Assessment of Damage Caused to Pavements by Heavy Trucks in New England

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An attempt was made to investigate damage caused to pavements by benchmark (based on federal maximum weight limits for interstate highway systems) and heavy trucks in New England. Because the weigh-in-motion (WIM) data were available from Maine and Rhode Island, this study used WIM data rather than sample or partial data. Two computer programs, HETROM and HETROR, were developed to extract heavy axles or trucks from WIM data for further analysis. Two empirical procedures based on AASHTO Interim and 1986 Design guides were developed. These require two computer programs, HETRIG and HETRNG, respectively, to convert heavy axles to the equivalent 18-kip single-axle loads. After creating the traffic input data, a series of analyses was performed with the aforementioned empirical procedures. In addition, a preliminary analysis was also carried out using mechanistic procedures based on the Asphalt Institute's DAMA and the Federal Highway Administration's VESYS 3A-M programs. There were consistent observations, in all cases, that heavy trucks caused more damage than benchmark trucks. It was also observed that more damage caused by heavy trucks was predicted when there is a higher legal weight limit.

Highway transportation of goods has risen to the top of private sector transportation issues. Innovation in the movement of freight on the highway system promises tremendous productivity advantages but brings with it complex safety and regulatory issues. For example, heavy vehicles, which are being used more frequently, account for a disproportionate share of pavement wear. The size and weight of the vehicle fleet affect the costs associated with building and repairing roads. Research in truck productivity, safety, and road wear will continue to play a significant role in resolving these issues (*1*–*5*).

This research project investigated one of the issues, i.e., damage caused to pavements on the interstate highway network by benchmark (based on maximum weight limits for an interstate highway system) and heavy trucks. The project was initiated by the New England Surface Transportation Consortium (NETC), Cambridge, Mass. The NETC set their objectives to address the problems of the highway network and to resolve these issues. To achieve these goals, the NETC assigned projects or topics to research teams within the New England region. The pieces of information found in this research will provide a significant link in the objective scheme of NETC. In addition to NETC's primary interest, the consortium would also like to make uniform the five NETC states—Maine, Massachusetts, New Hampshire, Vermont, and Rhode Island—with respect to such factors as weight limits, design methods, and fee issuance (*6,7*). Table 1 shows the limits that currently apply to these states (*8*). This project concurred with this interest by making uniform the weight limits used.

The intent of this project was to provide procedures to assess pavement damage caused by overweight trucks or heavy axles. In doing so, a procedure may be chosen to determine how much damage is occurring on a pavement. The assessment's results can be applied to NETC's goal by providing vital information to plan more adequate pavement designs or issue more appropriate trucking fees, or both. Consequently, the building, repairing, and fee costs more proportionately will reflect the damage.

ASSESSMENT OF PAVEMENT DAMAGE CAUSED BY HEAVY TRUCKS

To assess the pavement damage it was necessary to develop procedures to quantify the damage, identify the legal axle loads to be used, select a representative location for the data collection, and formulate input data.

It was found that each NETC state has various combinations of legal load limits, as shown in Table 1. To develop a more uniform procedure for these states, the uniform load limits were set for each axle configuration. These limits were agreed on by the NETC technical committee to follow the current federal load limits.

The representative locations were selected where the weigh-in-motion (WIM) data were available and most recently collected on flexible pavement interstate highways. Two states, Maine and Rhode Island, provided the WIM data to be used.

In addition to the traffic data, the states were also asked to provide the pavement cross-section at the site, properties of subgrade soils, and monthly average air or pavement temperature, or both, on these locations. This project was mainly intended to provide procedures that assess the pavement damage. The project also presents some of the actual effects of heavy trucks on highway pavements. This report could serve as a basis for future studies of this region and related areas.

Data Management

Items for the data management included (a) the site location, (b) pavement structure and truck fleets, (c) the method of

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TABLE 1 LEGAL AXLE AND GROSS LOADS BY AGENCY FOR INTERSTATE HIGHWAYS

AGENCY	STATUARY AXLE LIMITS (LB) SINGLE	TANDEM	GROSS VEHICLE WEIGHT (LB) FIVE AXLES	OTHER COMB.	BASIS FOR GROSS WT. LIMIT
MAINE	20,000[a]	34,000	80,000	80,000	SM, BF
MASSACHUSETTS	22,400	36,000	80,000	80,000	SM,BF
NEW HAMPSHIRE	22,400[a]	40,000[b]	80,000	80,000	TB,SM
RHODE ISLAND	22,400	44,000	80,000	80,000	SM,BF
VERMONT	22,400	36,000	80,000	80,000	OT
FEDERAL LIMIT (NETC) (STAA, 1982)	20,000	34,000	80,000		

BF = BRIDGE FORMULA

TB = A TABLE OF ALLOWABLE GROSS VEHICLE WEIGHTS DERIVED FROM THE BRIDGE FORMULA

OT = TABLE OTHER THAN THE BRIDGE TABLE

SM = SPECIFIED MAXIMUM LIMITS

a = 20,000 LB. IF GROSS WEIGHT EXCEEDS 73, 280 LBS

b = 34,000 LB. IF GROSS WEIGHT > 73,280 LBS AND IF AXLES ≤ 8 FT. APART

data collection, and (d) the arrangement of the data collected. The data management was necessary to develop a link from data collection to the analysis process.

