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16. Abstract

The Texas legislature has authorized the issuance of annual permits allowing commercial motor vehicle operators to operate nonagricultural vehicles exceeding the legislative mandated axle weight by 10 percent and the allowable gross vehicle weight by 5 percent, with heavier loads allowed for agriculture. The $75 permit (and $15,000 bond) allows operation on state and county roads except the interstate system. The interpretation has been that this effectively allows 84,000 lb vehicles on roads designed for 58,420 lb vehicles.

The movement of goods on our surface transportation infrastructure is an important factor in the economic health of the state; and truck shipping productivity is a key element in this movement. There is often a trade-off between vehicle weight management policies and pavement management policies in the maximization of productivity. AASHTO pavement design procedures indicate that the effect of the Texas legislation would be a five fold increase in pavement damage. Other literature suggests that such legislation should be accompanied by a permit costing significantly more than $75.

The study included a full scale truck loading experiment on two County roads and one State highway. General agreement with AASHTO damage models was found. Surveys of state and county agencies as well as the trucking industry were conducted. In general, the trucking industry showed substantial cost savings with the increase in load. Government agencies responsible for pavement and bridge management did not obtain receipts from the permit fee sufficient to offset maintenance and enforcement costs associated with this management activity.

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Permit, Overweight, Pavement Damage, Fee Distribution

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WEIGHT TOLERANCE PERMITS

by

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Research Report 1323-2F

Study Title: Evaluation of the Weight Tolerance Permits Authorized in House Bill 2060

Conducted for

The Texas Department of Transportation
in cooperation with the U.S. Department of Transportation,
Federal Highway Administration

by the

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

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IMPLEMENTATION

Study results provide the Department with the necessary background information to seek altered legislation. Recommended changes, if implemented, will result in considerable savings for the taxpayer in Texas. A relatively intangible increase in the quality of life for the taxpayer should also occur since the riding quality of local roads might be preserved or even improved in some cases. In addition, it should help clarify trucking industry issues and perhaps give that industry some new ideas for methods to improve productivity without substantially increasing damage to pavements.

DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes.

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The engineer in charge of the study was William W. Crockford, PhD, PE 67547.

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
CTI	Central Tire Inflation (Cab-Controlled tire pressure)
FM	Farm-to-Market Road
FWD	Falling Weight Deflectometer
GIS	Geographic Information System
GPS	Global Positioning System
HB	House Bill
MDD	Multidepth Deflectometer
NAFTA	North American Free Trade Agreement
SDD	Single Depth Deflectometer
SH	State Highway
TFPS	Texas Flexible Pavement System
TxDOT	Texas Department of Transportation
VPD	Vehicles per Day
WIM	Weigh in Motion

SUMMARY

In 1989, the Texas legislature authorized the issuance of annual permits allowing commercial motor vehicle operators to operate nonagricultural vehicles exceeding the legislative mandated axle weight by 10 percent and the allowable gross vehicle weight by 5 percent. The $75 permit (and $15,000 bond) allows operation on state and county roads except the interstate system. The interpretation has been that this effectively allows 84,000lb (356kN) vehicles on roads designed for 58,420lb (260kN) vehicles. The legislation allows even heavier loads for transporters of agricultural products in their natural state.

The movement of goods on our surface transportation infrastructure is an important factor in the economic health of the state, and truck shipping productivity is a key element in this movement. There is often a trade-off between vehicle weight management policies and pavement management policies in the maximization of productivity. The design procedures used by the American Association of State Highway and Transportation Officials (AASHTO) indicate that the effect of the Texas legislation would be a five fold increase in pavement damage. General agreement with the AASHTO guidelines was found. Other literature suggests that such legislation should be accompanied by a permit costing significantly more than $75.

The Scurlock case involving county jurisdiction in overweight permit matters, unless heard by the Supreme Court or overturned by other decisions in similar cases, will stand as the law supporting state authority in the issuance of 2060 permits. The reasoning of the Scurlock Court appears to be well founded and logical. Since the case is decided upon well-reasoned, legal principles and particularly long standing rules of construction where conflicts of law exist, the more successful approach to modifying the existing law would be through Legislative efforts.

A recommendation for a substantial rewrite of the legislation is followed by recommendations for significantly increased permit fees and penalties for noncompliance. A suitable method for obtaining a waiver of the permit fee is proposed.

I. INTRODUCTION

In 1989, the Texas legislature authorized the issuance of annual permits allowing commercial motor vehicle operators to operate nonagricultural vehicles exceeding the legislative mandated axle weight by 10 percent and the allowable gross vehicle weight by 5 percent. The $75 permit (and $15,000 bond) allows operation on state and county roads except the interstate system. The interpretation has been that this effectively allows 84,000lb (356kN) vehicles on roads designed for 58,420lb (260kN) vehicles. The legislation allows even heavier loads for transporters of agricultural products in their natural state.

The movement of goods on our surface transportation infrastructure is an important factor in the economic health of the state; and truck shipping productivity is a key element in this movement. There is often a trade-off between vehicle weight management policies and pavement management policies in the maximization of productivity. The design procedures used by the American Association of State Highway and Transportation Officials (AASHTO) indicate that the effect of the Texas legislation would be a five fold increase in pavement damage. Other literature suggests that such legislation should be accompanied by a permit costing significantly more than $75.

LEGISLATION

The passage of House Bill 2060, amending Article 6701d-11, Section 5B, set the stage for the political and legal battle regarding overweight vehicle permits that has now culminated in the issuance of an "Opinion" by the Court of Appeals, the 1st Circuit of Houston, in the Brazos County "Scurlock" case. The 2060 permit problem in the political arena has pitted the trucking industry and its economic interest in the moving of large loads against the political entities responsible for levying taxes necessary to maintain such road systems. The Scurlock case, as decided by the Houston Appellate Court on November 10, 1993, currently stands as the most prevailing interpretation of the law and as the prevailing endorsement of the authority of the State Department of Transportation to issue the "2060 permits", preempting county authority.

Attempts to gain some insight into the conflict between county permitting and state permitting under House Bill 2060 commenced through a Request for Attorney General's Opinion made by the Brazos County Attorney. The February 28, 1991 request for an opinion regarding the construction of House Bill 2060's amendments to Article 6701d-11 is titled as follows:

> Does a permit issued under Article 6701D-11, Section 5B, authorize a vehicle to operate at 5% over the maximum gross weight *for which the vehicle can be registered*, or is the vehicle limited to the 5% over the posted load limit of the road of which it is traveling?

As was stated by Brazos County Attorney Kuboviak:

> At the heart of this issue is whether or not counties may require trucking companies to obtain special permits to travel over county roads and bridges at weights exceeding the posted limits or whether a "Texas 2060 permit" preempts any other local permits requirements.

Brazos County sought affirmation of the county's authority to regulate traffic over roads and bridges which were not structurally designed nor maintained to handle the traffic of a legally permitted overweight vehicle. Clarification would resolve the conflict of the state authorizing overweight vehicles to operate on county roads and bridges which were load-zoned for weights substantially less than the legal permitted amount.

The Attorney General's response dated June 27, 1991 (Opinion DM-28), focused upon the initial inquiry of Brazos County Attorney Kuboviak, and stated specifically that the interpretation of Section 5B, Article 6701d-11 authorizes the issuance of a permit for vehicles operating in excess of their gross allowable weight without regard to the load-zoned limits of roads or bridges. The effect of this interpretation was to apply the language of the statute, in regards to the excess weight question, to the vehicle without regard or concern for the load limits of the roads or bridges. So long as a valid 2060 permit was obtained, an overweight vehicle was implicitly authorized to traverse any and all county roads without regard to the load limits set by a commissioner's court.

Opinion DM-28 made mention of the retained authority of the county to prevent overweight vehicles from using certain roads and bridges pursuant to Article 6702-1, Section 2.301(g) and Section 2.302. In addition to mentioning such specific retained powers of the Commissioner's Court, the language of 6701d-11 was quoted to include in Section 2(b)(5) the italicized portion which states as follows:

> *If a county judge, county commissioner, county road supervisor or county traffic officer requires such vehicle to travel over a designated route, it shall be presumed that such designated route, including any bridges or culverts located thereon, is of sufficient strength and design to carry and withstand the weight of the vehicle traveling over such designated route.*

The amendments under House Bill 2060, Article 6701d-11, Section 2(b)(5), could imply that the county has specific authority to designate such routes of travel. The caveat to this implied grant of authority, where there is damage by such overweight vehicles to the roads and bridges, could be no right of recovery since this amendment provides a presumption of strength and design of roads and bridges to withstand the weight of the overweight vehicles.

The District Court of Brazos County on June 22, 1992 decided the Scurlock case. The Court's decision was construed as a victory for Brazos County's authority to require separate issuances of permits for overweight vehicles. The Court deemed that HB 2060 amendments were unconstitutional. Scurlock Permian Corporation had sought to enjoin Brazos County from issuing permits and to enforce the claim that HB 2060 had preempted such authority of the counties. Brazos County prevailed by the Court's ruling of the unconstitutionality of HB 2060.

The Houston Appellate Court gave some insight into the interpretation of this legal question by its commentary under the factual recitation of the case. The Court noted specifically (in outlining the factual background) that the County Road and Bridge Act "does not specifically authorize counties to require overweight vehicles to have a county permit." By virtue of the absence of this specific grant of authority, the Court (in its analysis) implied that HB 2060, through its codification under Article 6701d-11 2(b)(1), was the grant of the authority to the county for the regulation and the issuance of permits for overweight vehicles. Since the County Road and Bridge Act did not contain specific grants of authority for such issuances of overweight vehicle permits, the Court implied that the expressed provisions of Article 6701d-11 were the authority for which the county was vested. The Court found the specificity contained within Article 6701d-11, Section 2(b)(1) set out the county authority which was not expressed under the County Road and Bridge Act provisions. Utilizing several rules of construction under conflict of law questions, the Court was able to reconcile what had been alleged as an irreconcilable conflict between the County Road and Bridge Act and the enactment of HB 2060 amendments into Article 6701d-11. The Court stated:

> The County Road and Bridge Act deals generally with the county's authority to regulate traffic on county roads. Article 6701d-11 specifically authorizes the state to issue permits for overweight vehicles, and grants counties limited power to issue permits for overweight vehicles. We find that the two statutes are not irreconcilable; the specific provisions of Article 6701d-11 are an exception or qualification to the general provisions of the County Road and Bridge Act; that Article 6701d-11 prevails over the County Road and Bridge Act. (*1993 WL 459903, *7 (Tex. App.-Hous.(1 Dist.))*)

While the Court gave full superior position and standing to the provisions of Article 6701d-11 in regard to the state's authority to grant the permit, the county's authority was validated in regards to particular permits on the following types of vehicles:

> Overweight, oversize or overlength commodities that cannot reasonably be dismantled, and for the equipment used to transport these commodities. (*VCS Art. 6701d-11 § 2(b)(1)*)

The language of the opinion validates equal authority in the issuing of permits to such particular vehicles as authorized by Section 5B of 6701d-11; however, where the state had issued the 2060 permit, there was no authority remaining in a county to require another permit. As put succinctly by the Appellate Court, "A vehicle with a valid 2060 permit does not have to get a Brazos County overweight permit."

The Scurlock case, unless heard by the Supreme Court or overturned by other decisions in similar cases will stand as the law supporting state authority in the issuance of 2060 permits. The reasoning of the Scurlock Court appears to be well founded and logical. Since the case is decided upon well-reasoned, legal principles and particularly long standing rules of construction where conflicts of law exist, the more successful approach to modifying the existing law would be through Legislative efforts.

The 73rd Session of the Texas Legislature saw the introduction of legislation that would have amended either the County Road and Bridge Act or Article 6701d-11 in a manner allowing the county to have specific authority for regulating overweight vehicle traffic or excluding it on roads where there are weight or load limits established by a Commissioner's Court. This remedial and corrective legislation did not survive committee scrutiny. Article 6701d-11, being introduced in 1989 as HB 2060, continued to stand as the law on this issue and was as subsequently interpreted by the Scurlock Court.

If the cost of maintenance, repair and replacement is to be borne by those who utilize the roads then, either through increased permitting fees or proportionate usage charges, such maintenance and repair costs must be recovered. If the state is to be in the lead role under the 2060 permitting process, an equitable way must be found to make fee assessment proportionate to usage. The blanket fee does not equate to utilization and certainly is not proportional to the wear and tear imparted by increased utilization of roads and bridges within a county. Similarly, unless the language of Article 6701d-11, Section 5B is utilized for the designation of routes, the county has no control over the course and path of such truck traffic.

PROJECT BACKGROUND

Assessment of the trade-off between vehicle weight management policies and pavement management policies in the maximization of productivity often assumes that a profit maximization industry will pass transportation cost savings on to the consumer if more efficient (in this case more efficient means more heavily loaded) trucks are allowed on public roads and bridges. If the savings are greater than the costs for pavement and bridge repair, a positive net present value project is indicated. However, the consumer cost saving is not totally described by the savings on transportation of consumer goods in the reality of imperfectly efficient markets. In general, the consumer also pays taxes that, in effect, decrease the tax burden of the freight carriers -- a savings to the carrier that may or may not be passed along to the consumer depending on the ethics and fiscal health of the carrier. A general description of the issues at hand on the national level is given by the Committee for the Truck Weight Study (*TRB 1990*).

