Heavy Vehicle Evaluation for Overload Permits

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Highway agencies often receive requests for permits to allow the movement of overloaded machinery, structures, and other commodities. Many highway departments issue permits up to a standard axle loading of approximately 27,000 lb; however, they do not have sufficient data to respond to requests for other loads and axle configurations. A study for the Pennsylvania Department of Transportation analyzed the expected pavement damage resulting from overloaded axle configurations, in particular, four- and five-axle configurations with loads up to 34,000 lb. A computer simulation approach was used to model both flexible and rigid pavements. Flexible pavements were analyzed with structural numbers of 2.92 and 4.82 representing a low and high structural capacity, respectively. Rigid pavement was analyzed as a 10-inch slab on 6 inches of crushed aggregate base. Calculated strains and deflections were compared to limiting tensile and vertical strains (flexible pavements) and stress ratios (rigid pavements). The remaining life of each pavement was evaluated. It was found that four- and five-axle configurations developed the same tensile stresses as the single- and tandem-axle configurations for a thin flexible pavement, but the strains were lower for the thick pavement cross section. The stress ratios for the rigid pavement for all axle loads and configurations were below 50 percent, which implies that an unlimited number of repetitions can be applied.

Highway agencies are often asked to issue permits to allow the movement of overloaded machinery, structural components, and other commodities. The movement of such commodities is vital to the economic health of the state and nation; on the other hand, it is necessary to ensure that permitted overloaded vehicles do not damage the pavement system. For example, the Pennsylvania Department of Transportation (PennDOT) currently issues permits for axle loadings up to 27,000 lb, but it does not have sufficient data to respond to requests for other loads and configurations.

The AASHO Road Test results showed that pavement damage is a function of many variables, including axle load and axle configuration. The 18-kip equivalent single-axle load (ESAL) concept was developed to allow various axles and loads to be combined into a single design axle. The 18-kip ESAL tables for single- and tandem-axle configurations have been used by highway designers for the past 25 years without significant changes. The recent AASHTO Design Guide provides 18-kip ESAL for triple axles; however, no information is available for 18-kip ESAL for multiple-axle configurations, such as four- and five-axle units. Because many of the heavy axle loads in Pennsylvania are on four- and five-axle units, it was decided to study the potential damage effect of these configurations.

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The objective of the study was to evaluate, by means of computer simulation, the pavement damage resulting from overloaded four- and five-axle configurations.

The evaluation was conducted for one rigid pavement cross section and two flexible pavement cross sections. Stresses, strains, and deflections were calculated for four- and five-axle configurations, as well as for standard single- and tandem-axle configurations. Axle loads from 18,000 to 34,000 lb were evaluated.

PAVEMENT MODELING

Computer Simulation

There are basically two ways to evaluate pavement damage: field experiment and computer modeling. The AASHO Road Test is the classic example of a full-scale field experiment designed to study axle loading and pavement damage. The field approach is the best evaluation method; however, it is extremely expensive and time-consuming. Computer modeling, on the other hand, is not as realistic as full-scale field work, but it is much less expensive and can provide quick responses to a complex question (such as the amount of pavement damage caused by overloaded vehicles).

A computer simulation approach was used in this study, because it would provide answers in a timely manner. The flexible pavement was modeled as an elastic-layered system. The BISAR computer program was used to calculate strains and deflections under the selected loadings (*1*). The rigid pavement systems was modeled as a slab on a Winkler foundation (liquid). The JSLAB computer program was used to calculate stresses for the rigid pavement system (*2*).

Pavement Cross Sections

Both a thin and thick flexible pavement cross section were evaluated in the study. The layer depth and engineering properties are shown in Figures 1 and 2. The thin pavement section represented a system with a structural number (SN) of 2.92. The thicker section had an SN of 4.82. These two sections were selected because the thin pavement could represent a typical low-volume road, while the thicker section would represent a primary or arterial-type facility.

A single rigid pavement cross section, typical of that found in Pennsylvania, was used in this study (see Figure 3). For computer modeling purposes, the slab was assumed to be 60 ft long. Contraction joints had load transfer devices consisting

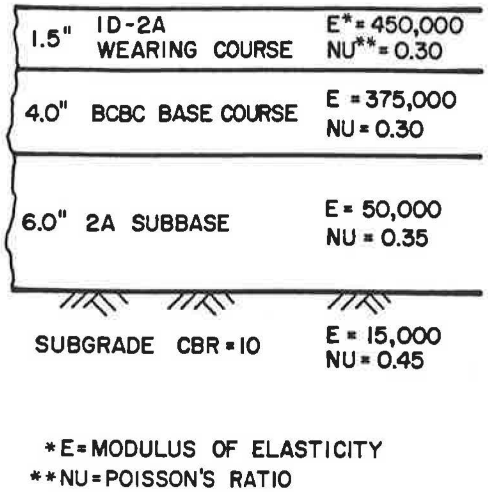

FIGURE 1 Thin flexible pavement cross section used in analysis.

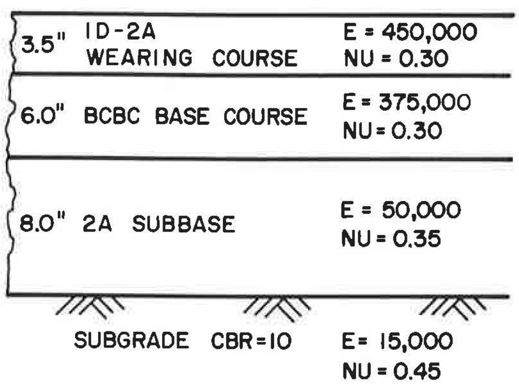

FIGURE 2 Thick flexible pavement cross section used in analysis.