Site Location

The data for both states were collected on Interstate 95. The sites were in Yarmouth-Freeport, Maine, and Hopkinton, R.I. The highway in both cases is a four-lane divided highway having two lanes in each direction.

Highway Pavement Structures and Truck Fleets

Route 95 in Maine was opened to traffic in November 1973. The pavement structure consists of a 3-in. asphalt concrete surface course, a 6.5-in. asphalt concrete base course, a 4-in. aggregates base course, a 9-in. aggregates subbase course, and a 16.5-in. selected granular material subgrade (Figure 1). Many of the pavement properties were not supplied; therefore, a majority needed to be estimated. The average air temperature per season is as follows for this area: summer, 66.9°F; fall, 48.4°F; winter, 21.7°F; and spring, 43.1°F. These temperatures are for the year the WIM data were collected.

The original Route 95 interstate in the Hopkinton area of Rhode Island was constructed in 1962. A contract was put out in 1969 for a resurfacing. The original structure consisted of a 3-in. asphalt concrete surface course, a 2.5-in. bituminous macadam penetration course, a 5.5-in. crushed gravel base course, and a 12-in. gravel foundation on the subgrade of a fine brown sand. The resurfacing consisted of a 3-in. asphalt concrete course (Figure 2). Since most of the original construction data were also not available, many of the material properties had to be estimated by using design texts and references (*9–12*). The average air temperature per season is as follows: summer, 72.2°F; fall, 54.4°F; winter, 34.8°F; and spring, 39.4°F. These temperatures are for the year in which the WIM data were collected.

The truck fleet, as mentioned previously, was determined based on the FHWA classifications and legal limits (Table 1).

Data Collection

WIM has several advantages over the conventional static weighing operations. It offers a safe and efficient method for high-volume weighing of trucks (*13*). The WIM technique is also a more precise method to obtain data. Ordinarily, drivers would have to pull off into a weigh station to be statically weighed. Weigh stations are where weight violations are issued most often. Static weighing to obtain research data is conditional because most of the truckers are warned that the weighing is being conducted and opt to either pull off the highway and wait or choose an alternative route to avoid a possible violation. In most cases, when data are being taken using WIM, drivers do not even know they are being weighed. Therefore, a more precise, representative, and accurate group of data can be obtained.

The WIM used for Maine is a semipermanent weight pad, produced by International Road Dynamics, set into the pavement. It consists of two rectangular weighing platforms that rest on a common concrete foundation. They each measure 5 ft, 4 in. by 1 ft, 9 in. by 9 in. deep (1.6 m by 530 mm by 230 mm). Also, it is an associated electronic roadside monitoring system. The platforms are positioned so that there is one in each of the two wheel paths. The loads that are applied to the platforms produce vertical displacement in an oil-filled piston located in the center of the rectangle. These pistons act as load cells. In conjunction with the pistons, inductive loops are used to acquire speed and presence data. The initial installation requires heavy equipment for placement; there-

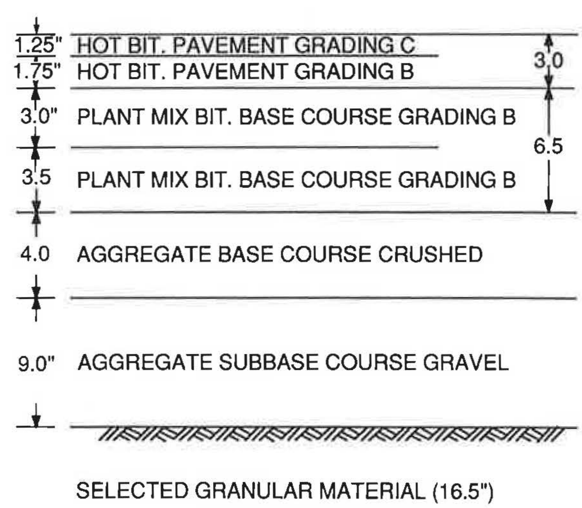


FIGURE 1 Cross-section of pavement structure for the Maine site.