> The impact analyses conducted for this study support findings from previous truck size and weight studies mandated by Congress. It has been found that increasing truck weights can significantly reduce the cost of goods movement and that cost savings due to more efficient trucks generally exceed the additional pavement and bridge costs incurred by highway agencies. At the same time, other study findings suggest the need for caution in implementing increases in truck weights. Unless the revenues required to cover additional pavement and bridge costs are provided to highway agencies, the condition of the highway system will deteriorate, thereby increasing vehicle repair costs, lowering fuel economy, increasing travel delays and accidents, and adversely affecting driver and passenger comfort. Also, increasing truck weights has both positive and negative effects on safety and traffic operations. On one hand, reduced truck traffic serves to decrease truck-related accidents and congestion. On the other, simply allowing more weight on existing trucks could adversely affect truck operating characteristics and increase accident rates. Further, if user charges do not increase in step with truck costs, inefficient levels of rail diversion might occur. This new truck traffic could cause net losses for the transportation system as a whole if added pavement and bridge costs resulting from diversion exceed savings in transport costs. (*p. 14*)

An important phrase in the preceding quotation is that "unless the revenues required to cover additional pavement and bridge costs are provided to highway agencies, the condition of the highway system will deteriorate . . . ." Certainly the authors of House Bill 2060 did not mean the $75 fee to cover the additional pavement and bridge costs. Surely the bond and the penalties were meant to cover these increased costs. However, it is a well known fact that overweight penalties and the probability that the operator will get caught in an overweight condition go into the trucking industry computation of profitability. In more than a few cases, it makes more economic sense to operate overloaded (even above that specially permitted) than to operate within the permit authorization. In one study, the average apprehension rate for illegally overweight trucks was found to be once in every 12,500 miles of travel (*TRB 1990*). Therefore, the reader of the bill must assume that the $75 is for administration of the permitting process and for implementing an intensive enforcement program. Increases in enforcement capability, not decreases in such capability as has apparently been proposed within the last year, must accompany legislation such as that found in 2060. The ambiguity of the bill in terms of the definition of "damage" the potential cost in terms of litigation to prove that a given vehicle or operator was actually the cause of the damage, and the lack of thought given to the formula for redistribution of the permit fee receipts indicate that actual collection of damages from anyone other than the taxpayer will be virtually impossible.

When Florida increased its legal weight limit, it anticipated that the number of overweight violations would decrease. Instead, the number increased (*Downs 1981*). If the number of violations increases, either enforcement must increase or maintenance costs must increase, or both. NCHRP (*1980*) states that the percent of overweight vehicles drops significantly when 70 to 120 X 10^{-6} enforcement work hours per truck mile are expended. Appropriately then the $75 fee must cover both state and county enforcement efforts at this level of effort or greater.

In Minnesota, policy decisions have been made in response to public and shipper comments as discussed below.

> Mn/DOT began reassessing its weight management policies in 1984. A number of actions were implemented to support state economic development objectives and improve shipping productivity. For example, the number of weight restriction categories was reduced. More important, a risk management philosophy was implemented to decrease spring weight restrictions and expand the number of miles open all year to gross vehicle loads of 10 tons per single axle or 80,000lb. Under this philosophy, spring weight restriction signs were removed from many highway segments in response to public and shipper comments. These actions were taken despite pavement strength testing data that showed many of these routes to have inadequate structural capacity to carry heavier loads. Mn/DOT reserved the right to impose weight restrictions again, if necessary, to prevent significant deterioration.
>
> Removing weight restriction signs without strengthening highways to allow them to carry additional weight is not an acceptable long-term solution. Many of these roads are not structurally designed to accommodate heavier trucks. Therefore, they will experience accelerated deterioration and possible roadway failures. On the other hand, the cost of upgrading all 12,100 mi of the state's trunk highway system to carry 80,000-lb truck loads is prohibitive. In 1985 an Mn/DOT report estimated that the short- and long-term costs of establishing a statewide trunk highway system capable of carrying 80,000-lb loads would be over $32 million per year just for road strengthening . . . . To put this into context, Mn/DOT spent about $35 million in 1988 to address total reconstruction needs on the 12,100-mi state trunk highway system. Road strengthening needs of this magnitude would require diverting funding resources away from other high-priority highway and bridge improvement needs. (*Bloom & Kreideweis 1990, pp. 1-2*)

The Minnesota cost estimates of removing weight restrictions may be conservative, even on a per lane mile basis, compared to the cost of the 2060 legislation. For example, the 2060 legislation will almost certainly redirect some traffic off the interstate system and onto load-zoned pavements and bridges. In some cases, this may result in load applications that are on the order of twice the load-zoning on the road. In addition, the 2060 program could act almost like a legalized form of interstate weigh station bypass, given the probable magnitude of the enforcement problem.

Many of the county bridges will not safely support the full weight of vehicles with 2060 permits. Many of the county roads and state non-interstate routes are flexible pavements (either unsurfaced/gravel, surface treated, or thin asphalt surfaced). Often, these roads were designed using Figures 16 through 23 in Test Method Tex-117-E. More recently, the TFPS and AASHTO procedures have been used in conjunction with Tex-117-E. In some cases, the original design of some of these roads did not involve *any* engineering computations. This is especially true of some of the county roads. In these designs, the thin surface layers such as seal coats do not really contribute very much to the load carrying capacity of the structure except in terms of their ability to decrease the adverse effects of water. This means that the aggregate base course is the primary load carrying, or structural, layer. Therefore, any required repairs will almost certainly involve the base course as well as the surface course (if present). In areas of the state that have relatively high rainfall coupled with clay subgrades, poorly drained base materials, and very heavy vehicle loads (*i.e.* the logging and energy producing areas east of I-35), a formula for potentially serious problems is in place. The Brazos County Engineer estimates that the county roads that have been designed for 58,420 pound (260kN) loads with typical sections containing 6 inches (15cm) of compacted limestone base would require an additional 9 inches (23cm) of base material to support 80,000 pound (356kN) loads, resulting in a total cost increase by a factor of about 2.0 to 2.5.

The 1986 AASHTO Guide (*AASHTO 1986*) includes a section on low-volume road design. The primary differences between a standard design and a low-volume design is that the low-volume design typically assumes a maximum traffic level of 100,000 18-kip (80kN) ESAL applications, a lower level of reliability, and a lower terminal value of the present serviceability index (PSI). As a rough example of the implication of House Bill 2060 in terms of the AASHTO pavement design procedure, consider the case of a single axle vehicle on a pavement with a structural number of 3.0 and a planned terminal serviceability index of 2.0. A 10% increase in the axle load from 20,000 to 22,000 pounds (89-98kN) changes the load equivalency factor by 51%. The load equivalency factor represents a ratio that relates the reduction in PSI (an indicator of damage) due to the axle weight and configuration in question to the reduction in PSI that would be caused by an 18-kip (80kN) single axle load. In this scenario, a 22-kip (98kN) load induces about 2.35 times the reduction in PSI as an 18-kip load, while a 20-kip load (89kN) induces about 1.56 times the reduction in PSI caused by an 18-kip (80kN) load.

The example given above illustrates two subtle points that were either not understood or not considered by the authors of the bill. The fundamental cause of pavement failure is the application of a *tire contact pressure* that exceeds the *load carrying capacity* of the pavement. The *tire contact pressure* (or the next best indicator, *axle load*) is important to minimization of damage. To the trucking industry, this means that the *gross vehicle weight* is almost unlimited by the pavement structure (within reason of course). Disregarding vehicle overturning safety considerations and total bridge loading, it follows that the legislation would have been better in terms of pavement life if the tolerance figures had been reversed (*i.e.* 5% axle weight and 10% gross weight). The reason gross vehicle weight is almost unlimited by the pavement structure is that tire contact pressure can be reduced by increasing the number of axles, the number of tires, or by using low inflation pressure tires. Dynamic loads can be altered by changing the suspension system. Low inflation pressure tires have been studied in reasonable detail in connection with farm applications, airport firefighting vehicles, and logging operations (*e.g. Powell & Brunette 1991*). The reason that the axle load is called the "next best indicator" of pavement loading is that Specialized Hauling Vehicles (SHV) and some standard trucks (*e.g.* 3-S2) may, in the future, employ "super-single" tires. There is some evidence that the maximum pavement deflections induced by super-singles is greater than that induced by dual tires (*Akram et al 1992*). Therefore, axle loads do not describe the loading quite as well as tire contact pressure distribution and wheel configuration.

The second of the subtle points from the example is built into the structural number used in the example. The structural number is a function of the engineering properties of the pavement layers (including the subgrade), the layer thicknesses, and the drainage characteristics of the pavement materials. Therefore, the structural number is not, in reality, a constant. It varies with seasonal changes. The effects of rainfall (and spring thaw in northern climates) have been shown to be quite detrimental to low-volume road life (*e.g. Dittmer & Johnson 1975, Richter & Hsia 1987*). Of course, if the pavement is designed for a load that is only 70% of that being applied, the thickness will not be adequate to protect the subgrade and failure will occur. Therefore, thickness is a variable that is controlled by material properties, loading, and seasonal influences on the material properties.

Most of the safety issues are by-products of the infrastructure damage issues. For instance, pothole development and shoulder damage can be a serious safety hazard for passenger cars and school buses. Rut development can contribute to severe hydroplaning potential. In the case of relatively narrow county roads, the potential hazards are obvious. Catastrophic bridge failures caused by legally permitted vehicles ignoring load limits also result in obvious hazards.

II. SYNOPSIS OF APPENDICES

In terms of basic monetary information, Appendix A illustrates the inadequacy of the permit fee. The total annual collection of fees for the entire State of Texas would build one new bridge and seal coat about 8 miles (13km) of FM or county roads. Even if all of the money went to repair seal coats, only about 38mi (61km) of roadway could be repaired.

Appendix B makes interesting reading and shows that the literature is replete with documentation of two points: (1) heavy vehicles damage roads, and (2) it is possible to carry heavy loads without perpetuating this undue damage. An important point made by one author is that the infrastructure repairs necessitated by heavy loads must be in concert with the intended use of the road. For load restricted roads, the 2060 permit means a change in intended use. This change further increases maintenance costs because the repair becomes a reconstruction project to upgrade the structure. Many articles discussed enforcement and concisely stated that fines, permits, and enforcement are not effective either in offsetting maintenance costs or in deterring violators.

The Data Analysis section of this report, Appendix C, contains a discussion of the data acquired on this study. Almost all states have overweight permits, but not very many states have much of a damage assessment program. This suggests that this issue is a national problem and not confined to the State of Texas. The results of the surveys conducted within Texas suggest that the overwhelming cause of observed damage is the synergistic effect of combining rainfall and heavy loads. This comes as no surprise to anyone who has operated a vehicle in rural areas. The energy related industry caused significantly more damage than agricultural related industry. This might be expected based on the fact that much of the energy related industry in Texas is petroleum based and requires road construction (aggregate hauling), machine transport (drilling rigs), and product movement (oil, drilling fluids).

The response from the trucking industry survey was reasonably good and was enlightening especially on two fronts. The first point is that well over half of the miles traveled by these firms (all of whom hold at least one 2060 permit) required 2060 permits. The second point is that the distribution of the operations in terms of geography was bimodal in nature. Most of the operators operated in less than 5% of the counties for which they were permitted. The revenue added to the firm's balance sheet ranged from 0-50% of gross receipts with the average being approximately 22%. Most of the firms said they passed all of these savings along to customers.

In an ironic turn of events, the author of this study happened to be having some earthwork done at his residence during the time of the study. The equipment mover required a 2060 permit and passed the entire cost of the permit on to the customer. If this is standard practice among trucking firms, the State is unwittingly fostering a boondoggle of epic proportions in which the trucking firm pays $75 a year for the power unit and then charges each customer the $75 fee on top of the usual shipping charge. This fee is then explained as "yet another wasteful state tax policy."

The field experiment conducted during this study demonstrated that the AASHTO damage factors are reasonable for estimating damage impacts. In some cases, the AASHTO damage prediction is too high and it is too low in others. Based on the study results, a range of damage factors was identified spanning from a low of 1.8 to the AASHTO high prediction of 5.57. The moisture condition did affect the pavement response to some degree.

The damage analysis in Appendix D shows that the fourth power rule of thumb for damage reduces to a factor of 2.8 on the rut depth portion of the total damage for the two subject vehicles. A derivation is also given for modeling a sharp crack fatigue failure in a bridge member. The results indicate that bridge inspections may be needed at more frequent intervals than would be feasible for county bridge inspectors.

Appendix E presents the script for the companion videotape to this document. Excerpts from the Texas Traffic Laws and a TxDOT information sheet on HB 2060 can be found in Appendix F.

III. CONCLUSIONS

The legislation is poorly conceived and only considers a part of the total economic picture in the State of Texas. Potential conflicts of law have apparently been resolved and the law will probably stand as written. Only legislative correction will alter the law as it currently stands. Correction is needed in at least three areas: (1) the amount of the permit fee, (2) the distribution of the permit fee receipts, and (3) fines and penalties associated with noncompliance.

The legislation allows the counties to specify routes for the permitted vehicles. However, if this action is taken, the county effectively relinquishes any possibility of collecting damages. On the other hand, this method concentrates the damage in controlled areas so that repair activities can be consolidated. Basically, the county would be sacrificing the designated route to have better control over damage and maintenance.

Although the scope of the study limited the amount of field testing that could be done, the results indicate that the fourth power rule of thumb describing AASHTO damage functions gives a reasonable estimate of the impact of House Bill 2060 at the network level. Variability in the experimental data obtained in this study indicate that the fourth power rule is sometimes too conservative, and sometimes not conservative enough. Pooling all the data for the year at the better of the county roads in the study (Hardy Weedon Road) indicates that the *minimum* impact on infrastructure maintenance costs is an increase by a factor of 1.8. Although not as severe as the maximum damage observed in this study, the AASHTO damage factor of 5.57 for this situation appears to be sufficiently close to the maximum to warrant its use as a maximum for planning purposes. Therefore, infrastructure maintenance costs should increase by a factor ranging from approximately 2 to 5 if 2060 permitted vehicles are allowed on roads designed for 58,420lb (260kN) vehicles.

The AASHTO damage concept is based on a serviceability index. This index does not directly incorporate some significant forms of damage such as bleeding or flushing of asphalt pavements which can be caused by heavy loads on asphalt surfaces that have been designed for lighter loads. This type of damage results in a loss of skid resistance and is usually the result of too much or too soft asphalt being used for pavements supporting the heavy loads. In the case of a seal coat, the amount of asphalt used to bond the rock can be decreased in an effort to reduce damage due to heavy trucks. However, if the agency building the road cannot afford the proper heavy construction equipment, personnel, and time, the rock used for the seal will be loose until it is seated by the heavy truck traffic, and substantial passenger car and truck windshield and paint damage will occur during the seating period.

