9 | 1188 | 17018 | 1267 | 1276 |
| 1000 | 110 | 4 | 23 | 4021 | 61019 | 2993 | 4045 |
| 1000 | 145 | 4 | 46 | 8108 | 125590 | 5574 | 5943 |
| 1000 | 170 | 4 | 67 | 11795 | 184307 | 7940 | 6765 |
| 4000 | 75 | 4 | 18 | 1087 | 14015 | 1734 | 1439 |
| 4000 | 110 | 4 | 56 | 4883 | 66579 | 4907 | 5242 |
| 4000 | 145 | 4 | 121 | 13157 | 185050 | 9959 | 9595 |
| 4000 | 170 | 4 | 182 | 21809 | 310024 | 14718 | 13042 |
| 12000 | 75 | 4 | 48 | 874 | 7665 | 3346 | 1938 |
| 12000 | 110 | 4 | 204 | 6588 | 70942 | 13072 | 9306 |
| 12000 | 145 | 4 | 524 | 24888 | 296009 | 32787 | 23812 |
| 12000 | 170 | 4 | 852 | 45666 | 555828 | 52985 | 38543 |
| 20000 | 75 | 4 | 90 | 746 | 3727 | 5486 | 2527 |
| 20000 | 110 | 4 | 436 | 7434 | 60083 | 25688 | 14641 |
| 20000 | 145 | 4 | 1222 | 34102 | 337732 | 71811 | 44540 |
| 20000 | 170 | 4 | 2051 | 65382 | 671535 | 120624 | 76787 |
| 40000 | 75 | 4 | 241 | 793 | 4434 | 13153 | 4401 |
| 40000 | 110 | 4 | 1389 | 5791 | 33654 | 76703 | 33532 |
| 40000 | 145 | 4 | 4258 | 46120 | 139125 | 240221 | 124849 |
| 40000 | 170 | 4 | 7361 | 96556 | 391642 | 418225 | 228150 |
| 1000 | 75 | 5 | 10 | 1211 | 17033 | 1345 | 1269 |
| 1000 | 110 | 5 | 27 | 4430 | 67100 | 3309 | 4047 |
| 1000 | 145 | 5 | 57 | 9167 | 142584 | 6448 | 6033 |
| 1000 | 170 | 5 | 86 | 13480 | 212064 | 9411 | 6968 |
| 4000 | 75 | 5 | 21 | 1093 | 13520 | 1896 | 1486 |
| 4000 | 110 | 5 | 72 | 5386 | 71656 | 5674 | 5636 |
| 4000 | 145 | 5 | 158 | 15317 | 211793 | 11951 | 10898 |
| 4000 | 170 | 5 | 242 | 25862 | 362095 | 17964 | 15337 |
| 12000 | 75 | 5 | 63 | 862 | 6330 | 3844 | 2129 |
| 12000 | 110 | 5 | 277 | 7323 | 72631 | 16186 | 10979 |
| 12000 | 145 | 5 | 731 | 29738 | 336834 | 42379 | 29955 |
| 12000 | 170 | 5 | 1201 | 55517 | 646714 | 69568 | 49709 |
| 20000 | 75 | 5 | 121 | 751 | 2310 | 6494 | 2869 |
| 20000 | 110 | 5 | 611 | 8369 | 57354 | 32813 | 17929 |
| 20000 | 145 | 5 | 1746 | 41282 | 375308 | 95720 | 57863 |
| 20000 | 170 | 5 | 2952 | 80279 | 763383 | 163055 | 101616 |
| 40000 | 75 | 5 | 338 | 1001 | 6132 | 16181 | 5140 |
| 40000 | 110 | 5 | 2003 | 7088 | 51947 | 101131 | 42327 |
| 40000 | 145 | 5 | 6218 | 57557 | 92760 | 329320 | 166351 |