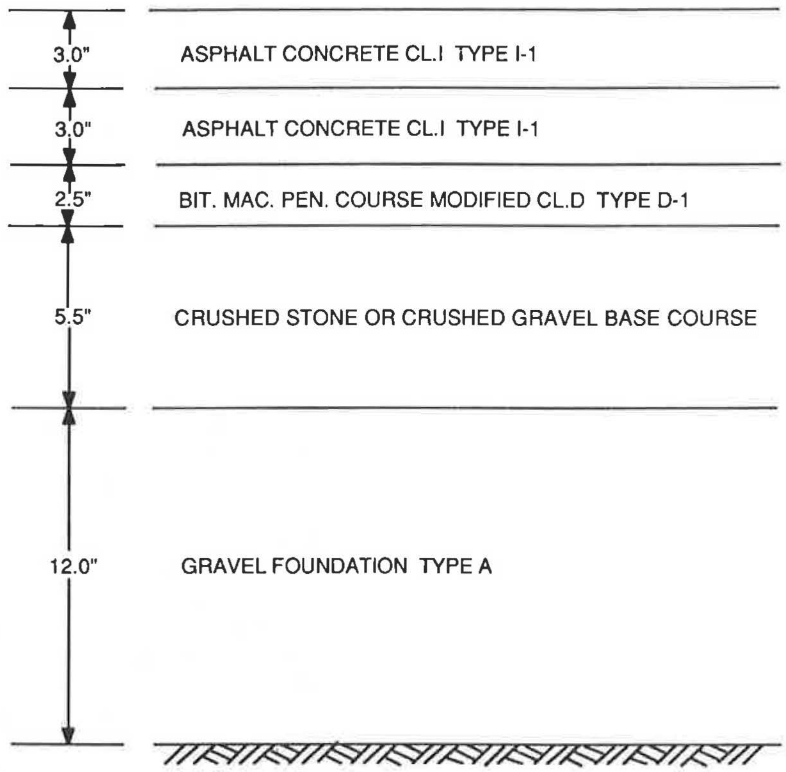


FIGURE 2 Cross-section of pavement structure for the Rhode Island site.

after, it needs only to be programmed and started for data collection. No further set-up or installation is needed.

The WIM used for the data collection in Rhode Island is semipermanent. It is a pad that is adhered to the pavement and left for a period of time, usually 2 days, to collect data (*14*). The pad or weighmat, produced by The Golden River Corporation, uses two inductive loops to acquire speed and presence data. The weighmat is 6 ft wide by 20 in. long and is made of three sheets of steel separated by soft rubber. This set-up acts as a three-plate capacitor. Vertical displacement on the mat produces an increase in capacitance, which is interpreted as a weight via an attached microprocessor-based data collection system. The mat is adhered to the pavement with pop-rivets and bituminous adhesive tape on the edges. It is located in one wheel path of the traffic lane. Its installation takes only 1 hour, but calibration may be required at every installation.

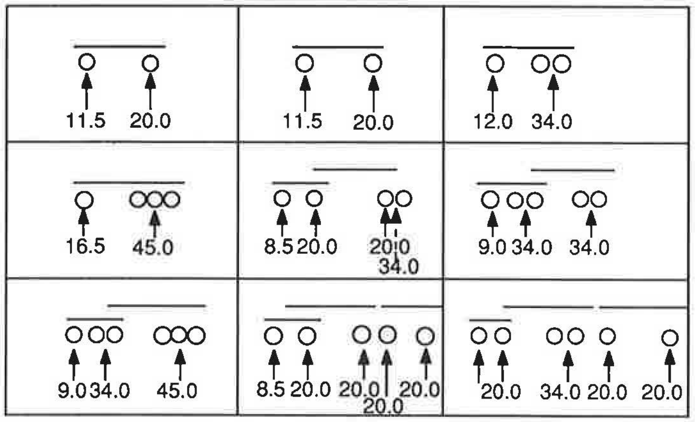
Data Preparation

To utilize available design methods or models, the initial step was the classification of the truck fleet. It was agreed on by the NETC technical committee that the classifications would follow those recommended by the FHWA for uniformity. These configurations are shown in Figure 3.

To work with the heavy trucks, they must be extracted from the original WIM data, which were given to the University of Rhode Island by the two states. Computer programs HETROM and HETROR were developed for this purpose in this study. HETRO stands for Heavy Truck Occurrence. The last characters, M and R, stand for Maine and Rhode Island, respectively. Each one takes its corresponding input data and processes them through comparisons based on the FHWA classifications to sort out the heavy axles. As briefly described above, two different computer programs were developed for the Maine and Rhode Island data sets, since the given format of the WIM data was slightly different. The programs vary through read statements to input the format of a truck occurrence from the data file, and the load unit of the axle weights—kips for Maine and pounds for Rhode Island. The programs first read the data and assign the occurrence to variable names. Each field in a data record has a variable name. The first comparison looks at the truck classification. Then the program sends the data record to the first weight comparison. This comparison depicts whether or not an axle is over the legal limit. The heavy axles are sent to an output file to represent the heavy trucks, and the legal axles are unrecorded. The programs generate output files in a form ready to be used by the empirical methods. The output format can be easily changed depending on its future use.