It is virtually impossible to prove that a given truck caused damage to a road mainly because the damage usually accumulates over a relatively long period. In this study, sensitive electronic measurement devices were used to detect very small deformations in the pavement system. The instrumentation is not practical for use as an enforcement tool. Therefore, the only way to recover the bond provided for in 2060 is to be present at a site when an unusually rapid failure occurs or to glean the evidence from proceedings of an accident investigation (*eg.* the truck is disabled as a consequence of the damage it produced). In portions of the State subjected to freeze-thaw cycles, the most likely time of year for unusually rapid failures is during the thaw period, while the most likely time in other portions of the State is during the rainy season. In all parts of the State, rapid failures can occur with any asphalt based pavements during the hot part of the year due to a reduction in the viscosity of the asphalt if the stone skeleton cannot carry the heavy loads.

Receipts from the permit fee do not offset the cost of pavement maintenance and repair. Counties received an average of approximately $1,500 each from the permit fee during fiscal year 1992. This amounts to approximately $2.32/mi ($1.44/km) in revenue to maintain the roads. At a cost of approximately $10,000/mi ($6,214/km), for a minimal seal coat repair, it is obvious that the fee is inadequate if the least bit of incremental damage takes place due to 2060 permitted vehicles. In many cases, actions such as seal coating are more cosmetic than effective, and much more expensive, deeper pavement system repairs are warranted. Such deep repairs or upgrading roads to accept greater loads can easily triple the cost of construction over that associated with just maintaining the existing pavement without structural capacity improvement.

Likely, 10-25% of the legally permitted vehicles will actually operate beyond the allowable load tolerance. This expectation comes from previous studies at the national and state levels (*Terrell & Bell 1987*). Only 1 in 400 overweight violations were detected in a New Jersey study on the subject. Enforcement costs amount to an estimated 9% of the damage costs.

In reality, gross vehicle weight does not need to be regulated. Extremely heavy loads can be carried if the vehicle is properly designed. Tire-pavement contact pressure and wheel configuration that interact with pavement structure, materials, and environmental conditions to cause damage should be the targets of regulation. Axle load, used in the AASHTO method of pavement design, is the next best indicator of damage potential. Axle spacing enters into the problem as well. Finally, most studies, including this one, concentrate on the trailer axle set. However, the steering axle can do significant damage to the pavement. In fact, some observations in this study show more total deflection under the steering axle than under the trailer axle. These experimental observations can be caused by such factors as: (1) different horizontal offset positions between (a) the tire on the steering axle and the deflection sensor, and (b) the trailer axle dual tires and the deflection sensor, (2) dynamics of the suspension system on the tractor especially in low gear, and (3) the fact that the steering axle is almost always supporting approximately 5,000lb (22kN) static weight per tire while the trailer tires carry only 3,000-4,700lb (13-21kN) each, depending on the loading. The trailer tires are distributing the load reasonably well since they are in groups of four. The steering axles also have the unique capability to induce very high shear forces that can severely damage even a good seal coat by dislodging the rocks on the surface during turning operations (especially sharp turns at low speed or during deceleration).

There is a need for more detailed study of the steering axle impacts, especially with respect to combined power/payload units such as concrete trucks, produce and aggregate hauling/dump trucks, and other single units without trailers. Because of the moments associated with the load distribution in an 18 wheeler, a heavy load in the trailer may actually reduce the weight on the steering axle. On the other hand, in a combined unit such as a dump truck, part of the weight of heavy loads placed in front of the rear axle set are transferred to the pavement through the steering axle. These types of vehicles are important not only from the standpoint of axle load, but also from the standpoint of gross weight because the entire truck weight will be applied to bridges (even on those bridges with relatively short spans).

IV. RECOMMENDATIONS

The legislation should be rewritten based on the input of a small team of professionals representing five factions outside the State legislature: (1) county commissioners, (2) pavement and bridge engineers, (3) economists, (4) trucking industry leaders, and (5) lawyers. This team should prepare a draft of a bill to be submitted to a legislative committee. The draft will address, as a minimum, the following issues: (1) potential conflicts with existing laws, (2) method of enforcement, (3) trade practices with external entities especially with respect to movement of foreign goods associated with NAFTA, (4) distribution of permit receipts, and (5) incentives for trucking industry participation. The fines and penalties for noncompliance need to be reviewed. They need to be increased significantly and a mechanism for applying the penalty to the *cause* of the problem needs to be developed so that they become an *effective* deterrent. The cause of the problem is not always the driver, because the driver is often simply doing what it takes to keep a job. Recommendations concerning some of these issues follow.

Damage will occur at higher rates than planned when vehicle weights exceed the weights for which a road is designed. The damage will occur over time and will be very difficult to assign to a given operator. Although the bond idea sounds good at first, the reality is that it will almost never be collected. If an annual permit is desired that allows the weight tolerances in the current legislation and specifically allows legal operation at these weights on roads that are load restricted to 58,420lb (260kN), the fee structure must be realistic. In this study, evidence in published literature was found to support a permit fee increase from $75 to $2,033.66/year based on the AASHTO damage factor concept. The literature suggests that the cost of enforcement is approximately 9% of the cost of damage. This would make the total cost of the permit $2,216.69. The cost of administration of the permit program would need to be added to this figure. Administrative fees are not included in these recommendations.

The study showed that most operators are operating in less than 5% of the counties for which they are permitted. The current distribution formula spreads all the permit fee income over the total number of permitted counties. A portion of the fee goes to the State as well. This means that the counties falling into the 5% in which the operator actually operates do not get the funds they need to repair damage. Rectifying this situation may require a more detailed permit application process. Firms would be required to estimate the percentage of their operation that would occur in each county for which they are permitted and this percentage would be applied to the fee redistribution formula to provide equitable distribution to counties and TxDOT districts.

In the limited field experiment conducted on a county road during this study, a range of damage factors was developed. It is proposed that the annual fee structure be established as a function of these damage factors. The basic fee for the permit should be established on the basis of a ratio between the minimum and maximum damage factors. Therefore, the basic fee would be \$2,216.69(1.8/5.57)=\$716.35 (1992 dollars) which would allow operation in one county or for a given distance from the point of origin, and would cover the minimum damage case. The fee would increase until total State coverage for maximum damage could be had for \$2,216.69. Funds should be dedicated to pavement and bridge repair and not allowed to disappear into a general fund at any level of government. Nine percent of the funds should go to law enforcement earmarked for permit enforcement and acquisition of evidence of damage. This minimum allotment for enforcement is crucial to the infrastructure maintenance issue, because, even at the maximum damage fee amount, the funds will not cover isolated major damage. For instance, consider the hypothetical case of a county that receives the income from only one permit. If that single permit holder operates all year on only one short stretch of one road and creates significant damage at that location, the county's permit fee income will still be woefully inadequate to accomplish the necessary repairs, even at this significantly increased fee. A mechanism must be retained for the responsible jurisdiction to recover damages in excess of the maximum fee receipt, and the crucial factor in this recovery is enforcement resources. Since the enforcement issue is so critical, a specific program plan and oversight system must be implemented to assure that the funds are actually used in support of the specific objectives for which they are intended. The plan and the oversight system must be flexible enough to be immediately responsive to the needs of the local state and county jurisdictions that are responsible for pavements and bridges. With this system, it may be possible to eliminate the bond requirement if the fee receipts are adequate for repair and effective enforcement.

TxDOT could establish a minimum number of trips that would result in a requirement for this permit and have a separate permit that only requires a nominal fee and perhaps a bond for a limited number of trips (*eg.* single trip, week, month, or quarter permits). The limited trip permit should require route, date, and time information so that enforcement, pavement, and bridge personnel could be notified.

Trucking firms should be motivated to help reduce damage to the infrastructure. To facilitate such behavior, the damage and enforcement portions of the fee should be waived (leaving only an administrative fee to issue the permit) if the firm can show that a given axle set has a total tire contact area equal to or greater than a triple axle, dual wheel configuration. This triple axle configuration, when loaded to the 2060 permit load of 37.4kips (166kN), is only slightly more damaging than the tandem set on a 58,420lb (260kN) vehicle (AASHTO damage factor 1.2 versus 5.4 for the same condition with tandem duals). This amounts to approximately 760in^2 (4908cm^2) for the total of the 12 tires on a triple axle set. Each tire will have a tire contact patch area on the order of 45-65in^2 (290-419cm^2) depending on the vehicle application (reduced diameter tires used on 'low-boy' type flatbeds usually have contact areas on the low end of the scale while standard freight trailers are usually on the high end).

This increase in tire contact area can be accomplished by several means. One method is control of tire inflation pressure from the cab of the tractor with a CTI system. Another is by manually changing the inflation pressure to match the load being transported.

However, the contact area must be obtained at or below the rated inflation pressure of the tire and must not be unsafe in the estimation of the tire manufacturer. This limitation is important because the contact patch can be increased either by deflating the tire or by overloading the axle. If it is obtained by overloading the axle, and the inflation pressure is at or above the rated pressure, there may be safety problems associated with increased risk of tire damage resulting from factors such as heat generation, especially at highway speeds. The inflation pressure approach will usually require a radial tire and may even require special tires to be effective. Finally, additional tires may be installed by actions such as adding an axle. The tires must be arranged in such a way that the stress distribution in the pavement approximates that of the conventional triple axle (*i.e.* the expected damage should be less than or approximately equal to that of a triple axle configuration).

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APPENDIX A - MONETARY INFORMATION

CONSTRUCTION COST ESTIMATES

Table A-1 Texas Department of Transportation cost estimates (revised November 1992).

ITEM	COST/mi ($/1.6km)
Cost to Repair Deteriorating Pavement[1]	
Interstate [38ft (11.6m) wide, 2in (5cm) asphalt overlay[2]]	85,000
Total for 4 lane divided	170,000
State highway [36ft (11m) wide, 2in (5cm) asphalt overlay]	80,000
Farm-to-Market [24ft (7m) wide, 2in (5cm) asphalt overlay]	50,000
[24ft (7m) wide, 2in (5cm) seal coat[3]]	10,000
Cost to Repair Damaged Pavement[4]	
Interstate (4 lane divided)	350,000
State highway (2 lane)	175,000
Farm-to-Market	75,000
Average New Bridge Costs	
Interstate	900,000
State highway	650,000
Farm-to-Market	300,000

[1]Deteriorating pavement: In need of some remedial action to prevent major structural damage. Generally only needs work on the surface of the pavement.
[2]Asphalt concrete overlay: A layer of asphaltic concrete placed on an existing pavement surface to restore a satisfactory riding surface and to improve the strength of the pavement.
[3]Seal coat: Liquid asphalt applied to the pavement surface and covered with crushed stone for the purpose of waterproofing and preserving the surface.
[4]Damaged pavement: In need of immediate repair. Generally requires repair of surface and subsurface.

Source: 30 December 1992 TxDOT Memorandum from Byron Blaschke to District Engineers and Division Directors on the subject "Department's Position on Legislation Increasing Allowed Vehicle Weights."

1992 FEE RECEIPT DISTRIBUTION TO COUNTIES

Table A-2 Fiscal year 1992 2060 receipts by county.

COUNTY	MILES	TOTAL
ANDERSON	1181	$2,734.03
ANDREWS	312	$722.29
ANGELINA	738	$1,708.48
ARANSAS	280	$648.21
ARCHER	433	$1,002.40
ARMSTRONG	584	$1,351.97
ATASCOSA	605	$1,400.59
AUSTIN	669	$1,548.75
BAILEY	950	$2,199.26
BANDERA	514	$1,189.92
BASTROP	708	$1,639.03
BAYLOR	365	$844.98
BEE	481	$1,113.52
BELL	963	$2,229.36
BEXAR	1147	$2,655.32
BLANCO	223	$516.25
BORDEN	256	$592.65
BOSQUE	800	$1,852.01
BOWIE	1262	$2,921.55
BRAZORIA	1100	$2,546.51
BRAZOS	470	$1,088.06
BREWSTER	512	$1,185.29
BRISCOE	399	$923.69
BROOKS	140	$324.10
BROWN	798	$1,847.38
BURLESON	505	$1,169.08
BURNET	418	$967.67
CALDWELL	448	$1,037.13
CALHOUN	248	$574.13
CALLAHAN	560	$1,296.40
CAMERON	1100	$2,546.51
CAMP	264	$611.17
CARSON	710	$1,643.67
CASS	910	$2,106.67

COUNTY	MILES	TOTAL
CASTRO	922	$2,134.44
CHAMBERS	422	$976.94
CHEROKEE	979	$2,266.40
CHILDRESS	485	$1,122.78
CLAY	750	$1,736.26
COCHRAN	573	$1,326.50
COKE	395	$914.44
COLEMAN	890	$2,060.36
COLLIN	857	$1,983.97
COLLINGSWORTH	559	$1,294.09
COLORADO	728	$1,685.34
COMAL	644	$1,490.87
COMANCHE	751	$1,738.57
CONCHO	414	$958.42
COOKE	850	$1,967.76
CORYELL	619	$1,433.00
COTTLE	414	$958.42
CRANE	176	$407.44
CROCKETT	439	$1,016.29
CROSBY	685	$1,585.79
CULBERSON	693	$1,604.30
DALLAM	494	$1,143.61
DALLAS	1227	$2,840.53
DAWSON	953	$2,206.21
DEAF SMITH	1072	$2,481.70
DELTA	334	$773.21
DENTON	700	$1,620.51
DEWITT	713	$1,650.61
DICKENS	433	$1,002.40
DIMMIT	255	$590.33
DONLEY	632	$1,463.09
DUVAL	537	$1,243.17
EASTLAND	732	$1,694.59
ECTOR	920	$2,129.82
EDWARDS	559	$1,294.09
ELLIS	1456	$3,370.66
EL PASO	520	$1,203.81