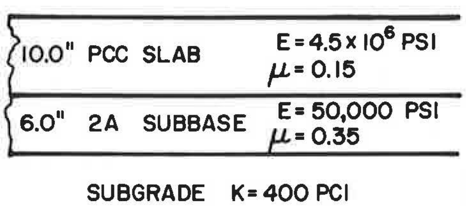

FIGURE 3 Rigid pavement cross section used in analysis.

of twelve 1¼-in.-diameter dowel bars. The slab was 12 ft wide. A 6-in. base consisting of dense-graded material was placed under the slab.

Tire and Axle Loadings

Four axle loadings were modeled for the analysis. The axle loadings are shown in Figures 4–7. The truck loadings represent single-, tandem-, four-, and five-axle configurations. The single and tandem axles were included because they rep-

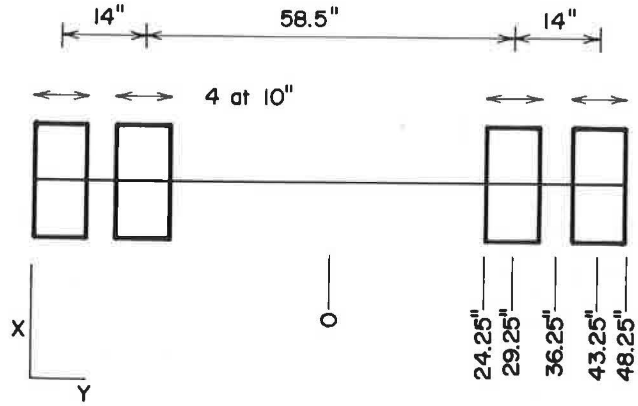

FIGURE 4 Single-axle loading configuration.

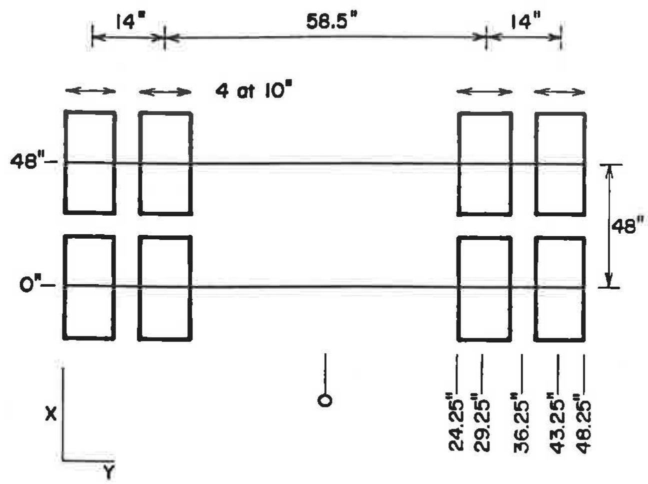

FIGURE 5 Tandem-axle loading configuration.

resent the typical axle configurations found on Pennsylvania highways. Also, the single and tandem axles represent the type of axle for which there are 18-kip ESAL AASHTO tables. The four- and five-axle configurations are the axle types used to haul heavy, overloaded materials.

For the analysis, each axle of the configuration was subjected to incremental axle loadings of 18,000, 20,000, 22,400, 24,000, 26,000, 27,000, 28,000, 29,000, 30,000, 31,000, 32,000, 33,000, and 34,000 lb. The 18,000-lb and 22,400-lb loadings were selected because the 18,000-lb loading represents the typical design axle load, while the 22,400-lb loading is the legal single-axle load in Pennsylvania. The other axle loads were incremented to provide a spread of loads that ranged up to 34,000 lb.

For purposes of this study, it should be noted that the selected axle loading was placed on each axle of the configurations. For example, a 26,000-lb axle load means that the gross tandem load was 52,000 lb, the four-axle load gross was 104,000 lb, and the five-axle load gross was 130,000 lb.

The simulated tires used in the study were assumed to have a pressure of 100 psi. As the load increased on the axle, the contact area changed because the pressure was held constant. For each load, a footprint area and a comparable circular area (radius) were calculated.

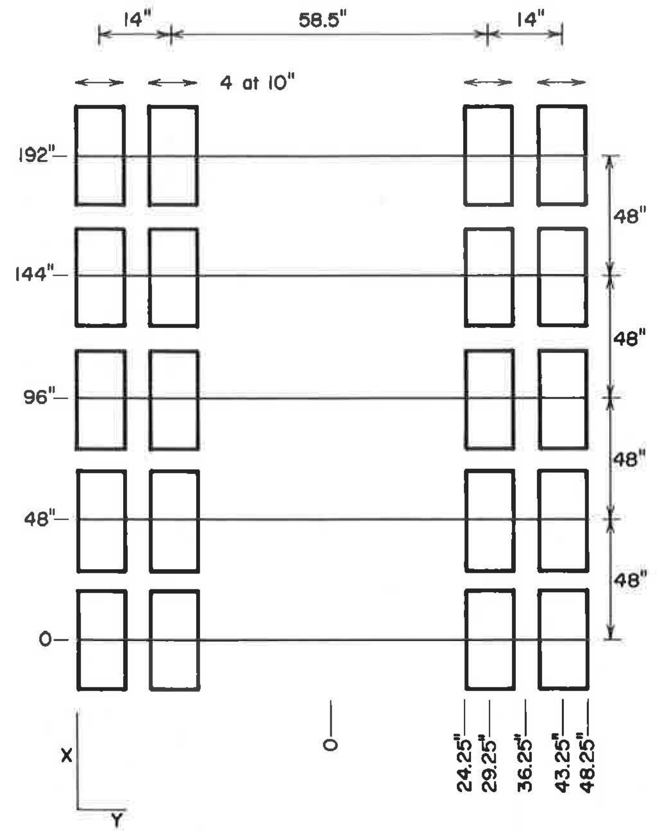

FIGURE 6 Four-axle loading configuration.