Procedures To Assess Pavement Damage

The study originally considered utilizing five design methods: the AASHTO Interim Design Guide (*15*); the AASHTO 1986 Design Guide (*16*); the Five Consortium States Design Methods (*10,11*); the Asphalt Institute's DAMA (*17*); and the Federal Highway Administration's VESYS 3A-M (*18*).



FHWA TRUCK CLASSIFICATIONS

FIGURE 3 Recommended FHWA truck classification and axle loads.

A review of the five states' design methods for flexible pavements indicated that most states use the AASHTO Interim Guide method. The only states with variations to this method are Rhode Island and Massachusetts (*10,11*). Even though there is some uniqueness for these two states in comparison to the others, the end results would be very similar. Thus, no further consideration was given in developing a procedure for NETC states' current methods other than using the same procedure with the AASHTO Interim Guide.

The Procedure Based on AASHTO Interim Design Guide

One of the important concepts used in the AASHTO Road Test in the Equivalent 18-kip single-axle load (ESAL). The ESAL shows the damaging effects of an axle load of any type as expressed as an equivalent number of 18,000-lb single axles. The Guide offers tables to compute equivalency factors for two terminal present serviceability indices (PSI)—2.0 and 2.5. These tables are used for single and tandem axles in the flexible pavement. Because no tridems are used at the road test, two-thirds of the factor for the tandem axles is used to determine the ESAL factors for the tridem axles.

The AASHTO Guide is a semiempirical method that was used in this study to assess pavement damage caused by heavy trucks. It does not, however, take into account the presence of uneven loads between axles or an increase in tire pressure. These issues could be considered better by a mechanistic approach.

After the data are processed through HETROM or HETROR, sorting computer programs, the output is used in the next program based on the AASHTO Interim Design Guide. This computer program, HETRIG, is a modified version of the New Jersey program developed by Barros (*19*). HETRIG stands for the Heavy Truck Impact using the procedure based on the Interim Guide. It was written by utilizing the AASHTO Interim Design Guide method to calculate the accumulated number of ESALs of the heavy axles.

HETRIG computes the corresponding ESAL of each heavy axle according to the traffic equivalence factors provided in the Interim Design Guide charts. An ESAL for each overweight axle is computed and summed for a total ESAL for the truck fleet. In addition to computing ESALs for the heavy trucks, the program also computes ESALs for a fleet of legal weight trucks hauling the same total weight as one of the heavy trucks. The program subtracts all the weight over the acceptable amount for each heavy axle and transfers it to the additional truck. It computes ESALs for the fleet of all legally loaded trucks and no heavy trucks. Consequently, a comparison can be made to see the difference in ESALs between the fleet with and without heavy axles hauling the same amount of freight.

The computed ESALs are also available to be compared with the design ESALs of the highway where the data were collected. Pavements are designed to carry a certain number of loads within a specified amount of time. For instance, if a pavement had a value of 10 million ESALs for a 20-year design life, this would be equivalent to 500,000 ESALs per year. If heavy trucks operating on this pavement have an ESAL of 200,000 annually, then 40 percent of the pavement's serviceability is consumed by this type of traffic yearly.

Tables 2 and 3 indicate that there were 46,956 and 315,042 heavy trucks on the travel lane annually (1988) at the Maine and Rhode Island sites, respectively. For the Maine site, the total occurrence of heavy trucks was originally 78,260 for the combined two lanes. Assuming that 60 percent of the trucks will use the travel lane, the total occurrence of 46,956 was estimated. Then, the total occurrences were converted by the program to cause 227,273 and 1,911,337 ESALs of pavement damage at the Maine and Rhode Island sites, respectively.

Only the state of Maine provided the average daily design ESALs for the Yarmouth-Freeport site as being 1,017, which was converted to the average annual design ESALs of 371,205. For the Rhode Island site, the annual design ESALs were estimated by multiplying 371,205 by the ratio of heavy truck occurrences of two sites (= 315,042/46,956), i.e., 2,490,527. Based on these design ESALs, the losses of pavement life

TABLE 2 ASSESSMENT RESULTS FOR THE MAINE SITE BY A PROCEDURE BASED ON THE AASHTO INTERIM GUIDE

HEAVY AXLES FOR BOTH LANES IN THE YEAR OF 1988

AXLE TYPE	TOTAL OCCURRENCES	TOTAL EXCESS WEIGHT, LBS	AVG EXCESS WEIGHT PER OCCURRENCE,LBS
SINGLE AXLE	120,848	204,282,001	1,690
TANDEM AXLE	5,720	28,379,000	4,961
TRIDEM AXLE	1,560	18,428,800	11,813
TOTAL	128,128	251,089,802	