COUNTY	MILES	TOTAL
ERATH	819	$1,896.00
FALLS	850	$1,967.76
FANNIN	991	$2,294.18
FAYETTE	853	$1,974.71
FISHER	678	$1,569.58
FLOYD	1094	$2,532.63
FOARD	378	$875.08
FORT BEND	838	$1,939.98
FRANKLIN	297	$687.56
FREESTONE	754	$1,745.52
FRIO	426	$986.19
GAINES	1046	$2,421.51
GALVESTON	364	$842.67
GARZA	346	$801.00
GILLESPIE	574	$1,328.82
GLASSCOCK	234	$541.71
GOLIAD	400	$926.00
GONZALES	868	$2,009.44
GRAY	718	$1,662.18
GRAYSON	1293	$2,993.32
GREGG	291	$673.67
GRIMES	600	$1,389.01
GUADALUPE	715	$1,655.24
HALE	1389	$3,215.55
HALL	526	$1,217.70
HAMILTON	583	$1,349.65
HANSFORD	493	$1,141.30
HARDEMAN	557	$1,289.46
HARDIN	601	$1,391.32
HARRIS	5246	$12,144.58
HARRISON	773	$1,789.51
HARTLEY	374	$865.82
HASKELL	1350	$3,125.28
HAYS	662	$1,532.54
HEMPHILL	377	$872.76
HENDERSON	1194	$2,764.13
HIDALGO	1580	$3,657.72

COUNTY	MILES	TOTAL
HILL	1083	$2,507.16
HOCKLEY	1164	$2,694.68
HOOD	410	$949.15
HOPKINS	905	$2,095.09
HOUSTON	753	$1,743.21
HOWARD	540	$1,250.11
HUDSPETH	1065	$2,465.49
HUNT	1069	$2,474.75
HUTCHINSON	561	$1,298.73
IRION	346	$801.00
JACK	474	$1,097.32
JACKSON	504	$1,166.77
JASPER	662	$1,532.54
JEFF DAVIS	67	$155.11
JEFFERSON	402	$930.63
JIM HOGG	103	$238.44
JIM WELLS	556	$1,287.15
JOHNSON	909	$2,104.34
JONES	1000	$2,315.01
KARNES	551	$1,275.57
KAUFMAN	990	$2,291.86
KENDALL	388	$898.23
KENEDY	7	$16.21
KENT	252	$583.38
KERR	596	$1,379.75
KIMBLE	339	$784.79
KING	157	$363.46
KINNEY	67	$155.11
KLEBERG	167	$386.61
KNOX	420	$972.31
LAMAR	1051	$2,433.09
LAMB	1208	$2,796.53
LAMPASAS	502	$1,162.13
LASALLE	251	$581.07
LAVACA	923	$2,136.76
LEE	502	$1,162.13
LEON	731	$1,692.28

COUNTY	MILES	TOTAL
LIBERTY	605	$1,400.59
LIMESTONE	930	$2,152.97
LIPSCOMB	421	$974.62
LIVE OAK	547	$1,266.32
LLANO	581	$1,345.02
LOVING	100	$231.50
LUBBOCK	1176	$2,722.46
LYNN	960	$2,222.42
MADISON	284	$657.46
MARION	387	$895.92
MARTIN	461	$1,067.23
MASON	292	$675.98
MATAGORDA	675	$1,562.63
MAVERICK	138	$319.48
MCCULLOCH	494	$1,143.61
MCLENNAN	1020	$2,361.32
MCMULLEN	207	$479.21
MEDINA	750	$1,736.26
MENARD	130	$300.96
MIDLAND	720	$1,666.81
MILAM	840	$1,944.61
MILLS	485	$1,122.78
MITCHELL	494	$1,143.61
MONTAGUE	1074	$2,486.32
MONTGOMERY	1749	$4,048.97
MOORE	422	$976.94
MORRIS	311	$719.97
MOTLEY	268	$620.42
NACOGDOCHES	972	$2,250.20
NAVARRO	1006	$2,328.90
NEWTON	718	$1,662.18
NOLAN	513	$1,187.61
NUECES	715	$1,655.24
OCHILTREE	742	$1,717.74
OLDHAM	301	$696.82
ORANGE	498	$1,152.88
PALO PINTO	541	$1,252.42

COUNTY	MILES	TOTAL
PANOLA	917	$2,122.87
PARKER	1045	$2,419.19
PARMER	1044	$2,416.88
PECOS	562	$1,301.04
POLK	686	$1,588.10
POTTER	478	$1,106.58
PRESIDIO	900	$2,083.51
RAINS	409	$946.84
RANDALL	742	$1,717.74
REAGAN	315	$729.23
REAL	281	$650.52
RED RIVER	560	$1,296.40
REEVES	591	$1,368.17
REFUGIO	217	$502.36
ROBERTS	275	$636.63
ROBERTSON	575	$1,331.13
ROCKWALL	138	$319.48
RUNNELS	899	$2,081.20
RUSK	972	$2,250.20
SABINE	360	$833.40
SAN AUGUSTINE	531	$1,229.27
SAN JACINTO	474	$1,097.32
SAN PATRICIO	626	$1,449.20
SAN SABA	620	$1,435.31
SCHLEICHER	266	$615.79
SCURRY	680	$1,574.21
SHACKELFORD	340	$787.11
SHELBY	963	$2,229.36
SHERMAN	414	$958.42
SMITH	1174	$2,717.83
SOMERVILLE	147	$340.31
STARR	504	$1,166.77
STEPHENS	462	$1,069.54
STERLING	37	$85.65
STONEWALL	446	$1,032.50
SUTTON	300	$694.50
SWISHER	1014	$2,347.43

COUNTY	MILES	TOTAL
TARRANT	523	$1,210.75
TAYLOR	679	$1,571.90
TERRELL	81	$187.52
TERRY	1045	$2,419.19
THROCKMORTON	446	$1,032.50
TITUS	477	$1,104.26
TOM GREEN	724	$1,676.07
TRAVIS	1692	$3,917.01
TRINITY	364	$842.67
TYLER	578	$1,338.08
UPSHUR	637	$1,474.67
UPTON	465	$1,076.48
UVALDE	392	$907.48
VAL VERDE	372	$861.19
VAN ZANDT	1445	$3,345.20
VICTORIA	661	$1,530.23
WALKER	633	$1,465.40
WALLER	624	$1,444.57
WARD	475	$1,099.63
WASHINGTON	608	$1,407.53
WEBB	366	$847.30
WHARTON	1013	$2,345.11
WHEELER	600	$1,389.01
WICHITA	441	$1,020.92
WILBARGER	693	$1,604.30
WILLACY	506	$1,171.40
WILLIAMSON	1240	$2,870.62
WILSON	601	$1,391.32
WINKLER	236	$546.34
WISE	1250	$2,893.77
WOOD	781	$1,808.03
YOAKUM	806	$1,865.90
YOUNG	520	$1,203.81
ZAPATA	63	$145.85
ZAVALA	230	$532.46
TOTAL	164,400	$380,588.62

APPENDIX B - REVIEW OF SELECTED LITERATURE

FACTORS IN OVERWEIGHT PERMIT POLICY

Cottrell, B. H., Jr. *The Avoidance of Weigh Stations in Virginia by Overweight Trucks.* Virginia Transportation Research Council: Charlottesville, VA., 1992

Two weigh stations were studied to examine the avoidance of weigh stations in Virginia by overweight trucks. Trucks would avoid the weigh stations by either taking an alternate or bypass route or waiting at a truck stop until the weigh station closes. Eleven to 14% of trucks avoided the two stations. The suspicion that heavier trucks run by the weigh stations was confirmed by data showing that 38% of the runbys weighed by a portable WIM system were overweight. One proposed reason for the runbys was the inability of the weigh station to handle the number of trucks needing to pass the station. The authors suggest that there is a need to increase the truck weighing capacity of the weigh stations. Twelve percent of trucks on Route 15, and 27% of the trucks on Route 29 were overweight.

Lee K. W. and W. L. Peckham. "Assessment of Damage Caused to Pavements by Heavy Trucks in New England," *Design and Evaluation of Rigid and Flexible Pavements 1990.* TRR 1286. pp. 164-172.

Weigh in motion was used in this study in New England. Inductive loops obtained speed and presence data. Golden River Corporation marketed the mats. WIM, traffic, and pavement factors were included in the analysis. Programs were developed based on the AASHTO Guide procedures. Additional design methods were considered: the AASHTO Interim Guide, TAI DAMA, and FHWA VESYS 3A-M. One of the programs looks at ESALs of the overweight vehicles (over the legal limit), but also compares this with a fleet of legal weight vehicles carrying the same total load. For a 5% overweight fleet, 20 vehicles would equate to 21 legal vehicles. In the study, the magnitude of the reduction in pavement life (1986 Guide procedures) in Maine and Rhode Island was decreased from 61.2% and 80.6% to 52.2% and 54.8% in the respective states by reducing the load per vehicle and increasing the number of vehicles. The following table is presented in the paper as an indication of the percent of expected pavement life by the overweight trucks versus the legal trucks carrying the same load.

Table B-1. Percent of expected pavement life due to overweight trucks.

Site	Interim Guide	1986 Guide	DAMA	VESYS 3A-M
Maine	85	85	83	91
Rhode Island	69	68	69	72

Kilareski, W. P. "Heavy Vehicle Evaluation for Overload Permits," ***Rigid and Flexible Pavement Design and Analysis, Unbound Granular Materials, Tire Pressures, Backcalculation, and Design Methods.*** **TRR 1227, 1989. pp. 194-204.**

A computer simulation method was used in this study. The BISAR program for layered elastic modeling of flexible pavements was used; the JSLAB program was used for rigid pavements. The study showed that the maximum strain occurs between the dual tires; the most critical axle was found to be the trailing axle of the set. Superposition was also used. For rigid pavements, the free edge and the joint were the critical stress locations. Limiting strains were developed from PTI test track studies. Flexible pavement surface cracking was associated with surface deflections of 0.02 inch (0.508 mm), a tensile strain of 120 microstrain at the bottom of the base, and a vertical strain of 450 microstrain at the top of the subgrade. Fatigue cracking and 0.25 inch (6.35mm) rutting occurred at approximately 1 million 18kip (80kN) ESALs. With respect to multiple axles, single axles were found to give lower surface deflections, but higher tensile and vertical strains at the bottom of the base and the top of the subgrade, respectively. In this portion of the study, each axle was assumed to carry the same load (e.g. 20kip, 89kN single axle; 100kip, 445kN 5-axle). Multiple axles induced similar strains in the lower layers.

"Rigid pavement usually fails because of cracking and/or joint-related problems. . . . 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" (*p. 200*). Four and five axle configurations developed the highest stress ratios on edge loading, but the ratios were all less than 50%.

In terms of cracking of thick flexible pavement, the author claims that an increase in axle load from 27kip to 32kip will reduce pavement life by 32%. For thin pavements, the author found no significant difference in pavement life between these two axle loads.

Mason, J. M., Jr. "Effect of Oil Field Trucks on Light Pavements." ***Journal of Transportation Engineering*****, 109 (3), 1983. pp. 425-439.**

Low volume rural roads in oil producing areas are not initially constructed to endure the impact of intense oil field truck traffic. Mason studies the detrimental impact of unintended oil field traffic on these light-duty roadway pavements in an attempt to determine the definitive elements of the oil field traffic demand.

Traffic information was obtained using a Super-8-mm camera to photograph vehicles using the roadway to provide a count of the number of axles and an identification of vehicle characteristics. Through this observation, Mason determined that the "vehicle mix" included a "disproportionate frequency of large vehicles as compared to typical operating conditions on many farm-to-market (F.M.) roads" (*p. 426*). Further analysis showed that traffic counts of up to 200 vehicles per day were recorded which is the typical average daily traffic on a low volume F.M. roadway serving only its intended use traffic. Also, the total truck percentage is almost three times the anticipated truck percentage on low volume F.M. roads. Finally, Mason finds that one oil well attracted 1,102 trucks in the design lane which is approximately 2.4 times the estimated 456 trucks assumed for intended use. This increase in truck traffic results in twice the 18 kip single axle repetitions that would be expected under normal traffic.

Mason then evaluates the effect of oil field truck traffic based on pavement serviceability. A comparison of resurfacing intervals over the design period indicated a reduction in pavement life. Mason concluded that if no additional wells are drilled during the expected service life (7.5 years), the net effect of the drilling and producing of one well is a reduced service life of 4.2 years. Thus, the first rehabilitation is required in year 1.0, rather than year 3.2; a second rehabilitation is needed in 3.3 years instead of 7.5 years.

This reduction in pavement life also increases the total annual costs. The annual cost for a 250 ADT F.M. roadway is $14,000 per mile (1.61 km). For a 250 ADT F.M. roadway also serving one oil well, the annual cost would be $26,500 per mile (1.61 km). This difference results in an increase in annual pavement cost of $12,500 per mile (1.61 km), which is 1.89 times the amount designated for intended use. It should be noted that this increase in cost reflects the money necessary to rehabilitate the road to its intended-use condition, not the necessary improvements needed to transform the roadway into a more suitable passage for oil field traffic. Mason states that this type of rehabilitation is "a losing battle using minimal maintenance techniques" (*p. 436*).

Finally, Mason discusses the implications of increased oil field traffic on light duty roads. The burden of the associated costs has, unfortunately, fallen on state agencies already obligated with a host of maintenance responsibilities. In his article, Mason states that:

> The capital loss due to increased oil field truck traffic represents a consumption, or expenditure of capital, that must be born by a highway department. These costs consider only the cost of an initial pavement structure and seal coat resurfacing, and do not include costs associated with a complete pavement reconstruction, vehicle damage, or accidents. (*p. 430*)

Mason's study has particular relevance to this research. There can be a significant difference in the cost of repairs if one changes the intended use of the road at the time of the repair. This article was published before 2060, so it is uncertain how many of the vehicles would have been in this category. However, Table 6 of Mason's article suggests that 49% of the tandem axles associated with the oil well traffic would have been on 2060 permitted vehicles and another 5% would have been illegally overloaded even with a 2060 permit.