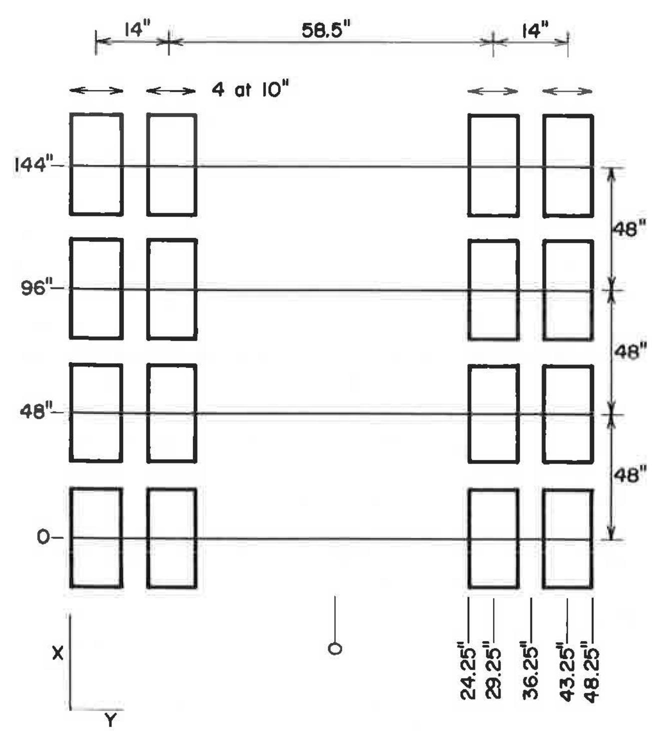

FIGURE 7 Five-axle loading configuration.

Location of Critical Strains, Stresses, and Deflections

Both the elastic layer program, BISAR, and the finite element program, JSLAB, can calculate pavement response at any point in the pavement system. This capability is a useful feature of the programs; however, it is extremely time-consuming and costly to calculate responses at multiple points. Consequently, an analysis was done to determine the location, within the pavement system, where maximum strains occur.

Several points within the pavement system were chosen to determine the location of the maximum tensile strain caused by the axle load (18,000 lb). An example of the study points for the four-axle configurations is shown in Figure 8, and the calculated strains for all axle configurations are presented in Table 1. As shown, the maximum strain occurs between the dual tires in all cases. The most critical axle for multiple-axle configurations was found to be the trailing axle. Consequently, point Number 3 was selected as the study location for all configurations. The depths of the critical strains are shown in Figure 9.

It has been shown that the critical stress location for jointed rigid pavements is at the free edge and/or at the joint (*3*). Consequently, the stresses along the edge of the concrete slab were evaluated. Maximum values were selected and used in the evaluation of the maximum stress ratio.

Half-Axle Modeling for Four- and Five-Axle Loads

The BISAR program can be programmed for up to 10 loads, but the four- and five-axle configurations have 16 and 20 loads, respectively. Consequently, a superposition technique was evaluated to determine the strains and deflections for each case. Strains and deflections were compared using the superposition technique and the critical locations under half loads. Tables 2 through 4 provide comparisons of deflection,

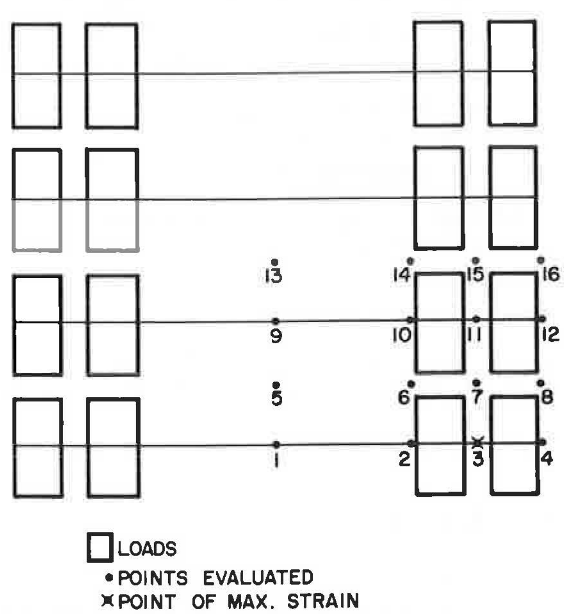

FIGURE 8 Location of maximum strain for four-axle configuration, flexible pavement.

TABLE 1 LOCATION OF MAXIMUM STRAINS FOR FLEXIBLE PAVEMENTS

Single-Axle Configurations	
1	0.173 E-04
2	0.130 E-03
3*(between tires)	0.168 E-03
4	0.129 E-03
Tandem-Axle Configurations	
1	0.127 E-04
2	0.123 E-03
3*(between tires)	0.160 E-03
4	0.123 E-03
5	compressive
6	0.128 E-04
7	0.295 E-04
8	0.162 E-04
Four-Axle Configurations	
1	0.584 E-05
2	0.122 E-03
3*(between tires)	0.159 E-03
4	0.122 E-03
5	compressive
6	0.181 E-04
7	0.327 E-04
8	0.181 E-04
9	0.361 E-04
10	0.116 E-04
11	0.152 E-04
12	0.116 E-04
13	compressive
14	0.184 E-04
15	0.331 E-04
16	0.184 E-04
Five-Axle Configurations	
1	0.582 E-05
2	0.122 E-03
3*(between tires)	0.159 E-03
4	0.122 E-03
5	0.352 E-05
6	0.116 E-03
7	0.152 E-03
8	0.116 E-03
9	0.319 E-05
10	0.115 E-03
11	0.151 E-03
12	0.115 E-03

*maximum strain

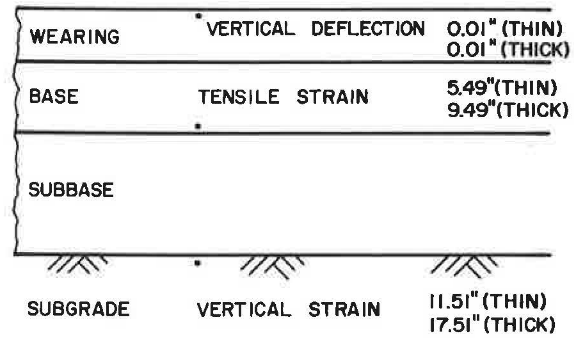

FIGURE 9 Maximum strain location depths for thin and thick flexible pavements.