18-KIP equivalent AXLE LOAD ANALYSIS, ANNUAL DATUM
(ONLY ON THE TRAVEL LANE ASSUMING 60% OCCUPATION)

	TOTAL OCCURRENCES	MODELED GROSS WEIGHT, KIPS	MODELED 18-KIP ESAL	MODELED ESAL % OF DESIGN
HEAVY TRUCKS	46,956	3,596,367	227,273	61.2
LEGALIZED TRUCKS	53,073	3,912,189	194,216	52.2
DIFF-ERENCE	6,117	315,822	-33,057	-9.0

TABLE 3 ASSESSMENT RESULTS FOR THE RHODE ISLAND SITE BY A PROCEDURE BASED ON THE AASHTO INTERIM DESIGN GUIDE

HEAVY AXLES FOR ONE LANE IN THE YEAR OF 1988

AXLE TYPE	TOTAL OCCURRENCES	TOTAL EXCESS WEIGHT, LBS	AVG EXCESS WEIGHT PER OCCURRENCE,LBS
SINGLE AXLE	89,180	319,774,001	3,586
TANDEM AXLE	362,726	2,738,161,792	7,549
TRIDEM AXLE	12,740	269,496,500	21,154
TOTAL	464,646	3,327,432,293	

18-KIP EQUIVALENT AXLE LOAD ANALYSIS, ANNUAL DATUM

	TOTAL OCCURRENCES	MODELED GROSS WEIGHT, KIPS	MODELED 18-KIP ESAL	MODELED ESAL % OF DESIGN
HEAVY TRUCKS	315,042	31,485,010	1,911,337	76.7
LEGALIZED TRUCKS	418,788	34,784,419	1,324,367	53.2
DIFF-ERENCE	103,746	3,299,409	-586,970	-23.5

were computed as 61.2 percent and 77.0 percent for the Maine and Rhode Island sites, respectively. The loss can be interpreted as follows: that for 1 year the corresponding percentage of pavement life was consumed solely by heavy trucks.

Because of the important benefits of transporting cargo by truck, a legal fleet was created so that heavy trucks were eliminated. A legal fleet is defined as trucks only at or under federal limits. It was achieved by adding more trucks to the original heavy truck fleet number. The additional trucks carry the excessive weight taken from the heavy trucks; therefore all trucks are transporting at or under the federal legal load limit. Tables 2 and 3 show that the additional 6,117 and 103,746 trucks would be added to the fleets to carry the excessive weights in Maine and Rhode Island, respectively. Because each additional truck also introduces a tare weight, the pavement is required to carry an additional 315,822 and 3,299,409 pounds over a 1-year period at the Maine and Rhode Island sites, respectively. But even with the additional tare weight load the consumed design ESAL percentage decreased to 52.2 percent and 53.0 percent, respectively. This decrease occurred because each axle group was required to carry less weight; consequently, the total ESALs computed were lower. Therefore, the same amount of cargo can be transported and cause less damage to the pavement.

Tables 2 and 3 also supply the various impact and traffic mix data for the Maine and Rhode Island sites. At the Maine site, the net loss in service life attributable to detected heavy trucks is 61.2 less 52.2, or approximately 9.0 percent, whereas at the Rhode Island site the net loss is 76.7 less 53.2, or approximately 23.5 percent. Whereas the Maine legal limits are the same as the federal limits or the benchmarks (Table 1), the Rhode Island legal limits are higher than the federal limits, especially for the tandem axle. This could explain why there is a greater difference in total heavy ESALs and total legal ESALs for the Rhode Island site. At the Maine site the difference is almost negligible. Also of note is that 94 percent of the overweight trucks observed were single trucks. Consequently, it can be concluded that more damage will occur when the legal limits are higher.

The Procedure Based on 1986 AASHTO Design Guide

The 1986 AASHTO Design Guide is a culmination of the revisions made to the AASHTO Interim Guide. Most steps for the procedure based on the 1986 Design Guide are the same as the one based on the Interim Guide. The inputs needed for this procedure are again the heavy truck data and the design ESAL for the highway pavement. The Interim Guide program treats the tridem axles as 3/2 a tandem axle and computes them using the tandem method, whereas the 1986 Guide computes them separately as tridems using the tridem conditions.

Tables 4 and 5 show the results for the Maine and Rhode Island sites using the procedure based on the 1986 Guide method (HETRNG), respectively. These tables portray the actual number of heavy truck occurrences within a 1-year period and their total weight, ESALs, and percentage of design ESALs.