Middleton, D. R., A. Villarreal, and J. D. Blaschke. "Evaluation of Oversize/Overweight Permit Policy and Fee Structure." ***TTI Research Report 1109-1F*****, 1988. College Station, TX.**

This study reviews 1988 policies of Texas and neighboring states for oversize/overweight vehicles. Also, the impact of overweight trucks on pavements, structures, safety, and capacity is evaluated.

The authors suggest that TxDOT should proceed to implement automated routing capabilities to improve response time in issuance and to manage pavement and bridge strategies. Also, with this automated system, the level of sophistication in assessing appropriate fees can be increased. For example, a different fee might be assessed for a heavy load moving over a thin-surfaced Farm-to-Market road as opposed to moving over a U.S. Highway, which usually has a heavy duty pavement.

The authors also suggest that the current fee structure be changed to incorporate a weight-distance factor. Fees should be sufficient to cover administrative costs plus the loss of pavement and structure life resulting from the move. Costs based on the number of bridge spans appears to be the most equitable. However, if the fee must be known in advance of structural evaluation, costs based on past experience might be applied.

Terrell R. L. and C. A. Bell. ***Effects of Permit and Illegal Overloads on Pavements.*** **NCHRP Synthesis 131, 1987.**

This publication discusses many of the important issues in the permit problem including pavement damage, cost allocation, permit administration, and enforcement. Of particular interest are the enforcement and cost allocation topics.

For instance, New Jersey found that enforcement costs amounted to approximately 9% of the cost of damage, but only 1 in 400 violations were detected. The study also says that 10-25% of the trucks are operating overloaded. An acute lack of weighing equipment was a significant enforcement problem at the time of the study. Fines and other punitive actions were found to be inadequate as deterrents to overload operations, and local judges seldom have time for such cases in their courts.

The fuel savings resulting from a reduced number of trips may be offset by highway deterioration and increased fuel consumption on damaged pavement. The implication of many of the findings of the study is that most states are undercharging. The cost allocation method that was discussed in some detail was that of setting permit fees by an axle weight-mile tax schedule. There are still problems with this method since the miles traveled by the vehicle to be used in the computation could be reported most accurately by the operator who is being taxed.

Mention was made of using a mapping system to help with routing questions. With significant advances in GPS and GIS technology since the time this document was published in 1987, it seems reasonable to expect that this technology could be implemented at this time to help in publishing preferred routes and possibly in vehicle tracking efforts for enforcement and taxation.

The full text of the introductory summary to the document is given below. The reader should note that the document applies to all types of permits. Therefore, it includes not only 2060 type permits, but also permits for some of the much heavier loads than those authorized in 2060:

> In recent years it has become apparent that the nations' highways are wearing out--many of them far earlier than anticipated. One of the causes of premature deterioration is increased traffic, often much more than expected. The volume of truck traffic has increased rapidly as the Interstate Highway System has become available and popular. However, a serious contributor to early pavement wear-out is the overloaded truck, whether legal or illegal.
>
> The majority of the states surveyed for this synthesis indicated that they perceive truck overloading to be a moderate problem; i.e., 10 to 25 percent of trucks were overloaded. Other information shows that about 20 percent of the vehicles operating on federal-aid highways have axle or gross loads in excess of statutory limits. Furthermore, estimates of the cost of overloaded vehicles to the federal-aid highway system are of the order of $1 billion annually.
>
> AASHTO (American Association of State Highway and Transportation Officials) equivalency factors can be used to estimate the effects of overloaded vehicles on pavement damage. For example, it was estimated that a 24,000-lb single axle was about twice as damaging as a 20,000-lb single axle (the usual statutory limit), and a 28,000-lb axle about four times as damaging. Similarly, for tandem axles, a 40,000-lb axle was about twice as damaging as a 34,000-lb axle (the usual statutory limit), and a 48,000-lb axle about four times as damaging.
>
> There is considerable nonuniformity in practices in pavement design, permit issuance, and enforcement among the states. This problem has been recognized for many years (e.g., by NCHRP Report 80 and Synthesis 68).
>
> Most permit fees are based on gross vehicle loads. However, a more effective fee structure for permit issuance could be based on the weight-mile concept already used in several states. By considering axle loads rather than gross vehicle loads,

this type of fee structure would recognize that it is heavy axle loads, rather than heavy vehicles, that cause pavement damage. Current permit fee schedules do not reflect the damage inflicted by overloaded vehicles.

States have permit issuance procedures that are usually simple and rapid, but that vary considerably regarding criteria for issuing permits, and their cost. Methods are based on expediency rather than on a critical evaluation of the effects of overloaded vehicles.

Several states have axle and gross weight limits in excess of federal limits because of grandfather clauses. Such clauses permit operation of vehicles in excess of federal weight limits on Interstate and other federal-aid highways if they could be legally operated before July 1, 1956 when the Federal Aid Highway Act was created.

The majority of states agreed that use of an electronic license plate system in conjunction with weigh-in-motion could help in identifying overloaded vehicles and in quantifying the extent of overloading. However, the majority also perceive a problem in implementing such technology.

The majority of states have an enforcement problem. They have insufficient personnel to identify overloaded vehicles and regard penalties for illegal overloads to be insufficient. Fines for illegal overloading often are not related to the actual cost of pavement damage. Furthermore, operators of illegally overloaded vehicles often escape fines because of the failure of the judicial or administrative procedures dealing with detected violators.

Among the recommendations of this synthesis are:

* States should examine their permit issuance policies and fee structures carefully with a view toward more uniformity and to fees that are commensurate with the probable costs to their highways of overloaded vehicles. Equitable fee structures could be established by considering axle or tire loads and distance traveled, since gross vehicle load is not the best indicator of damage.

* Uniform policies among states regarding vehicle size and weight regulations would be beneficial as would uniform policies within a state regarding limits on Interstate highways and other federal-aid highways. A research effort is needed to

establish limits commensurate with economic development.

* Pavement design and evaluation practices should be capable of considering overloaded vehicles. This would require comprehensive traffic data and design procedures that can be used to analyze the effect of identified overloads. Use of weigh-in-motion (WIM) equipment and adoption of sampling plans should ensure adequate data collection. Adoption of improved pavement design and analysis procedures should ensure improved prediction of the effects of overloads.

* In addition to the use of weigh-in-motion, states should investigate the use of a heavy vehicle electronic license plate (HELP) system. Such a system is being demonstrated in Oregon and on a regional basis with the Crescent Project. Similarly, NCHRP project 3034 will evaluate the feasibility of a national system. Such systems offer substantial benefits to government, truckers, and manufacturers. In particular, these systems offer the solution to practical problems in implementing weight-mile fee structures for permits as well as for regular user charges.

* A comprehensive education program should be developed to better inform the various decision makers of the detrimental effect of overloaded trucks on the nation's highways.

* The states should evaluate appropriate methodology in the courts to enforce the law against those who actually control the loading operation of overweight vehicles and who profit from it, in addition to the driver. The approach using expert testimony (Texas) to show that every overloaded truck decreases the pavement's life could be used to prove that a given overloaded truck did a certain amount of damage to a given section of roadway. (*pp. 1-2*)

The following statement from the document is particularly appropriate to the situation with Texas 2060 permits, "Many states have very low permit fees that are not commensurate with the probable costs to their highways of overloaded vehicles. Equitable fee structures could be established by considering axle loads and distance traveled, and possibly tire pressure and tire load, because gross vehicle load is not the best indicator of damage" (*p. 59*).

Wyoming State Highway Department. *The Wyoming Weight Study*. WSHD, Cheyenne, Wy. 1988.

This study examines the effect of raising the allowable gross vehicle weight on the Wyoming interstate system from an 80,000 pound (356kN) maximum to a 117,000 pound

(520kN) maximum threshold by monitoring the trips of participants hauling in excess of 80,000 pounds (356kN) on the Wyoming interstate system.

The average vehicle weighed almost 104,000 pounds (463kN) and carried 67,000 pounds (298kN) of cargo weight. The standard 80,000 pound (356kN) vehicle carries 52,000 pounds (231kN) of cargo weight. Over the two years of the study, almost 26,000 fewer trips were made than if the same amount of freight would have been hauled on the interstate at the 80,000 pound (356kN) limitation. An estimated 670,000 gallons (2,536m^3) of fuel were saved over the study period. Additional savings on wear and tear of vehicles and equipment could be assumed but were not estimated. Apparently, the state lost revenue ($56,000) in the collection of the diesel fuel tax.

No relationship between the heavier loads and the potential damage to the road system were discussed. This report concludes that the ability to haul on the interstate at the same weights that are allowed on Wyoming's non-interstate highways and the interstate highways of its neighbors is essential to an efficient transportation system.

Many of the "estimates" the authors make in illustrating the success of the program seem subjective. Relevant to this study, possibly Texas would experience many of the same results found in Wyoming with increased tolerances. However, without looking at road damage because of the heavier loads, any benefit of such an action is unknown.

VEHICLE EFFECTS

Grau, R. W. and L. B. Della-Moretta. "Effects of Variable Tire Pressure on Road Surfacings." ***TRR 1291*** **(vol. 2), 1991. pp. 313-328.**

This study examined the effects of variable tire pressure on road surfacings. A test road was designed to determine the effect of tire pressure (deflection) on road surface deterioration and thickness design of low-volume roads. This road was approximately 0.7 mi (1.1 km) in circumference with parallel 12 ft (3.7m) wide traffic lanes. Pavement layers and construction are discussed.

Traffic was applied to the test road with two 18-wheel log trucks, including both loaded (80,000 lb, 356kN) and unloaded passes. One truck was operated at a typical highway tire inflation pressure of 100 psi (689kPa) in all tires, which resulted in tire deflections of about 7 and 10% when unloaded and loaded, respectively. The low-pressure truck operated at a constant tire deflection (21%), which required tire pressures of approximately 25 and 39 psi (172 and 269kPa) for the unloaded and loaded conditions, respectively.

Two major results were discussed. First, when failures occurred in both lanes of the same asphalt concrete section, the ratio of 39-psi (269kPa) tire pressure traffic to 100-psi (689kPa) tire pressure traffic ranged between 1.5 and 21. Clearly, failures and distresses in the high-pressure lane of the AC sections were more pronounced than those in the low-pressure lane. Also, considerable maintenance would be required on aggregate-surfaced grades receiving high-tire-pressure unloaded traffic because of severe washboarding.

Finally, the authors suggest that the installation of central tire inflation systems that allow a driver to adjust a vehicle's tire pressure while in motion will be cost-effective for heavy trucks traveling on low-volume, low-speed roads. This article points out the problem of operating a heavy truck with a high tire pressure. One remedy for this problem is to lower the tire pressure to ensure that minimal damage is experienced.

Greenfield, P. H. and A. E. Cohn. "Effects of Variable Tire Pressure on Tire Life." ***TRR 1291*** **(vol. 2), 1991. pp. 346-352.**

This study is concerned with the question of what effects reduced tire pressure will have on tire performance. Testing of reduced pressure effects on tires covers two general categories, tire tread wear (the effects of reduced tire pressure on rate of tread loss) and tire carcass life (the effects of reduced tire pressure on the structural performance of the tire).

Results indicate that the larger ground contact area of reduced tire pressure operation, in an off-highway condition, is not detrimental to tire wear, and may be beneficial to tire wear on rough roads where energy is wasted because of a vehicle's bounce or hop. Also, results indicate no detrimental effects on tire carcass life; however, Greenfield and Cohn deem it too early to make conclusive statements on the basis of the tests presented in this article.

This article further supports an implementation of the CTI for heavy vehicles. It also helps to illustrate that the CTI system does not cause significantly more damage to the tire, thus increasing the benefit of employing a CTI system.

Hajek, J. J. and A. C. Agarwal. "Influence of Axle Group Spacing on Pavement Damage," ***Design and Evaluation of Rigid and Flexible Pavements.*** **TRR 1286, 1990. pp. 138-149.**

The report examines the significance of axle spacing from a pavement damage perspective. The AASHTO Pavement Design Guide appears to underestimate the damaging effect of dual and triple axles in relation to single axles. The AASHTO Guide also distinguishes between the damaging effects of dual and triple axle combinations, but disregards axle spacing within the combination. The report goes on the expose AASHTO's disregard for the significance of axle spacing and suggests that axle spacing should be considered for determining permissible load limits of dual and triple axle units. The report suggests that, within the practical range of axle spacing, pavement damage can be significantly reduced by increasing axle spacing.

Powell, B. and B. Brunette. "Reduced Tire Inflation Pressure--A Solution for Marginal-Quality Road Construction Rock in Southeast Alaska." ***TRR 1291*** **(vol. 2), 1991. pp. 329-334.**

In some areas of Alaska, only poor- to marginal-quality rock materials are available for road construction, thus leaving the road surface too weak to support truck haul. The road surface tends to rut and the rock continually breaks down after heavy repeated wheel loads, and when combined with wet conditions, reduces the gravel to fine silt and clay-sized particles that do not support construction vehicles.

The solution proposed in this study is to use radial tires with lowered tire pressures (25 psi, 172kPa). Deep rutting was virtually eliminated with the reduced tire pressure. The low-pressure radial tires acted similarly to pneumatic rollers and compacted the road surface, rather than producing deep agitation of the road base. This result has produced large savings for the state and is expected to provide future contract savings for road building and logging activities.

This article follows the Grau and Della-Moretta article nicely. It shows that having the proper tire and a lower tire pressure could inflict less damage to roads and result in considerable savings for the state.

Simonson, R. "Effects of Tire Deflection on Rear-Axle Torque." ***TRR 1291*** **(vol. 2), 1991. pp. 335-341.**

Simonson discusses the advantages of incorporating a central tire inflation (CTI) system that permits the vehicle tire pressures to be regulated by the vehicle driver from within the vehicle cab while on the move.