| Ers psi | Tire Press. psi | J | LT | MT | TS | TT | TST |
|---|---|---|---|---|---|---|---|
| | | | | 18KESAL PER 1000 | | TRUCKS | |
| 40000 | 170 | 5 | 10791 | 120778 | 320277 | 580010 | 308105 |
| 1000 | 75 | 6 | 11 | 1231 | 17088 | 1406 | 1276 |
| 1000 | 110 | 6 | 29 | 4731 | 71409 | 3506 | 4101 |
| 1000 | 145 | 6 | 60 | 10030 | 156216 | 6877 | 6164 |
| 1000 | 170 | 6 | 90 | 14915 | 235457 | 10061 | 7170 |
| 4000 | 75 | 6 | 24 | 1106 | 13336 | 2003 | 1520 |
| 4000 | 110 | 6 | 82 | 5728 | 75123 | 6182 | 5915 |
| 4000 | 145 | 6 | 184 | 16762 | 229516 | 13287 | 11798 |
| 4000 | 170 | 6 | 283 | 28570 | 396495 | 20153 | 16910 |
| 12000 | 75 | 6 | 71 | 866 | 5777 | 4091 | 2227 |
| 12000 | 110 | 6 | 318 | 7743 | 73867 | 17783 | 11846 |
| 12000 | 145 | 6 | 846 | 32396 | 359181 | 47390 | 33163 |
| 12000 | 170 | 6 | 1396 | 60890 | 695971 | 78284 | 55550 |
| 20000 | 75 | 6 | 136 | 761 | 1772 | 6903 | 3015 |
| 20000 | 110 | 6 | 692 | 8825 | 56381 | 35878 | 19367 |
| 20000 | 145 | 6 | 1992 | 44658 | 393135 | 106235 | 63749 |
| 20000 | 170 | 6 | 3375 | 87255 | 806416 | 181825 | 112612 |
| 40000 | 75 | 6 | 375 | 1094 | 7313 | 17092 | 5345 |
| 40000 | 110 | 6 | 2233 | 7448 | 58348 | 109533 | 45125 |
| 40000 | 145 | 6 | 6971 | 60555 | 59282 | 361588 | 180561 |
| 40000 | 170 | 6 | 12119 | 127115 | 255524 | 639350 | 335866 |
| 1000 | 75 | 7 | 3 | 822 | 12843 | 1101 | 1665 |
| 1000 | 110 | 7 | 3 | 1659 | 26548 | 1305 | 2560 |
| 1000 | 145 | 7 | 4 | 2372 | 38450 | 1499 | 3667 |
| 1000 | 170 | 7 | 4 | 2804 | 45846 | 1632 | 4588 |
| 4000 | 75 | 7 | 5 | 968 | 14652 | 1741 | 1590 |
| 4000 | 110 | 7 | 8 | 2435 | 37785 | 2615 | 2930 |
| 4000 | 145 | 7 | 12 | 4260 | 67046 | 3445 | 4218 |
| 4000 | 170 | 7 | 14 | 5783 | 91700 | 4011 | 5107 |
| 12000 | 75 | 7 | 9 | 1211 | 17395 | 3392 | 1506 |
| 12000 | 110 | 7 | 20 | 3976 | 59596 | 6090 | 3715 |
| 12000 | 145 | 7 | 32 | 8290 | 127239 | 8775 | 5383 |
| 12000 | 170 | 7 | 42 | 12320 | 191132 | 10684 | 6243 |
| 20000 | 75 | 7 | 12 | 1242 | 17109 | 4959 | 1591 |
| 20000 | 110 | 7 | 30 | 4750 | 69548 | 9535 | 4209 |
| 20000 | 145 | 7 | 51 | 10859 | 164063 | 14307 | 6104 |
| 20000 | 170 | 7 | 68 | 16815 | 257335 | 17836 | 7017 |
| 40000 | 75 | 7 | 13 | 388 | 3142 | 8514 | 2542 |
| 40000 | 110 | 7 | 42 | 3328 | 42540 | 18016 | 4165 |
| 40000 | 145 | 7 | 85 | 10887 | 153887 | 29025 | 5969 |
| 40000 | 170 | 7 | 125 | 19115 | 277470 | 37810 | 7369 |
| 1000 | 75 | 8 | 3 | 855 | 13347 | 1151 | 1628 |
| 1000 | 110 | 8 | 4 | 1742 | 27787 | 1419 | 2611 |
| 1000 | 145 | 8 | 4 | 2528 | 40836 | 1666 | 3892 |
| 1000 | 170 | 8 | 4 | 3028 | 49304 | 1830 | 4989 |
| 4000 | 75 | 8 | 5 | 1008 | 15169 | 1913 | 1561 |
| 4000 | 110 | 8 | 10 | 2628 | 40561 | 2975 | 3004 |
| 4000 | 145 | 8 | 14 | 4726 | 74012 | 4013 | 4439 |
| 4000 | 170 | 8 | 17 | 6517 | 102840 | 4740 | 5460 |
| 12000 | 75 | 8 | 10 | 1261 | 17833 | 3882 | 1513 |
| 12000 | 110 | 8 | 24 | 4405 | 65478 | 7178 | 3877 |