The computed ESALs for heavy trucks are 228,053 and 1,933,618 for Maine and Rhode Island, respectively. The consumed design ESALs were 61.2 percent and 80.6 percent, respectively. HETRNG also gives the legalized information for the same fleet. With an additional 6,117 and 103,746 trucks, the computed ESAL values were 195,401 and 1,313,268, and the consumed design ESAL percentages were 52.2 percent and 54.8 percent, respectively. Again it is observed that the same cargo can be transported legally causing less damage to the pavement. Again, the difference between heavy and legal

TABLE 4 ASSESSMENT RESULTS FOR THE MAINE SITE BY A PROCEDURE BASED ON THE 1986 AASHTO DESIGN GUIDE

HEAVY AXLES FOR BOTH LANES IN THE YEAR OF 1988

AXLE TYPE	TOTAL OCCURRENCES	TOTAL EXCESS WEIGHT, LBS	AVG EXCESS WEIGHT PER OCCURRENCE,LBS
SINGLE AXLE	120,848	204,282,001	1,690
TANDEM AXLE	5,720	28,379,000	4,961
TRIDEM AXLE	1,560	18,428,800	11,813
TOTAL	128,128	251,089,802	

18-KIP equivalent AXLE LOAD ANALYSIS, ANNUAL DATUM
(ONLY ON THE TRAVEL LANE ASSUMING 60% OCCUPATION)

	TOTAL OCCURRENCES	MODELED GROSS WEIGHT, KIPS	MODELED 18-KIP ESAL	MODELED ESAL % OF DESIGN
HEAVY TRUCKS	46,956	3,596,367	228,053	61.4
LEGALIZED TRUCKS	53,736	3,912,189	195,401	52.6
DIFF-ERENCE	6,117	315,822	-32,652	-8.8

TABLE 5 ASSESSMENT RESULTS FOR THE RHODE ISLAND SITE BY A PROCEDURE BASED ON THE 1986 AASHTO DESIGN GUIDE

HEAVY AXLES FOR ONE LANE IN THE YEAR OF 1988

AXLE TYPE	TOTAL OCCURRENCES	TOTAL EXCESS WEIGHT, LBS	AVG EXCESS WEIGHT PER OCCURRENCE,LBS
SINGLE AXLE	89,180	319,774,001	3,586
TANDEM AXLE	362,726	2,738,161,792	7,549
TRIDEM AXLE	12,740	269,496,500	21,154
TOTAL	464,646	3,327,432,293	

18-KIP EQUIVALENT AXLE LOAD ANALYSIS, ANNUAL DATUM

	TOTAL OCCURRENCES	MODELED GROSS WEIGHT, KIPS	MODELED 18-KIP ESAL	MODELED ESAL % OF DESIGN
HEAVY TRUCKS	315,042	31,485,010	1,933,618	77.6
LEGALIZED TRUCKS	418,788	34,784,419	1,313,268	52.7
DIF-FERENCE	103,746	3,299,409	-620,351	-24.9

ESALs was far greater for Rhode Island than it was for Maine. Tables 2 through 5 relate the occurrence of each axle type and the excessive weight for each group and the fleet. The comparisons indicate that when the same amount of weight is hauled legally, i.e., within the load limits, less damage will be done to the highway pavement. Less damage is done even with the additional tare weight of the extra trucks required to haul the excess weight. For both states, the procedure based on the 1986 Design Guide provides a slightly higher ESAL value than the one based on the Interim Guide.

The Procedure Based on Asphalt Institute's DAMA

The Asphalt Institute computer program, DAMA, was originally developed to analyze a multilayered elastic pavement structure by a cumulative damage technique for a single or dual wheel load system (*20,21*). The program also can be used for design purposes by analyzing several proposed pavement structures. Most pavement structures made of asphalt concrete, emulsified asphalt mixtures, untreated aggregate materials, and subgrade soils can be analyzed with a maximum of five layers.

Only the maximum strain at a given interface is used for the computation of the damage. The fatigue cracking of each stabilized layer and the subgrade deformation distresses are observed on a cumulative monthly basis. The design life and number of load repetitions to failure are summarized for fatigue cracking and deformation, in which the governing layer is also noted for the design situation. Environmental aspects are also considered in DAMA.

The third procedure, or the first mechanistic procedure, utilized the Asphalt Institute's DAMA program to compute the amount of fatigue cracking and permanent deformation caused by the heavy trucks. Tables 6 and 7 show the summary of damage computed, the pavement design life, and the governing layer of the design for the Maine and the Rhode Island sites, respectively. The outputs show the damage or reduction in design life because of heavy trucks. It relates the damage or life reduction in terms of fatigue cracking and deformation (rutting). The layer with more damage cracking governs the design. Because this program does not allow analysis of a pavement structure with two aggregate layers, the structures had to be modified. For both states the two aggregate layers were combined to be analyzed as one base layer. The subbase was converted into the base by lessening the thickness by a ratio of the layer coefficients, i.e., $0.1(12.0)/0.14 = 8.5$ or approximately 9.0 in. Therefore, the subbase layer for Rhode Island was converted into an additional 9 in. of base.