TABLE 2 SURFACE DEFLECTION COMPARISON OF SUPERPOSITION AND CRITICAL LOCATION DATA FOR FOUR AXLES ON THIN PAVEMENT

Axle Load	Surface Deflection Superposition	Critical Location
18,000	0.2614 E-01	0.200 E-01
20,000	0.2902 E-01	0.222 E-01
22,400	0.3244 E-01	0.248 E-01
24,000	0.3478 E-01	0.266 E-01
26,000	0.3767 E-01	0.288 E-01
27,000	0.3911 E-01	0.299 E-01
28,000	0.4055 E-01	0.310 E-01
29,000	0.4199 E-01	0.321 E-01
30,000	0.4240 E-01	0.332 E-01
31,000	0.4490 E-01	0.343 E-01
32,000	0.4630 E-01	0.354 E-01
33,000	0.4780 E-01	0.365 E-01
34,000	0.4920 E-01	0.376 E-01

For four axles on the thin pavement section.

tensile strain, and vertical strain; it can be seen that the critical location technique provided results that compare with the superposition technique. Consequently, the critical location technique was used to model the four- and five-axle configuration.

Analysis of Flexible Pavement Strains and Deflections

As was stated in previous sections, the BISAR program was used to calculate surface deflections, tensile strains, and vertical strains in the flexible pavement system. The tensile strains at the bottom of the stabilized base layer are associated with fatigue cracking of the asphalt concrete. On the basis of a mechanistic analysis approach, the number of load repetitions to cracking of the asphalt is a function of the magnitude of the tensile strain. On the other hand, the vertical strain in the subgrade is associated with the rutting of the pavement.

TABLE 3 TENSILE STRAIN COMPARISON OF SUPERPOSITION AND CRITICAL LOCATION DATA FOR FOUR AXLES ON THIN PAVEMENT

Axle Load	Tensile Strain Superposition	Critical Location
18,000	.1588 E-03	.159 E-03
20,000	.1748 E-03	.175 E-03
22,400	.1937 E-03	.194 E-03
24,000	.2067 E-03	.207 E-03
26,000	.2223 E-03	.222 E-03
27,000	.2287 E-03	.229 E-03
28,000	.2367 E-03	.237 E-03
29,000	.2437 E-03	.244 E-03
30,000	.2507 E-03	.251 E-03
31,000	.2576 E-03	.258 E-03
32,000	.2646 E-03	.265 E-03
33,000	.2726 E-03	.273 E-03
34,000	.2786 E 03	.279 E-03

For four axles on the thin pavement section.

TABLE 4 VERTICAL STRAIN COMPARISON OF SUPERPOSITION AND CRITICAL LOCATION DATA FOR FOUR AXLES ON THIN PAVEMENT

Axle Load	Vertical Deflection Superposition	Critical Location
18,000	.3920 E-03	.400 E-03
20,000	.4343 E-03	.443 E-03
22,400	.4852 E-03	.495 E-03
24,000	.5185 E-03	.529 E-03
26,000	.5605 E-03	.572 E-03
27,000	.5811 E-03	.593 E-03
28,000	.6017 E-03	.614 E-03
29,000	.6232 E-03	.636 E-03
30,000	.6438 E-03	.657 E-03
31,000	.6643 E-03	.678 E-03
32,000	.6849 E-03	.699 E-03
33,000	.7055 E-03	.720 E-03
34,000	.7250 E-03	.740 E-03

For four axles on the thin pavement section.

If the vertical strain is too high, the soil will shear, and plastic deformation will occur. High surface deflections are usually associated with shortened pavement life.

Examples of the calculated surface deflections, tensile strains, and vertical strains are presented in Tables 5 and 6. The data are for the four-axle configurations and both thin and thick flexible pavements. All of the data were plotted and are shown in Figures 10 through 12.

TABLE 5 FOUR-AXLE DATA FOR THIN PAVEMENT AT THE POINT (0, 36.25)

Axle Load (lb)	Surface Deflection at 0.01 in	Tensile Strain at 5.49 in	Vertical Strain (C) at 11.51 in
18,000	0.200 E-01	0.159 E-03	0.400 E-03
20,000	0.222 E-01	0.175 E-03	0.443 E-03
22,400	0.248 E-01	o.194 E-03	0.495 E-03
24,000	0.266 E-01	0.207 E-03	0.529 E-03
26,000	0.288 E-01	0.222 E-03	0.572 E-03
27,000	0.299 E-01	0.229 E-03	0.593 E-03
28,000	0.310 E-01	0.237 E-03	0.614 E-03
29,000	0.321 E-01	0.244 E-03	0.636 E-03
30,000	0.332 E-01	0.251 E-03	0.657 E-03
31,000	0.343 E-01	0.258 E-03	0.678 E-03
32,000	0.354 E-01	0.265 E-03	0.699 E-03
33,000	0.365 E-01	0.273 E-03	0.720 E-03
34,000	0.376 E-01	0.279 E-03	0.740 E-03

TABLE 6 FOUR-AXLE DATA FOR THICK PAVEMENT AT THE POINT (0, 36.25)