Steep topography and escalating road construction costs have led to the use of steeper roads. A steeper road reduces the length of construction necessary to reach higher elevations. However, traction for heavy trucks traveling along these steeper roads is a problem. Many times, a cost allowance for an assist vehicle to help these trucks up the steep grade is required.

Simonson concludes that using the proper tire deflection for the application (based on speed and load) appears feasible through the use of the CTI system. Benefits have been seen in reduced vehicular damage to forest roads and increased tire life. An additional benefit realized with the use of CTI is improved traction on some road surface types because of the increased tire tread length.

Relevant to this study, Simonson's article supports the recommendation by Grau and Della-Moretta that a system allowing the driver of a truck to change the tire pressure while operating the vehicle would be cost effective and would not cause any real damage to the vehicle or tire.

Sousa, J. B., McGhie J. and B. Shepard. "Heavily Loaded Trailers: An Approach to Evaluate Their Interaction with Asphalt Concrete Pavements." ***Design and Evaluation of Rigid and Flexible Pavements.*** **TRR 1286, 1990. pp. 95-111.**

The purpose of the study was to compare the relative behavior of the JXS super-heavy haul trailer, equipped with an hydraulic cylinder-nitrogen suspension, with that of four currently used semitrailer types. Results suggest that, from a dynamic point of view, the effect of suspension type is more significant than the number of axles. Leaf spring suspensions were compared to air bag suspensions, while tandem trailers were compared to tridem trailers. Leaf spring suspensions have the poorest static load distribution characteristics.

A dynamic load ratio of 0.30 was observed at low frequency with three types of suspensions: leaf spring, air bag tandem, and tridem. This value implies that the loads transmitted to the pavement could be as high as 130% static load or as low as 70% of the static load. In a computer simulation, the best JXS system was slightly better than tridem trailers in terms of the weight transported over the pavement life. However, they carried more for fewer passes before failure, indicating that pavement life was reduced.

Watkins, G. "Truck Operation at Constant Reduced Tire Pressure." ***TRR 1291*** **(vol. 2), 1991. pp. 342-345.**

This study, which employs the notion of constant reduced tire pressure, is an outgrowth of CTI studies that vary tire pressure to suit the load, road surface, and speed of the vehicle. Watkins suggests that it might be easier and more cost efficient for trucks to operate at a constant speed and tire pressure rather than have to change tire pressure.

In this case study, trucks operated at 65 psi (448 kPa), the lowest allowable pressure considering the maximum load and speed the vehicle will encounter during its operation.

Maximum speed was restricted to 55 mph (89 kph).

Watkins found that operating at constant reduced tire pressure can accomplish many of the benefits obtained with CTI systems, but without the need for expensive hardware. Benefits included reduced road damage to roads with weak structural sections and improvements in ride quality and traction.

No detrimental effects were observed in the tire casings, nor was there an increase in fuel consumption. However, trucks must be equipped with radial tires and there is a limit to the trip length at highway speeds.

This study offers another suitable option (besides CTI) for helping to reduce the amount of damage to roadways caused by heavy vehicles. This alternative is cheaper than the CTI approach. Also, the importance of having radial tires is expressed again.

SPRAYED SEAL COATS

Pidwerbesky, B. D. and J. S. Pollard. "Design and Performance of Sprayed Seal Coats for Unbound Granular Pavements Carrying Heavy Logging Trucks." *TRR 1291* (vol. 2), 1991. pp. 66-71.

Sprayed seal coat methods were examined on an arterial forestry road carrying heavily-loaded logging trucks. The functions of the seal coat are to provide an impermeable membrane over the base course and a skid-resistant surface, as well as a wearing surface.

The New Zealand seal coat design algorithm relating the bitumen application rate to the size of the stone chip, the ratio of the chip's average, least, and greatest dimensions, and the residual void space within the single-layer thickness of the aggregate cover are discussed.

Factors affecting sprayed seal coats are discussed. In addition to material properties and environmental factors, seal coats are dependent on operator skills and equipment precision. However, errors in bitumen application arising from incorrect design or any of the other factors tend to negate each other.

One serious trend that developed in the 1970s was an increase in the occurrence of flushing pavements under increasing traffic volumes. The main causes for this flushing were incorrect bar heights and worn, misaligned slot jets.

The case study presented in this article showed that less than 2 months after the second seal coat had been applied, bitumen in the wheel paths of the loaded lane had flushed to the extent that free bitumen was present on the surface. Also, the lane carrying unloaded vehicles was flushing but only to a minor degree. Subsequent investigation found that the flushing was primarily caused by a seal coat that was inappropriate for such unusually high loads. A seal coat design for low-volume roads under heavy axle loads is discussed.

APPENDIX C - DATA ANALYSIS

SURVEYS

Telephone surveys concerning overweight policies in other states were conducted. Surveys of county, state, and trucking industry officials were done by mail. The forms used to conduct the survey are illustrated at the end of each subsection below. Note that many of the questions do not require mutually exclusive answers, so there may be isolated cases in which there appears to be over 100% response, but this is merely an artifact of choosing all responses that apply in response to a particular question. Therefore, formal statistical analyses (analysis of variance) were conducted only on pairs of treatments which were of particular interest and which had a reasonable chance of being independent groups of data.

National Survey

A telephone survey of states was conducted. The results are presented in Table C.1 (abbreviations are defined at the end of the table).

Table C-1 Summary of telephone survey of states.

STATE	OVERWT. PERMITS < 90,000 LBS?	WHO RECEIVES FUNDS?	HOW USE FUNDS?	DAMAGE ASSESS?	OVERWT. PERMIT STUDIES?
Alabama	Y	GS	S	V	Y
Alaska	Y	GS	S	NA	Y
Arizona	Y	GH	H	NA	Y
Arkansas	Y	GH	H	NA	N
California	Y	GH	H	V	N
Colorado	N	GH	H	NA	N
Connecticut	Y	DOT	H	NA	N
Delaware	Y	GS	S	NA	N
Florida	Y	DOT	H	V	Y
Georgia	Y	DOT	M	NA	Y
Hawaii	N	GS	S	NA	N
Idaho	Y	DOT	S	NA	Y

STATE	OVERWT. PERMITS < 90,000 LBS?	WHO RECEIVES FUNDS?	HOW USE FUNDS?	DAMAGE ASSESS?	OVERWT. PERMIT STUDIES?
Illinois	Y	GH	H	V	I
Indiana	Y	GH	H	NA	I
Iowa	Y	GH	H	NA	N
Kansas	Y	GH	H	V	I
Kentucky	Y	GS	H	NA	N
Louisiana	Y	GH	H	NA	N
Maine	N	GH	M	V	N
Maryland	Y	DOT	M	NA	Y
Massachusetts	N	GS	S	NA	N
Michigan	Y	GS	S	V	Y
Minnesota	Y	GS	S	NA	N
Mississippi	Y	DOT	H	NA	N
Missouri	Y	GH	H	V	N
Montana	Y	GH	H	V	N
Nebraska	Y	GH	H	NA	N
Nevada	N	GH	H	NA	N
New Hampshire	N	GS	H	V	N
New Jersey	Y	GH	M	V	I
New Mexico	Y	GH	H	NA	N
New York	Y	GH	P	NA	Y
North Carolina	Y	GS	H	NA	N
North Dakota	Y	GH	H	V	N
Ohio	Y	DOT	M	NA	Y
Oklahoma	Y	GH	S	NA	N
Oregon	Y	GS	H	NA	N
Pennsylvania	Y	DOT	M	NA	Y
Rhode Island	Y	GS	S	V	N
South Carolina	Y	GS	H	NA	N
South Dakota	Y	GH	M	V	N

STATE	OVERWT. PERMITS < 90,000 LBS?	WHO RECEIVES FUNDS?	HOW USE FUNDS?	DAMAGE ASSESS?	OVERWT. PERMIT STUDIES?
Tennessee	Y	GH	S	NA	N
Utah	N	GS	S	V	N
Vermont	N	GS	S	NA	N
Virginia	N	GS	S	NA	N
Washington	Y	GS	S	NA	I
West Virginia	Y	GH	H	V	N
Wisconsin	Y	GS	S	NA	N
Wyoming	Y	GS	S	NA	N
	Y=YES N=NO	GS=GEN. STATE GH=GEN. HIGHWAY DOT=DEPT. OF TRANSPORTATION	S=STATE USE H=HIGHWAY M=MAINT. P=POLICE	NA=NO ATTEMPT MADE V=VISUAL INSPECTION	I=INTERNAL REPORTS

State and County Survey

Survey forms were sent to 24 TxDOT Districts in the State. An extremely high response rate of 92% was achieved at the State level. Of the Districts responding to the questionnaire, 18% knew how the permit fee was to be distributed, 73% had observed damage by vehicles holding 2060 permits, and 36% had photographic evidence of the damage. Approximately 64% of the respondents said that the fee receipts were not adequate for administration, enforcement, and maintenance. Twenty-three percent of respondents did not know which vehicles or operators caused damage. Only one District claimed to have such knowledge through the use of an aggressive enforcement program. The majority (59%) of the Districts knew which vehicles/operators were responsible for damage based on general knowledge of economic/industrial activity in the area, a source of information which would undoubtedly prove to be virtually useless in recovering damages. Evidence of damage was provided by photographs in 23% of the Districts, and by maintenance records in 27% of the Districts. The Districts were asked to rank the damage by source with 1 being severe damage and 10 being very little damage. These rankings were then reversed for clearer graphical presentation by taking the inverse of the rank and multiplying by 100, so that 100 would be very damaging and 10 would indicate very little damage in the following analysis.

It is interesting to compare the damage assessment from agricultural vehicles with that from the energy related industry in Figure C-1 (where *n* is the number of responses). Although the survey form was intended to rank damage from vehicles operating with, or exempt from the 2060 permit, respondents may have interpreted it as applying to any damage by any vehicle. In the latter case, the lower damage from the agricultural sector may be a simple reflection of lower loads or fewer vehicles. However, there is an alternative explanation. Agricultural vehicles are typically designed to have low earth contact pressures because their intended use often involves operation in soft soils. For this reason, an agricultural vehicle may have the same gross weight as an oil field truck, but the weight may be distributed over a larger area by relatively large, low pressure tires. A significant portion of the damage associated with construction of an oil well is associated with pad and road construction which usually requires hauling aggregate in multiple trucks at relatively high speeds. In general, the higher speeds and distances traveled dictate a different tire design for the aggregate hauling truck; this usually involves higher inflation pressures. In Table C-2, an analysis of variance is documented which shows that the damage reported for agricultural related traffic is significantly less than that attributed to energy (primarily oil) related transportation.

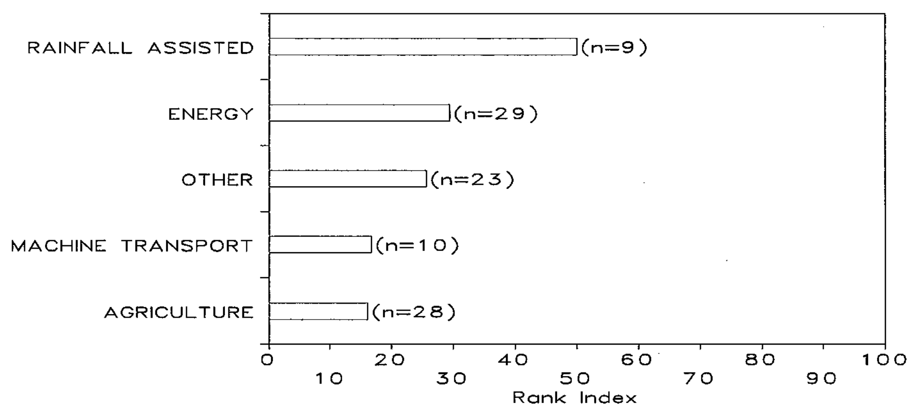


Figure C-1. Ranking of damage by activity (TxDOT Districts).

Survey forms were sent to 254 counties in the State. A response rate of 25% was achieved at the County level. Of the counties responding to the questionnaire, 22% knew how the permit fee was to be distributed, 63% had observed damage by vehicles holding 2060 permits, and 21% had photographic evidence of the damage. Approximately 68% of the respondents said that the fee receipts were not adequate for administration, enforcement, and maintenance. Twenty-nine percent of respondents did not know which vehicles or operators caused damage. Seven counties claimed to have such knowledge through the use of an aggressive enforcement program. Many (48%) of the counties knew which vehicles/operators were responsible for damage based on general knowledge of economic/industrial activity in the area. Evidence of damage was provided by photographs in 13% of the counties, and by maintenance records in 13% as well. The results of this survey are presented in Figure C-2 and Table C-3; they obviously match quite well the State experience shown previously.

Table C-2. Analysis of variance for TxDOT survey.