The Procedure Based on FHWA's VESYS 3A-M

The computer program VESYS was originally developed by FHWA in cooperation with the Massachusetts Institute of Technology (MIT). The original mechanistic model, VESYS II-M was based on an application of the viscoelastic theory to the design of pavements. From research findings, the model has been improved continuously, allowing various versions to be made available. This study used VESYS 3A-M, which is the latest version and is based on the elasto-plasticity theory. This model can be used on a wide range of paving materials, axle loads, and environmental conditions. The model predicts the performance of the pavement in terms of PSI as derived from the AASHTO Road Test. The program expresses PSI in the form of cracking, rutting, and roughness variables. To produce these variables, it uses information about the material properties, geometry of the pavement, traffic, and environment.

TABLE 6 ASSESSMENT RESULTS FOR THE MAINE SITE BY A PROCEDURE BASED ON THE ASPHALT INSTITUTE'S DAMA

	ESAL DETERMINED BY THE INTERIM GUIDE		ESAL DETERMINED BY THE 1986 GUIDE	
	HEAVY TRUCKS	LEGALIZED TRUCKS	HEAVY TRUCKS	LEGALIZED TRUCKS
DAMAGE:				
FATIGUE	.1358E-00	.1161E+00	.1363E+00	.1156E+00
DEFORMATION	.4633E-02	.3959E-02	.4649E-02	.3942E-02
DESIGN LIFE:				
FATIGUE	7.4 YRS	8.6 YRS	7.3 YRS	8.7 YRS
DEFORMATION	216 YRS	253 YRS	215 YRS	254 YRS

TABLE 7 ASSESSMENT RESULTS FOR THE RHODE ISLAND SITE BY A PROCEDURE BASED ON THE ASPHALT INSTITUTE'S DAMA

	ESAL DETERMINED BY THE INTERIM GUIDE		ESAL DETERMINED BY THE 1986 GUIDE	
	HEAVY TRUCKS	LEGALIZED TRUCKS	HEAVY TRUCKS	LEGALIZED TRUCKS
DAMAGE:				
FATIGUE	.2680E+00	.1857E+00	.2711E+00	.1841E+00
DEFORMATION	.5429E-01	.3762E-01	.5493E-01	.3731E-01
DESIGN LIFE:				
FATIGUE	3.7 YRS	5.3 YRS	3.6 YRS	5.3 YRS
DEFORMATION	18.4 YRS	26.6 YRS	18.2 YRS	26.8 YRS

The procedure utilizing the VESYS 3A-M program provides a more sophisticated and precise way to determine the damage caused to the pavement by heavy vehicles.

Tables 8 and 9 show the summary of the resulting damage and pavement life for the Maine site and Tables 10 and 11, for the Rhode Island site. Only the ESALs determined by HETRNG are used because the 1986 AASHTO Design Guide is the most current.

Tables 8 through 11 portray the following observations on the damage and pavement life. The values of cracking, rutting, roughness, and PSI are recorded for each of the specified periods of analysis. The values except for PSI appear to increase with an increase in time. This increase is to be expected because an increase in load repetitions causes an increase in damage, which decreases the PSI, which is also expected.

The tables also show values of pavement service life. The value is the time in years at which the pavement reaches its terminal serviceability index. The value of 2.5 is used because it is the value recommended by AASHTO for interstate highways. Tables 8 and 9 show that, for the Maine site, heavy trucks caused a shorter service life than legalized ones. Tables 10 and 11 indicate that, for the Rhode Island site, heavy trucks caused greater damage than legalized trucks. These values were expected because the ESAL values for legalized trucks are lower than those for the heavy ones. The most important observation was that the heavy trucks consistently provided shorter life than the legalized trucks in both cases.

CONCLUSIONS AND RECOMMENDATIONS

The conclusion and recommendations based on the findings of this investigation are summarized below.

Conclusions

1. It was necessary to develop two computer programs, HETROM and HETROR, to extract heavy truck occurrences from the WIM data for the Maine and Rhode Island sites, respectively.
2. Through either the computer program HETRIG or HETRNG the equivalent 18-kip single axle loads (ESALs) for the heavy trucks were computed as an initial step for each procedure developed.
3. Four procedures including the above computer programs

TABLE 8 RESULTS OF VESYS ANALYSIS USING ESAL OF HEAVY TRUCKS BASED ON THE 1986 GUIDE CONVERSION FACTOR FOR THE MAINE SITE

ANALYSIS TIME	DAMAGE INDEX	RUTTING DEPTH	ROUGHNESS	PSI
1.0 YRS	.24599E+00	.17097E+00	.82936E+00	4.38
5.0 YRS	.60222E+01	.36272E+00	.37358E+01	3.22
10.0 YRS	.23844E+02	.50142E+00	.71463E+01	2.60
20.0 YRS	.13641E+03	.75591E+00	.16273E+02	1.51