Axle Load (lb)	Surface Deflection at 0.01 in	Tensile Strain at 9.49 in	Vertical Strain (C) at 17.51 in
18,000	0.159 E-01	0.874 E-04	0.210 E-03
20,000	0.177 E-01	0.963 E-04	0.233 E-03
22,400	0.198 E-01	0.107 E-03	0.261 E-03
24,000	0.212 E-01	0.114 E-03	0.279 E-03
26,000	0.230 E-01	0.122 E-03	0.301 E-03
27,000	0.239 E-01	0.126 E-03	0.313 E-03
28,000	0.248 E-01	0.131 E-03	0.324 E-03
29,000	0.256 E-01	0.135 E-03	0.335 E-03
30,000	0.265 E-01	0.139 E-03	0.346 E-03
31,000	0.274 E-01	0.143 E-03	0.358 E-03
32,000	0.283 E-01	0.147 E-03	0.369 E-03
33,000	0.292 E-01	0.151 E-03	0.380 E-03
34,000	0.301 E-01	0.155 E-03	0.391 E-03

Also shown on each plot is a limiting deflection or strain. The limiting deflections and strains were developed as a result of test track research at the Pennsylvania Transportation Research Facility (*4*). The project demonstrated that Class II surface cracking correlated with a surface deflection of 0.020 in. The corresponding tensile strain at the bottom of the base was 120 microstrains, and the vertical strain at the top of the subgrade was 450 microstrains. The applied 18-kip ESALs were correlated with the data, and it was found that fatigue cracking and 0.25-in. rutting occurred at approximately 1 million 18-kip ESAL loads. Therefore, these limits were selected for this study.

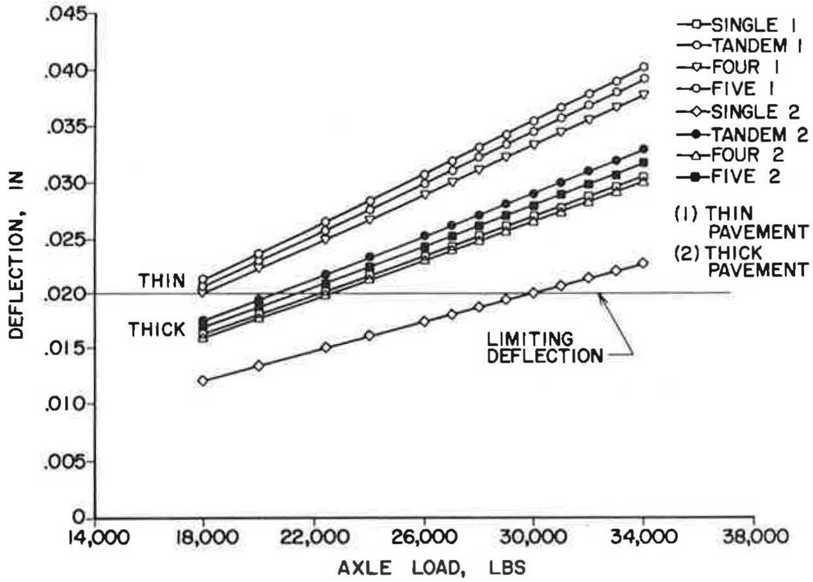

FIGURE 10 Surface deflection versus axle load for flexible pavements.

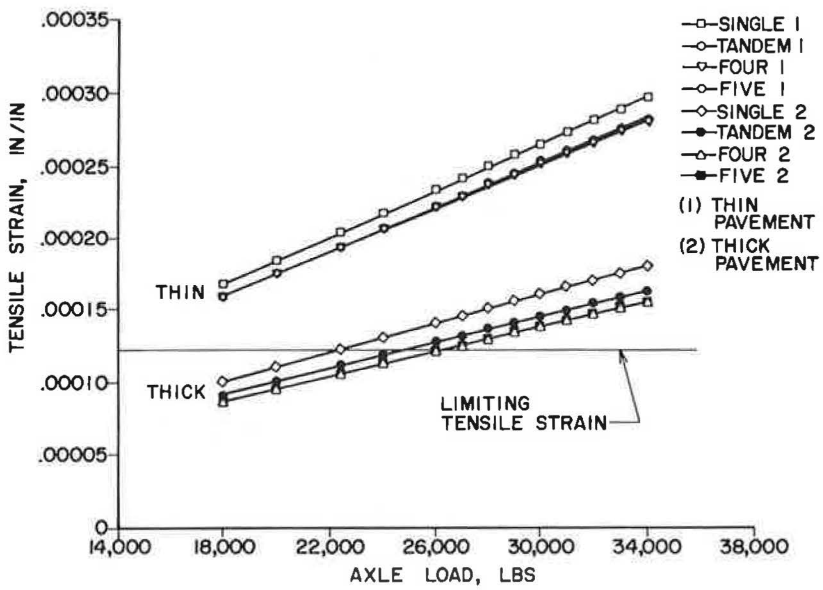

FIGURE 11 Tensile strain at the bottom of the base layer versus axle load for flexible pavements.

As can be seen in Figure 10, the thin pavement had the highest computer-predicted deflections, followed by lower deflections with the thick pavement. The lowest deflections occurred with the single-axle load on a thick pavement. Except for the single-axle thick pavement case, the four- and five-axle configurations created approximately the same deflections for both the thin and thick pavement systems.

Pavement deflections, tensile strain, and the vertical strain can all serve as criteria for evaluating pavement performance. The tensile strains at the bottom of the base, as shown in Figure 11, are grouped in two distinct lines: thick pavement and thin pavement. In both cases, the single-axle configurations produced higher strains than the tandem-, four-, and five-axle configurations. In fact, the tandem-, four-, and five-axle configuration lines overlapped each other. This implies that gross loads of a 40-kip tandem, 80-kip four axle, and 100-kip five axle all produce approximately the same tensile strain at the bottom of the base layer, while a 20-kip single axle produces a slightly higher tensile strain.