| Ers psi | Tire Press. psi | J | LT | MT | TS | TT | TST |
|---|---|---|---|---|---|---|---|
| | | | | 18KESAL PER 1000 | | TRUCKS | |
| 12000 | 145 | 8 | 40 | 9505 | 145011 | 10574 | 5698 |
| 12000 | 170 | 8 | 53 | 14345 | 221344 | 13062 | 6666 |
| 20000 | 75 | 8 | 14 | 1288 | 17304 | 5755 | 1656 |
| 20000 | 110 | 8 | 36 | 5328 | 77090 | 11458 | 4495 |
| 20000 | 145 | 8 | 64 | 12709 | 190595 | 17579 | 6663 |
| 20000 | 170 | 8 | 87 | 20025 | 304560 | 22206 | 7800 |
| 40000 | 75 | 8 | 17 | 369 | 2016 | 10025 | 2856 |
| 40000 | 110 | 8 | 57 | 3906 | 47911 | 22501 | 4929 |
| 40000 | 145 | 8 | 115 | 13830 | 193368 | 37025 | 7792 |
| 40000 | 170 | 8 | 167 | 24829 | 358224 | 48653 | 10319 |
| 1000 | 75 | 9 | 3 | 885 | 13771 | 1214 | 1598 |
| 1000 | 110 | 9 | 4 | 1845 | 29324 | 1558 | 2674 |
| 1000 | 145 | 9 | 5 | 2753 | 44292 | 1863 | 4025 |
| 1000 | 170 | 9 | 5 | 3368 | 54624 | 2055 | 5158 |
| 4000 | 75 | 9 | 6 | 1040 | 15571 | 2059 | 1542 |
| 4000 | 110 | 9 | 11 | 2793 | 42916 | 3289 | 3082 |
| 4000 | 145 | 9 | 16 | 5139 | 80178 | 4506 | 4595 |
| 4000 | 170 | 9 | 20 | 7178 | 112866 | 5368 | 5659 |
| 12000 | 75 | 9 | 11 | 1296 | 18149 | 4218 | 1526 |
| 12000 | 110 | 9 | 27 | 4696 | 69434 | 7942 | 4001 |
| 12000 | 145 | 9 | 46 | 10347 | 157262 | 11853 | 5944 |
| 12000 | 170 | 9 | 60 | 15762 | 242369 | 14761 | 7007 |
| 20000 | 75 | 9 | 16 | 1321 | 17492 | 6241 | 1702 |
| 20000 | 110 | 9 | 41 | 5692 | 81806 | 12652 | 4669 |
| 20000 | 145 | 9 | 72 | 13876 | 207273 | 19633 | 7042 |
| 20000 | 170 | 9 | 99 | 22057 | 334334 | 24968 | 8373 |
| 40000 | 75 | 9 | 19 | 375 | 1702 | 10696 | 2985 |
| 40000 | 110 | 9 | 64 | 4214 | 50845 | 24676 | 5250 |
| 40000 | 145 | 9 | 130 | 15353 | 213857 | 40978 | 8691 |
| 40000 | 170 | 9 | 188 | 27780 | 400011 | 54044 | 11869 |

# APPENDIX I

## EXAMPLE OF SOLUTION PROCESS FOR TREATING EFFECTS OF NONLINEAR SOIL BEHAVIOR FOR STEERING AXLE LOADS

Chapter 3 of this report described the development of new flexible pavement performance (damage) models that were used ultimately to derive improved load equivalence factors for higher loads and tire pressures. A rigorous analytical approach was applied that permitted consideration of the independent effects of steering axles and trailing load axles. Task 6 of Chapter 3 described briefly how the results of the materials characterization process for two separate deflection loading conditions could be extrapolated to conditions under a steering axle load. This step in the process was necessary because of the sensitivity of the soil and other layer materials to load (i.e., nonlinear behavior).

Figure 3.4 of Chapter 3 provided a diagram illustrating graphically how the material properties under the steering axle load were determined. The purpose of this appendix is to provide a little more detail on how that figure was generated. The methodology that is described here is contained within the STAX-1 computer program. (Fundamentally, the methodology is also the same as that used in the TANDAX-1 program for tandem axles.) This detailed description should provide a better understanding for those who may want to apply a similar process in the future.

The example was for the fall season of AASHO Road Test Section No. 601. The wheel loading on this section consisted of a three axle tractor semi-trailer in which the single-tired steering axle was 6 kips and the two dual-tired load axles were 18 kips. Deflections on the section were measured using a dual-tired axle with weights of 12 and 18 kips. Table I.1 provides a summary of the characteristics of the section, as well as the layer properties (i.e, elastic moduli) that were determined for the two deflection loading conditions. Note that, of the two deflection loads, the 18-kip load is identical to the 18-kip load axle used to fatigue the section. Thus, the properties determined under the 18-kip

Table I.1. Summary of characteristics and properties determined for AASHO Road Test Section No. 601.