ONE-WAY ANALYSIS OF VARIANCE

Data: Rank index

Level codes: Activity

Means plot: LSD   Confidence level: 95   Range test: LSD

Analysis of variance

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
Between groups	6329.233	1	6329.2335	7.818	0.0071
Within groups	44527.970	55	809.5995		
Total (corrected)	50857.204	56			

MULTIPLE RANGE ANALYSIS

Method: 95 Percent LSD

Level	Count	Average	Homogeneous Groups
Ag	28	25.793651	X
Oil	29	46.871921	X

TABLE OF MEANS

Level	Count	Average	Stnd. Error (internal)	Stnd. Error (pooled s)	95 % LSD intervals for mean	
Oil	29	46.871921	6.0086912	5.2836751	39.382860	54.360983
Ag	28	25.793651	4.4856062	5.3771987	18.172029	33.415272
Total	57	36.517683	3.7687530	3.7687530	31.175866	41.859500

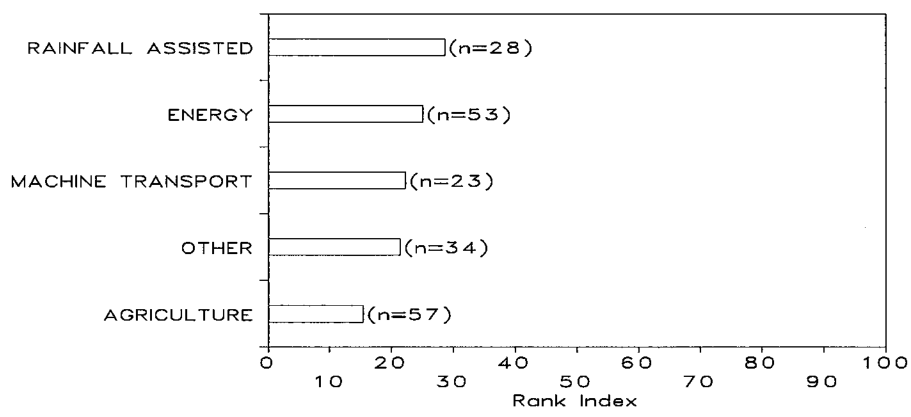


Figure C-2. Ranking of damage by activity (Counties).

Table C-3. Analysis of variance for county survey.

ONE-WAY ANALYSIS OF VARIANCE

Data: Rank index

Level codes: Activity

Means plot: LSD   Confidence level: 95   Range test: LSD

Analysis of variance

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
Between groups	18644.64	1	18644.643	15.365	0.0002
Within groups	131056.48	108	1213.486		
Total (corrected)	149701.13	109			

MULTIPLE RANGE ANALYSIS

Method: 95 Percent LSD

Level	Count	Average	Homogeneous Groups
Ag	57	28.111250	X
Oil	53	54.166667	X

TABLE OF MEANS

Level	Count	Average	Stnd. Error (internal)	Stnd. Error (pooled s)	95 % LSD intervals for mean	
Oil	53	54.166667	5.3756917	4.7849725	47.458508	60.874825
Ag	57	28.111250	4.0133482	4.6140251	21.642747	34.579754
Total	110	40.665224	3.3213989	3.3213989	36.008881	45.321566

TxDot Research Project 1323 Survey Form
EVALUATION OF THE WEIGHT TOLERANCE PERMITS AUTHORIZED IN HOUSE BILL 2060

In 1989, the Texas legislature authorized the issuance of annual permits allowing commercial motor vehicle operators to operate nonagricultural vehicles exceeding the legislative mandated axle weight by 10 percent and the allowable gross vehicle weight by 5 percent. The $75 permit (and $15,000 bond) allows operation on state and county roads except the interstate system. The interpretation has been that this effectively allows 84,000 lb vehicles on roads designed for 58,420 lb vehicles. The legislation allows even heavier loads for transporters of 'agricultural products in their natural state'. The movement of goods on our surface transportation infrastructure is an important factor in the economic health of the state and truck shipping productivity is a key element in this movement. There is often a trade-off between vehicle weight management policies and pavement management policies in the maximization of productivity. The purpose of this survey is to assist researchers in assessing the potential impact of this legislation on safety, economics, and infrastructure maintenance.

Please complete this form, fax or fold and mail to TTI by 30 July 1993 if possible. If you have questions concerning the survey, contact Bill Crockford at (409) 845-7511 or Fax 845-0278 (TEXAN exchange is 857). Thank you for participating in the survey.

Date: ____________________

Person Completing Form: ____________________

District or County: ____________________

Telephone/Fax: ( ) ____________________ ( ) ____________________

1. *Legislation*:

Do you know how the permit fee receipts are distributed? Y / N

If yes, and you disagree with the formula, please describe a better approach: ____________________

____

2. *Experience*:

Is your portion of the permit fee receipt adequate for administration, enforcement, and maintenance? Y / N

Have you observed pavement or bridge damage from vehicles operating with these permits? Y / N Do you have photographs of the damage? Y / N

How do you know which vehicles/operators caused the damage?
(a) don't know, (b) aggressive enforcement program, (c) general knowledge of economic/industrial activity, (d) photographic evidence, (e) maintenance records, or (f) other (explain) ____________________

____

If damage has been observed, rate the source (1=severe damage, 10=little to no damage, enter an 'X' if you have not observed in your jurisdiction):

(_) Oil field construction
(_) Agricultural (crops)
(_) Agricultural (timber)
(_) Other construction
(_) Other nonagricultural
(_) Other (specify) ________
(_) Oil field production
(_) Agricultural (livestock)
(_) Other energy (e.g. lignite)
(_) Machinery & vehicle transport
(_) Heavy vehicles coupled with higher than normal rainfall

Trucking Industry Survey

Survey forms were sent to 30 trucking firms holding 2060 permits in the State. A response rate of 30% was achieved. The 9 firms responding to the questionnaire transported goods a total of 16,809,521 miles (27,052,301km) within the State boundaries. Of the total mileage, 53% was off-interstate transport. Only one of the firms had ever had its bond collected by a government entity in a legal proceeding concerning road or bridge damage. In terms of the cost of the permit, 44% of the respondents said the permit was too expensive, 22% said the bond was too expensive, and only one company said the permit was too much trouble to get. Due to the combined effects of added income from additional freight and the savings made possible by the reduction in the number of trips necessary to haul a given amount of freight, the respondents realized additional revenue amounting to an average of 22% of annual gross receipts. The added revenue ranged from 0-50% of gross receipts. The only firm listing no revenue improvement operated 100% of its off-interstate vehicles at weights heavier than 58,420lb (260kN). Two plausible explanations for this situation are: (a) the operation is so large that the 2060 permit generates almost nothing compared to the firm's other sources of income, or (b) the company operated illegally or under some form of exemption for all the years prior to the legislation. Sixty-seven percent of the firms said they pass 100% of the savings along to the end-use consumer. However, the principal investigator of this study knows of at least one case in which the operator passed the full $75.00 permit fee on to the consumer as an itemized addition to the shipping fee. Operators have the potential to make significant profits by purchasing *one* permit and passing the entire cost of the permit on to *every* customer served by that vehicle.

The off-interstate mileage reported by the respondents is broken down by vehicle weight and illustrated in Figure C-3. The major portion of the mileage comprises loads that would involve 2060 permits. Figure C-4 illustrates a very important point concerning the redistribution of permit receipts. This figure depicts a histogram describing a distribution that might be termed 'bimodal'. Most of the companies actually operate their vehicles in less than 5% of the counties for which they are permitted. Another group of companies operates in 100% of the counties for which it is permitted. Most of the operations take place in a relatively small number of counties, yet *all* of the counties share in the fee receipts.

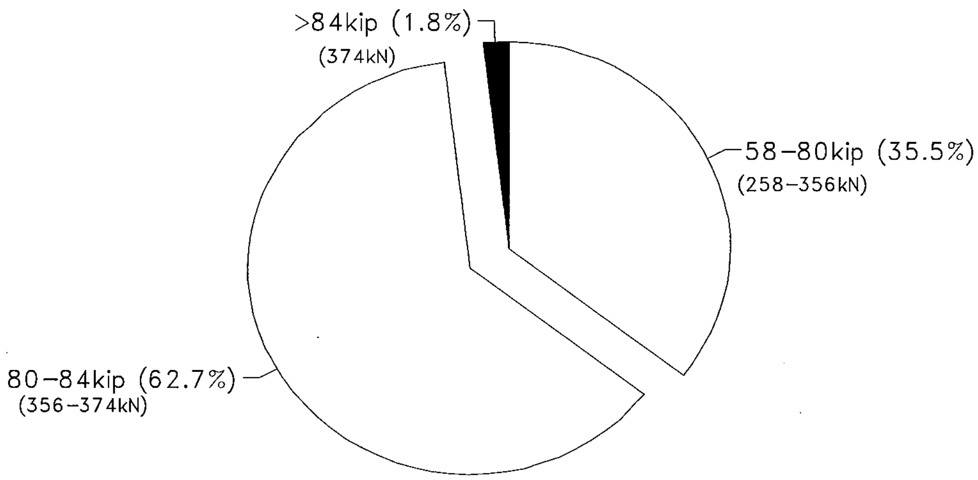


Figure C-3. Breakdown of mileage by vehicle weight.

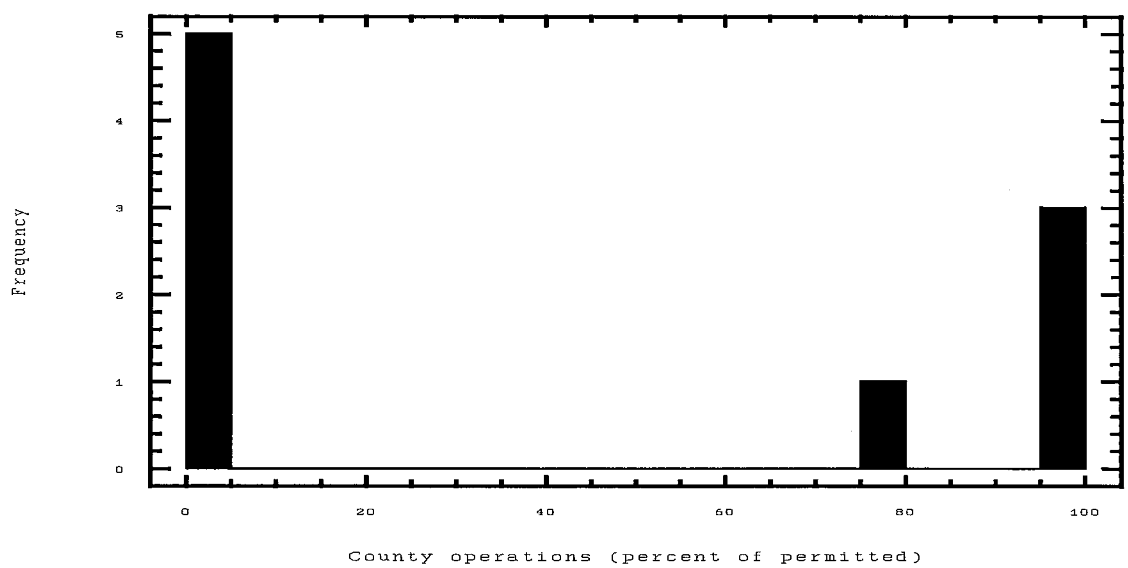


Figure C-4. Percent of permitted counties within which operations actually take place.

TxDOT Research Project 1323 Survey Form
EVALUATION OF THE WEIGHT TOLERANCE PERMITS AUTHORIZED IN HOUSE BILL 2060

In 1989, the Texas legislature authorized the issuance of annual permits allowing commercial motor vehicle operators to operate nonagricultural vehicles exceeding the legislative mandated axle weight by 10 percent and the allowable gross vehicle weight by 5 percent. The $75 permit (and $15,000 bond) allows operation on state and county roads except the interstate system. The interpretation has been that this effectively allows 84,000 lb vehicles on roads designed for 58,420 lb vehicles. The legislation allows even heavier loads for transporters of 'agricultural products in their natural state. The movement of goods on our surface transportation infrastructure is an important factor in the economic health of the state and truck shipping productivity is a key element in this movement. There is often a trade-off between vehicle weight management policies and pavement management policies in the maximization of productivity. The purpose of this survey is to assist researchers in assessing the potential impact of this legislation on safety, economics, and infrastructure maintenance.

Please complete this form, fax or fold and mail to TTI (postage is already on it) by 15 September 1993 if possible. If you have questions concerning the survey, contact Bill Crockford at (409) 845-7511 or Fax 845-0278. If you are not familiar with 2060 permits, so state and return the form anyway. There is room for further comments on the reverse side of the form. Thank you for participating in the survey.

Date: ______________________________

Person Completing Form (optional): ______________________________

Company (optional): ______________________________

Telephone/Fax (optional): (   ) ______________ (   ) ______________

Do you consider your company business to be primarily related to (circle one):
oil field / construction / agriculture / other __________ production?

Estimate the average number of miles per year that you transport goods within the boundaries of the State of Texas ____________ mi. Estimate the percentage of those miles that are off-interstate ___ %. What percentage of the off-interstate mileage is traveled between: 58,420 and 80,000 pounds ______ %? 80,000-84,000 lb ______________ %? Over 84,000 lb _________ %?

Do you have at least one 2060 permit? Y / N If yes, estimate the number of counties within which you actually operate under the permit as a percentage of the total number of counties for which you are permitted (*e.g.* permitted for 254 counties, but operating mostly in 2 counties is (2÷254)X100 = 0.79%) _______ %. Has your bond ever been collected by a government entity in a legal proceeding concerning road or bridge damage? Y / N

Is the permit too expensive? Y / N Is the bond too expensive? Y / N Is the permit too much trouble to get? Y / N

How much additional revenue do you realize by increasing the weight from 58,420 to 84,000 lb (the combined total of the added income from the additional freight and the reduction in the number of trips necessary to haul a given amount of freight)? ___________ % of gross receipts per year. What percent of this additional revenue is passed along as reduced pricing to end-use consumers? _________ %.

FIELD EXPERIMENT

An experiment was conducted on two county roads, one state highway, and one county bridge to try to assess damage based on a relatively small number of passes of the test vehicles. Two vehicles were used, a TTI dump truck, and a Brazos County 18 wheeler with a flatbed construction equipment hauling trailer. The intention was to use the dump truck to simulate an 18kip (80kN) single axle load. Aggregate was used to load this truck and the rear axle was not as close to 18kip (80kN) as was desired. The tractor-trailer vehicle was used to simulate 58.42kip (260kN), 80kip (356kN), and 84kip (374)kN vehicles, not in terms of gross weight, but in terms of the load on the rear tandem axle set. The weights were attained very accurately by moving concrete beams from one position to another on the flatbed. Four tests were conducted during the year to try to ascertain if there were any environmental effects that would influence the results. Each test required two days to complete. Only one bridge test was performed.

Pavement Structures

The pavement structures are described in Table C-4.