The same is true for the vertical strains, as shown in Figure 12. Again there are two distinct lines (one for a thin pavement and one for a thick pavement). All of the axle configurations, when loaded to the same axle weight, produce the same vertical strain in the subgrade.

With respect to the limiting criteria lines, Figure 11 shows that all of the loads on a thin pavement section exceeded the limiting criteria. Loadings greater than 26 kips on the thick pavements exceeded the limiting criteria. The vertical strains

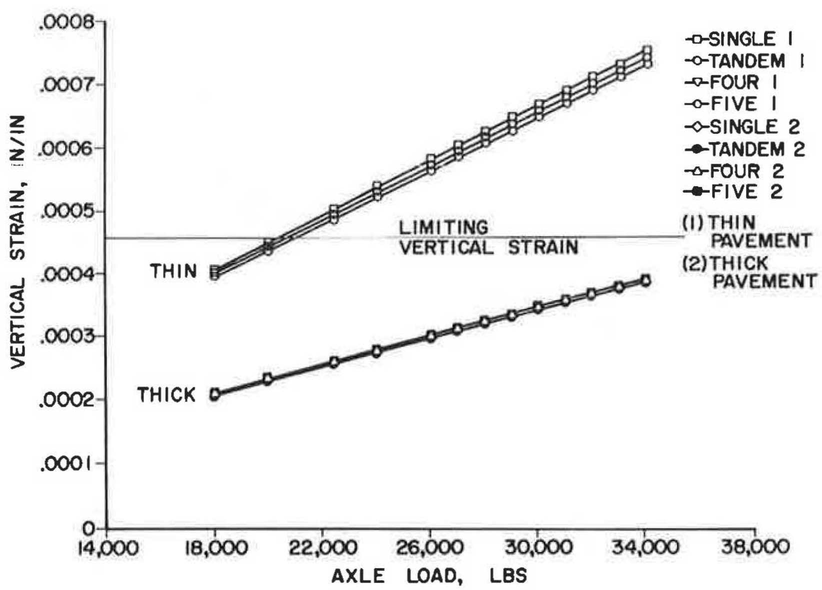

FIGURE 12 Vertical strain at the top of the subgrade versus axle load for flexible pavements.

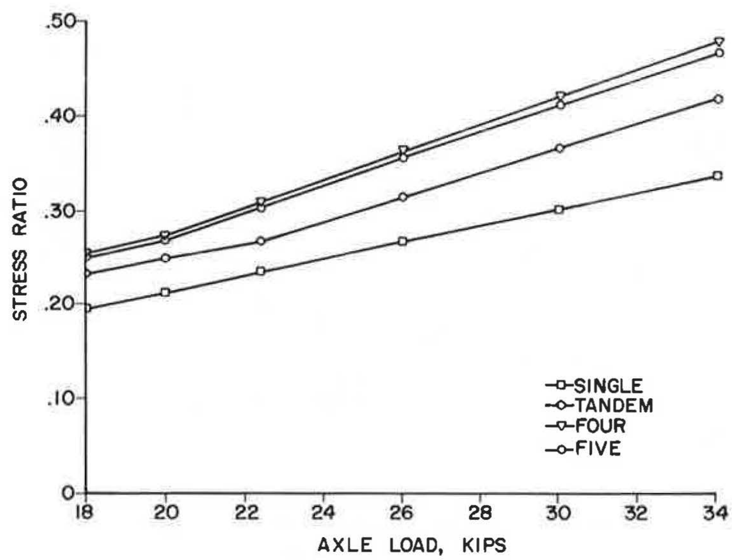

FIGURE 13 Stress ratios versus axle load for Portland Cement Concrete (PCC) pavement.

for thick pavements, as seen in Figure 12, were below the limit, while loads of 20 kips or greater exceeded the criteria for the thin pavements.

The data that are plotted in Figures 11 and 12 are significant with respect to the study. These data show that four- and five-axle configurations created strains of a similar magnitude as the strains under a tandem axle. In all cases, the single-axle configuration created higher strains than any of the other axle configurations.

Analysis of Rigid Pavement Stress Ratio and Bearing Stress

A rigid pavement usually fails because of cracking and/or joint-related problems. Consequently, the analysis of a rigid pavement system is much different from that of a flexible pavement system. Rigid pavement cracking can occur when the tensile stress (from loading, temperature, etc.) exceeds the modulus of rupture. If the stress ratio is kept under 50 percent, the concrete is expected to have infinite life; however, as the stress ratio exceeds 50 percent, the number of load cycles to failure decreases rapidly.

Joint deterioration, such as faulting, has been associated with excess bearing stress in the dowel/concrete area. As the bearing stress increases, the surrounding concrete deteriorates, and the life of the joint decreases due to faulting and pumping.