| Layer No. | Description | Thickness (inches) | Poissons Ratio | Estimated Unit Weight ($lb/ft^3$) | Layer Elastic Moduli (in psi) from Materials Characterization Process (MODEST-1 Analysis) for Fall Season: 12-kip Deflection Load | 18-kip Deflection Load |
|---|---|---|---|---|---|---|
| 1 | AC | 3 | 0.30 | 150 | 450,000 | 450,000 |
| 2 | Base | 6 | 0.55 | 120 | 19,659 | 20,933 |
| 3 | Subbase | 12 | 0.40 | 120 | 13,293 | 12,727 |
| 4 | Roadbed Soil | Semi-Infinite | 0.45 | N/A | 5,013 | 4,139 |

deflection load can be used directly to analyze the 18-kip load axle. On the other hand, the 12-kip deflection load is significantly different than the 6-kip steering axle load, making it necessary to consider stress sensitivity.

Two points were needed to establish the relationship in Figure 3.4. The two points shown correspond to the two deflection loads. The ordinates for the two points correspond to the elastic modulus values of the roadbed soil. The abscissas correspond to the maximum deviator stresses at the top of the roadbed soil. Deviator stress is a measure of the stress condition experienced by a soil element subjected to triaxial loading. The term was developed as part of the Resilient Modulus Test (ASTM D274) and is equivalent to the maximum vertical stress, $\sigma_v$, less the confining pressure, $\sigma_c$:

$$\sigma_d = \sigma_v - \sigma_c$$

For the in-situ case, there are two components to both the vertical stress and confining pressure, overburden and wheel load.

The overburden component of the vertical stress depends on the weight of the overlying materials:

$$(\sigma_v)_o = [3"*(150 \text{ pcf}) + (6"+12")*(120 \text{ pcf})] / (1728 \text{ in}^3/\text{ft}^3)$$
$$= 1.51 \text{ psi}$$

The overburden component of confining pressure depends on the soil's Poissons ratio ($v_{RS}$) as well as the magnitude of the overburden vertical stress:

$$(\sigma_c)_o = (\sigma_v)_o * [v_{RS}/(1-v_{RS})]$$
$$= (1.51) \text{ psi} * [0.45/(1-0.45)]$$
$$= 1.24 \text{ psi}$$

Thus, the total deviator stress due to overburden is:

$$(\sigma_d)_o = (\sigma_v)_o - (\sigma_c)_o$$
$$= 1.51 \text{ psi} - 1.24 \text{ psi}$$
$$= 0.27 \text{ psi}$$

The wheel load component of both the vertical and confining stresses are determined using ELSYM5 and the appropriate layer material properties. For the example, the deviator stresses obtained from ELSYM5 (SZZ-SXX) were 2.46 psi and 3.32 psi for the 12 and 18-kip deflection loads, respectively. Combining the overburden and wheel load components results in the abscissas for the two points:

| Deflection Load | $(\sigma_d)_o$ | $(\sigma_d)_w$ | $(\sigma_d)_{Total}$ |
|---|---|---|---|
| 12-kip | 0.27 | 2.46 | 2.73 |
| 18-kip | 0.27 | 3.32 | 3.59 |

With the straight log-log line defined by two sets of coordinates, (2.73, 5013) for the 12-kip deflection load and (3.59, 4139) for the 18-kip deflection load, the objective then was to find the point along this line which corresponds to the stress conditions under the 6-kip steering axle load. This was accomplished by identifying the theoretical steering axle relationship and determining where it intersects the in-situ relationship.

In the example, the theoretical relationship (which is generally very near linear on a log-log graph) was established using ELSYM5. For convenience, the ordinates for the two triangle points on the dashed line shown in Figure 3.4 were chosen to be the same modulus values as those determined for the deflection loads. The theoretical deviator stresses are different, however, since they are for the steering axle load condition. The layer moduli and components for the two deviator stresses are as follows:

| Roadbed Soil Resilient Modulus (psi) | Subbase Modulus (psi) | Base Modulus (psi) | $(\sigma_d)_o$ | $(\sigma_d)_w$ | [Abscissa] $(\sigma_d)_{Total}$ |
|---|---|---|---|---|---|
| 4139 | 12141 | 17346 | 0.27 | 1.29 | 1.56 |
| 5013 | 12941 | 17910 | 0.27 | 1.40 | 1.67 |

Note that an iterative process was applied with STAX-1 to determine the subbase and base moduli that satisfied the specified bulk stress relationships.

As can be seen graphically (or calculated arithmetically), the intersection of the in-situ relationship with the theoretical relationship represents the solution to the problem. For the example, the deviator stress was 1.84 psi (based on layer moduli of 6594 psi for the roadbed soil, 14,188 psi for the subbase and 18,748 psi for the base).