NOTE: THE PREDICTED SERVICE LIFE IS 11.69

TABLE 9 RESULTS OF VESYS ANALYSIS USING ESAL OF LEGALIZED TRUCKS BASED ON THE 1986 GUIDE CONVERSION FACTOR FOR THE MAINE SITE

ANALYSIS TIME	DAMAGE INDEX	RUTTING DEPTH	ROUGHNESS	PSI
1.0 YRS	.20866E+00	.16447E+00	.76752E+00	4.42
5.0 YRS	.51077E+01	.34892E+00	.34571E+01	3.29
10.0 YRS	.20225E+02	.48236E+00	.66135E+01	2.68
20.0 YRS	.11571E+03	.72718E+00	.15060E+02	1.63

NOTE: THE PREDICTED SERVICE LIFE IS 12.74

TABLE 10 RESULTS OF VESYS ANALYSIS USING ESAL OF HEAVY TRUCKS BASED ON THE 1986 GUIDE CONVERSION FACTOR FOR THE RHODE ISLAND SITE

ANALYSIS TIME	DAMAGE INDEX	RUTTING DEPTH	ROUGHNESS	PSI
1.0 YRS	.26417E+01	.27005E+00	.17169E+01	3.78
5.0 YRS	.64668E+02	.57561E+00	.78058E+01	2.43
10.0 YRS	.25606E+03	.79742E+00	.14995E+02	1.50
20.0 YRS	.14649E+04	.12054E+01	.34329E+02	-0.33

NOTE: THE PREDICTED SERVICEABILITY LIFE IS 4.48

TABLE 11 RESULTS OF VESYS ANALYSIS USING ESAL OF LEGALIZED TRUCKS BASED ON THE 1986 GUIDE CONVERSION FACTOR FOR THE RHODE ISLAND SITE

ANALYSIS TIME	DAMAGE INDEX	RUTTING DEPTH	ROUGHNESS	PSI
1.0 YRS	.17940E+01	.24640E+00	.14292E+01	3.90
5.0 YRS	.43917E+02	.52518E+00	.64980E+01	2.64
10.0 YRS	.17390E+03	.72755E+00	.12483E+02	1.79
20.0 YRS	.99485E+04	.10998E+01	.28577E+02	0.16

NOTE: THE PREDICTED SERVICE LIFE IS 6.18

were developed to assess pavement damages caused by heavy trucks using the following four available pavement design methods or models:

- AASHTO Interim Guide,
- AASHTO 1986 Guide,
- Asphalt Institute's DAMA, and
- FHWA's VESYS 3A-M.

The ratios of expected lives for legalized trucks to heavy trucks are summarized below.

Site	*Interim Guide*	*1986 Guide*	*DAMA*	*VESYS 3A-M*
Maine	.85	.85	.83	.91
R.I.	.69	.68	.69	.72

4. Only traffic variables were considered for the analysis by using procedures based on AASHTO's Guides. There was no significant difference in pavement damage caused by heavy trucks when procedures based on AASHTO Interim and 1986 Design Guides were compared.

5. For (specified) distress analysis, procedures based on mechanistic models (e.g., DAMA and VESYS 3A-M) could be utilized for damage assessment. Because of the lack of availability of input data except traffic, only demonstration analyses were performed with a reasonably estimated input data set.

6. There were consistent observations, in all cases, that heavy trucks caused more damage than benchmark trucks.

7. Finally, more damage from heavy trucks was predicted when there were higher legal weight limits.

Recommendations

1. Although most NETC states are still using the AASHTO Interim Guide primarily for the pavement design, it is highly desirable to use the procedure based on the 1986 AASHTO Design Guide to assess pavement damage caused by heavy trucks.

2. Because of limitations of DAMA (e.g., only one untreated base layer), the procedure based on VESYS 3A-M appears to be more appropriate for the mechanistic analysis.

3. Procedures based on DAMA and VESYS 3A-M require mechanical properties of pavement materials, such as resilient modulus of subgrade soils and fatigue and creep properties of asphaltic materials. Furthermore, VESYS analysis calls for preparing specimens using a California Kneading compactor. For a more accurate analysis, the above properties and equipment should be available in New England.

4. It is recommended that mechanistic methods (e.g., VESYS 3A-M) be used to assess effects caused by the configurations, tire pressure, nonstandard vehicles, and variables other than traffic.

5. Because of the lack of construction records or necessary data for this study (e.g., design ESAL for the Rhode Island site), the absolute values of results need to be validated for the interpretation. It is recommended that all NETC states look into establishing a good, possibly computerized, data base as a subset for the pavement management system for future activities.

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