The edge stresses for each axle configuration and loading were calculated with the JSLAB finite element program. Maximum stresses were selected for each case, and a stress ratio

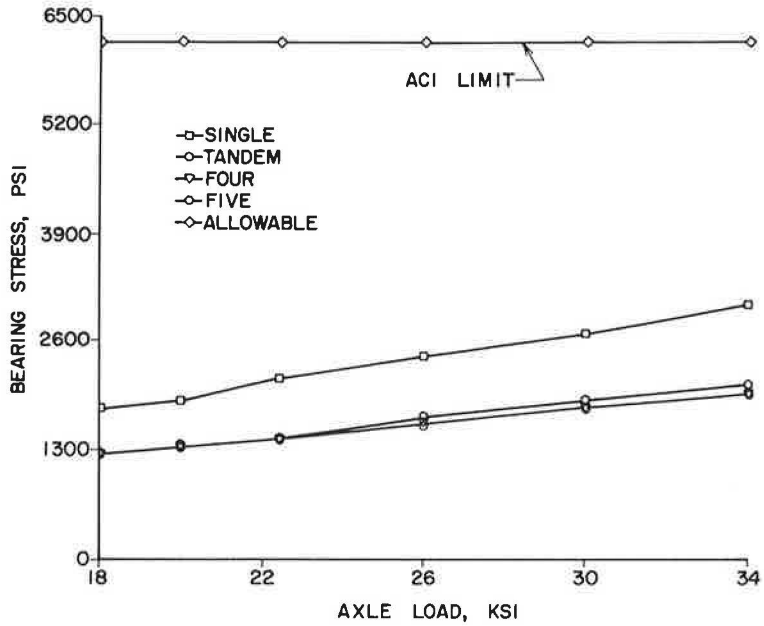

FIGURE 14 Bearing stress versus axle load for PCC pavement.

was calculated assuming a modulus of rupture of 500 psi. The stress ratios are presented in Figure 13. As can be seen, the four- and five-axle configurations developed the highest stress ratios, while the single-axle configuration developed the lowest values. All of the stress ratios, however, were less than 50 percent. Consequently, from a theoretical standpoint, the axle loads for all configurations studied never generate a stress large enough to crack the concrete.

The bearing stresses were also plotted and are shown in Figure 14. In this figure, it can be seen that the single-axle configuration creates the highest bearing stress, while the tandem-, four-, and five-axle configurations have lower values. The ACI bearing stress limit is also plotted on the figure. Again, from a theoretical viewpoint, the bearing stress is well below the limit for all load ranges.

PAVEMENT DAMAGE AND REMAINING LIFE

Rigid Pavement System Remaining Life Analysis

The objective of the study was to determine (theoretical approach) how much damage will be done to a pavement by an overloaded four- or five-axle configuration. On the basis of the calculated stress ratios and the calculated bearing stresses presented in the previous section, it can be concluded that these configurations do not significantly affect the rigid pavement systems found in Pennsylvania. The four- and five-axle configurations (at 32 kips) develop a stress ratio that is approximately 15 percent higher than the stress ratio for a tandem-axle load. For all cases studied, the ratio never exceeded the 50-percent limit. Therefore, the four- and five-axle load configurations should not reduce the service life of the rigid pavement any more rapidly than a tandem axle at the same load range.

Flexible Pavement System Remaining Life Analysis

The damage effect and the remaining life analysis for the flexible systems are different than for a rigid pavement. From a mechanistic approach, a relationship exists between tensile strains at the bottom of the base layer and the number of loads to cracking. An example of this is shown in Figure 15. The lines represent results from various researchers, while the line marked "Bituminous Concrete" is for data collected at the Pennsylvania Transportation Research Facility (PTRF).

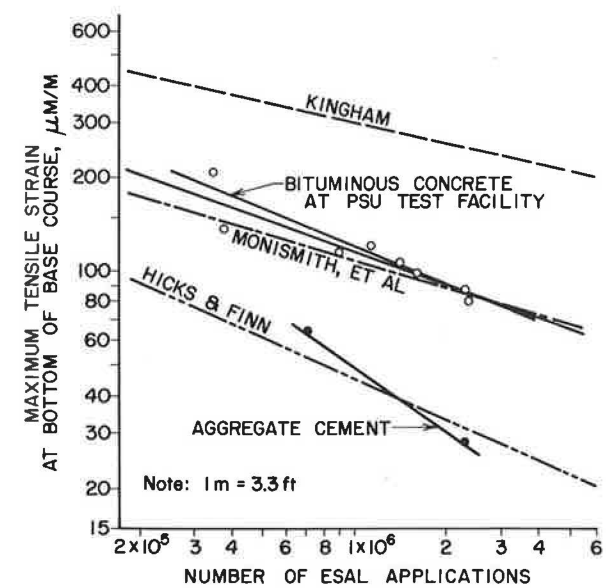

FIGURE 15 Tensile strain at the bottom of the asphalt layer versus total number of ESAL applications to cracking.

TABLE 7 NUMBER OF EQUIVALENT AXLE LOAD APPLICATIONS UNTIL CRACKING, SINGLE AXLE

Axle Load (kips)	Tensile Strain (10^{-6})	No. of EAL to Cracking (10^6)
	Thin Pavement	
18	168	.370
20	185	.285
22.4	205	.215
24	218	.195
26	234	.150
27	242	.135
28	250	.125
29	258	.115
30	265	.105
31	273	.100
32	281	
33	288	
34	296	
	Thick Pavement	
18	101	1.500
20	111	1.150
22.4	123	.880
24	131	.740
26	141	.600
27	146	.540
28	151	.500
29	156	.450
30	161	.410
31	166	.380
32	170	.360
33	175	.330
34	180	.300

TABLE 8 NUMBER OF EQUIVALENT AXLE LOAD APPLICATIONS UNTIL CRACKING, FOUR AXLES

Axle Load (kips)	Tensile Strain (10^{-6})	No. of EAL to Cracking (10^6)
	Thin Pavement	
18	159	.430
20	175	.330
22.4	194	.250
24	207	.210
26	222	.170
27	229	.155
28	237	.140
29	244	.135
30	251	.125
31	258	.115
32	265	.105
33	273	.100
34	279	
	Thick Pavement	
18	87	2.250
20	96	1.700
22.4	107	1.250
24	114	1.050
26	122	.880
27	126	.800
28	131	.720
29	135	.680
30	139	.620
31	143	.580
32	147	.540
33	151	.490
34	155	.460

The PTRF data were derived from full-scale truck traffic loadings on different flexible pavement cross sections. The strains in Figure 15 represent levels at which AASHTO Class II cracking took place.

The tensile strains for each axle configuration and associated loads were used with Figure 15 to select the number of 18-kip ESALs to cracking. Examples of the data are listed in Tables 7 and 8 with all data plotted in Figure 16. As can be seen in the figure, there are two distinct levels, one for thin pavements and one for thick pavements. All of the axle configurations overlap for the thin pavements; consequently, no significant difference exists among any of the axle configurations. Also with respect to the thin pavements, there is almost no difference in remaining life between a 26-kip axle load and a 32-kip axle load. Both produce a pavement life of approximately 100,000 repetitions.

However, a more distinct difference exists in pavement life with the thicker flexible pavements. Figure 16 shows that a single- and tandem-axle load, at the same axle weight, will produce shorter fatigue life. For example, a single-axle load of 22 kips will cause cracking after 880,000 passes. A tandem axle causes cracking after 1.15 million passes. The four- and five axle configurations cause cracking after 1.25 million passes.

Approaching this from another perspective, Figure 16 can be used to compare the loss of remaining life for each axle configuration. For example, a four-axle configuration at a 27-kip load will cause cracking after 800,000 ESAL passes, while a vehicle at a 32-kip load will cause cracking after 540,000

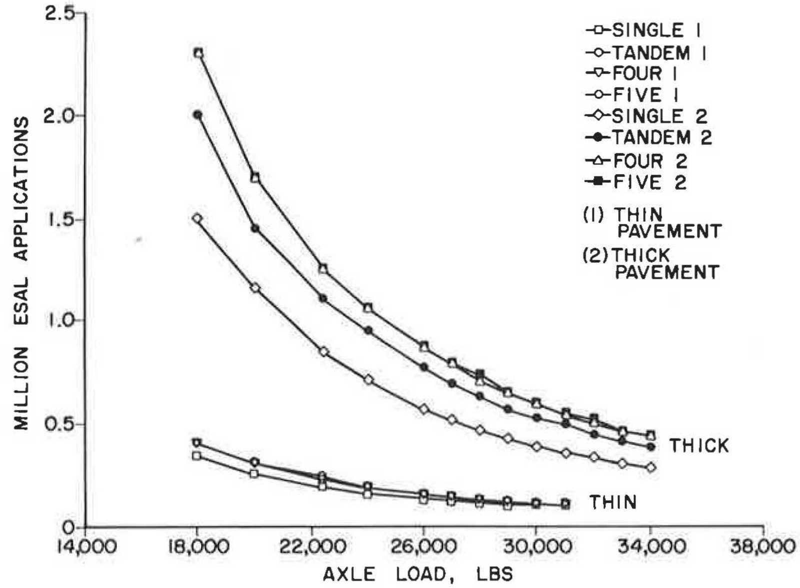

FIGURE 16 Number of ESAL applications until cracking for various axle loads.

passes. The increase in axle load will decrease the pavement life by 260,000 axle passes, or 32 percent.

DISCUSSION OF RESULTS

The analysis of the rigid pavement system showed that, regardless of the axle loading weight and type of axle configuration studied, there should be no detrimental effect on pavement life. Because the stress ratio for all loadings was below 50 percent, there should be no loss of service life. All bearing stress values were also below limiting values; consequently, there should be no adverse joint deterioration.

The analysis of the thin flexible pavements revealed that all loadings studied, regardless of weight and configuration, can have a significant effect on the thin flexible pavements. Axle loadings of from 27,000 to 32,000 lb, on all axle configurations, have approximately the same pavement-damage effect on the flexible pavements. Each load or configuration causes cracking after 100,000 axle passes.

With respect to the thicker flexible pavements, the single- and tandem-axle loads had a more severe effect on the pavement than equally loaded four- and five-axle configurations. A single configuration loaded at 22,400 lb will crack a pavement after 880,000 passes, while a four-axle configuration loaded to 89,600 lb will crack the pavement after 1.25 million passes. As can be seen in Figure 16, a single axle loaded at 22,400 lb and a four- and five-axle configuration loaded at 26,500 lb per axle (106,000 and 132,500 lb, respectively) require the same number of passes to develop similar cracking. A 26,500-lb, single-axle and a 32,000-lb, four- or five-axle load also have about the same damage effect.

It should be pointed out that the data presented in Figures 11 and 12 are for specific axle loads, when, in fact, the actual traffic stream consists of mixed traffic. Considering that the number of overloaded vehicles with permits constitutes a small percentage of the traffic spectrum, it is doubtful that four- and five-axle configurations will have any significant effect on pavement damage for rigid pavements and thick flexible pavements. There should be some concern, however, for thin flexible pavements and for those highways where a substantial number of heavy axle loads accumulate over a short time.

CONCLUSIONS

The following conclusions are based on the theoretical study conducted with computer modeling.

- The stress ratios for a 10-in. rigid pavement system (typical of Pennsylvania), for all axle loadings and configurations studied, were below the 50-percent limit.
- The bearing stresses for a 10-in. rigid pavement system, for all axle loadings and configurations studied, were below the recommended ACI limit.
- The four- and five-axle configurations developed the same tensile strains as the single- and tandem-axle configurations (at each load level) for a thin flexible pavement (SN = 2.92).
- The four- and five-axle configurations developed lower tensile strains than the single- and tandem-axle configurations (at each load level) for a thick flexible pavement (SN = 4.82).
- The four- and five-axle configurations for a thin flexible pavement (SN = 2.92) had the same number of axle loads to failure as the single- and tandem-axle loads (at all load levels).
- On the basis of strain criteria, the four- and five-axle configurations on a thick flexible pavement (SN = 4.82) required approximately 50 percent more equivalent-axle-load applications to develop the same amount of cracking as was developed by a single-axle configuration.

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