Table C-4. Pavement structures.

ROAD	LAYER	DESCRIPTION
Elmo Weedon	Surface	2 course surface treatment
	Base	8in (20cm) crushed limestone
	Subbase/grade	6in (15cm) stabilized subgrade
Hardy Weedon	Surface	1 course surface treatment
	Base	8in (20cm) crushed limestone
	Subbase/grade	6in (15cm) processed road gravel
SH-30	Surface	2in (5cm) hot mix asphalt over surface treatment
	Base	12in (30cm) flexible base material
	Subbase/grade	8in (20cm) stabilized subgrade

The bridge was approximately 42ft (12.8m) span, by 16.5ft (5m) wide. Eight W24X68 steel stringers supported the span and they rested on a transverse beam on each end of the span. The transverse beams rested on 13in (33cm) diameter pilings. These pilings did not appear to be tied back into the approach embankment through the wooden retaining wall. Most of the wooden beam components appeared to be approximately 3x8in (8x20cm), probably treated oak.

Instrumentation

Multi-depth deflectometers (MDDs) were used for in-pavement instrumentation. A single depth (SDD) variation of the MDD was developed and used on Elmo Weedon road and at Hardy Weedon road in conjunction with a standard MDD at that location. The MDD system is basically a string of displacement measuring devices buried in the pavement system with the displacement being measured with respect to an anchor rod installed relatively deep in the pavement (82in, 2.1m in this case). The newly developed variation on the MDD does not incorporate an anchor and measures deflection between two points which is easily converted to strain in the layer.

Other devices used in the testing included the dynamic cone penetrometer (DCP), falling weight deflectometer (FWD), profilometer, and ARAN. A small laser was used to measure bridge movement by projection of the laser dot (from a remote location) on targets that had been placed on one piling and at the center of the bridge. The position of the dot was marked on the targets before the vehicle was put on the bridge, then the vehicle was parked on the bridge and the new position of the dot caused by movement of the target with the deflection of the bridge was marked.

Truck Characteristics

Table C-5 and Figure C-5 illustrate some of the basic characteristics of the trucks used for loading the pavements. The weights for each axle set are given in the documentation of the test by month in subsequent subsections of this appendix.

Table C-5. Truck tire and axle characteristics.

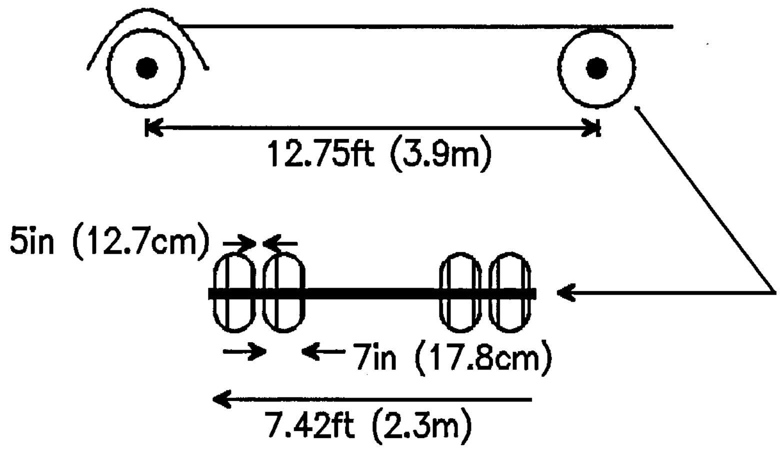
TRUCK	AXLE	TIRE DATA
Dump	Steering: single axle, single wheel	Ceat Super Highway I, 9.00-20, maximum 80psi (552kPa) inflation
	Drive: single axle, dual wheel	Cooper Roadmaster, 9.00-20, maximum 80psi (552kPa) inflation
18 wheel	Steering: single axle, single wheel	Goodyear Unisteel II, 10.00R20, maximum 105psi (724kPa) inflation
	Drive: tandem axle, dual wheel	Goodyear Unisteel II & G167A, 10.00R20, maximum 105psi (724kPa) inflation
	Trailer: tandem axle, dual wheel	Goodyear G114, 8.25R15TR, maximum 105psi (724kPa) inflation

December Test

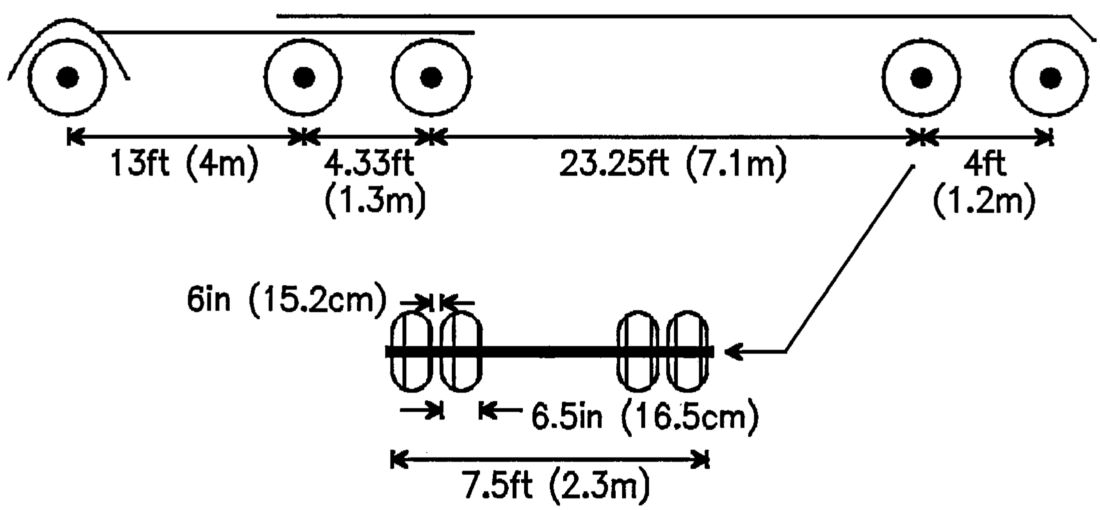
In the December test, an 18-wheel vehicle was not available. Therefore, only the dump truck was used in this test. Unfortunately, the limestone load was lighter than desired. A rear axle load of 18kip (80kN) was requested, but the total gross vehicle weight was only 18.34kip (81.6kN). Table C-6 illustrates the weight distribution in the truck.

Table C-6. Axle loads for December test.

TRUCK	TIRE PRESSURE PSI(kPa)	STEERING AXLE LOAD LB(kN)	DRIVE AXLE LOAD LB(kN)	TRAILER AXLE SET LB(kN)
2 Dec 92 Dump truck	80(552)	6,580(29)	11,760(52)	N/A



Dump Truck



18 Wheeler

Figure C-5. Dimensions of truck tire and axle spacing.

February Test

Starting in February, both the dump truck and the 18 wheeler were available. The loads for both vehicles were very close to the desired weights, with the dump truck being slightly over the desired load. The target values for the trailer axle set were 24,830 lb (110kN) to simulate the 58,420lb (260kN) truck, 34,000 lb (151kN) to simulate the 80,000lb (356kN) truck, and 37,400 lb (166kN) to simulate the 84,000lb (374kN) vehicle with a 2060 permit. The actual weights are shown in Table C-7.

Table C-7. Axle loads for February test.

TRUCK	TIRE PRESSURE PSI(kPa)	STEERING AXLE LOAD LB(kN)	DRIVE AXLE LOAD LB(kN)	TRAILER AXLE SET LB(kN)
17 Feb 93 Dump truck 18 wheeler	80(552) 85(586)	7,240(32) 9,520(42) 9,800(44)	20,880(93) 19,500(87) 20,060(89)	N/A 23,740(106) 34,020(151)
18 Feb 93 18 wheeler	85(586)	9,820(44)	16,740(74)	37,960(169)

May Test

Actual truck weights are given in Table C-8 for the test in May.

Table C-8. Axle loads for May test.

TRUCK	TIRE PRESSURE PSI(kPa)	STEERING AXLE LOAD LB(kN)	DRIVE AXLE LOAD LB(kN)	TRAILER AXLE SET LB(kN)
25 May 93 Dump truck 18 wheeler	85(586) 105(724)	6,940(31) 9,860(44)	19,660(87) 17,760(79)	N/A 24,840(110)
26 May 93 18 wheeler	105(724)	9,740(43) 9,820(44)	19,200(85) 16,480(73)	34,800(155) 37,380(166)

August Test

Actual truck weights are given in Table C-9 for the test in August.

Table C-9. Axle loads for August test.

TRUCK	TIRE PRESSURE PSI(kPa)	STEERING AXLE LOAD LB(kN)	DRIVE AXLE LOAD LB(kN)	TRAILER AXLE SET LB(kN)
17 Aug 93 Dump truck 18 wheeler	87(600) 105(724)	7,760(35) 10,080(45)	21,180(94) 17,480(78)	N/A 25,110(112)
18 Aug 93 18 wheeler	105(724)	9,660(43) 9,460(42)	19,040(85) 16,040(71)	34,700(154) 37,900(169)

Field Test Summary

The experiment was designed so that combined environmental and loading effects might be evaluated. Theory and experience suggest that moisture condition plays an important role in the damage process due to changes in a property called suction which is related to capillary phenomena. This was confirmed in the survey portion of the study by the top ranking of rainfall assisted damage. The rainfall was not particularly abnormal during this study; and temperatures were not particularly extreme; so, differences due to environmental factors were not as great as they would have been in recent years past. The rainfall situation for the year is illustrated in Figure C-6. The stairstep nature of the graph plot is a product of the way the data is plotted to magnify the scale for the two weeks immediately prior to each test. Almost no rain fell during the period immediately before the August test. May seemed to be the month with the most noticeable rainfall close to the starting date of the test. The moisture condition can affect the pavement stiffness at both ends of the spectrum. If the material is too wet, soft soil problems will occur. Many materials become stiffer as they dry out, but at the same time they may crack and eventually degrade into a weaker condition.

The stiffness of the pavement layers is often characterized through back-calculation methods with an FWD. The results of the back-calculation process for the subbase layers in the pavements are illustrated in Figures C-7 - C-9. These computations are produced from several drops at each site, with the drop causing approximately 10,000lb (44kN) load being used for the back-calculation.

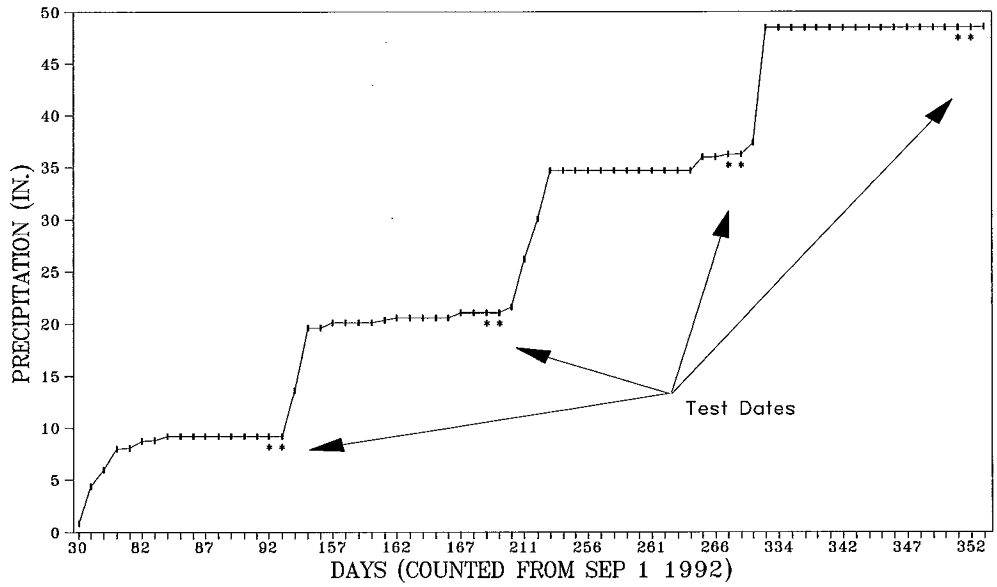


Figure C-6. Rainfall history for the period of the experiment.

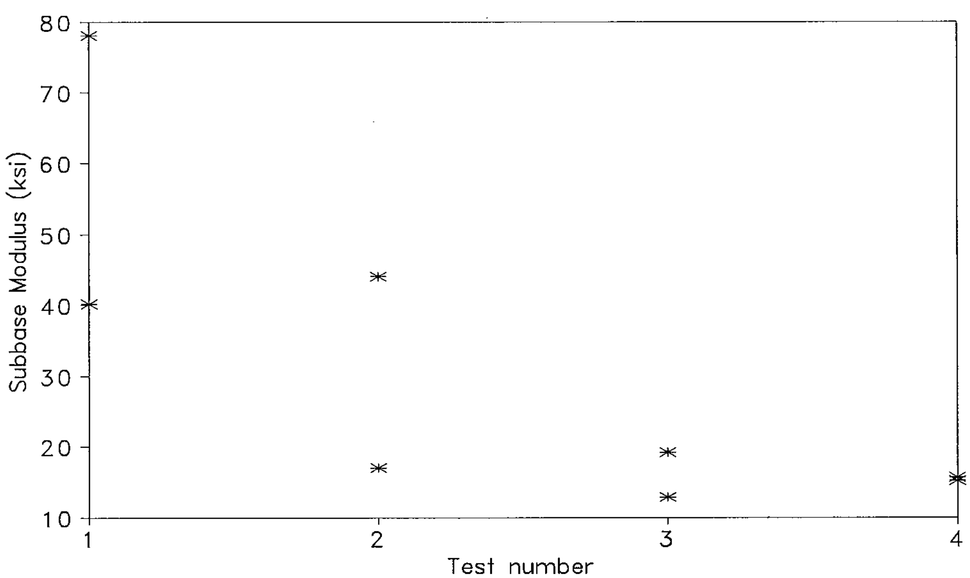


Figure C-7. Modulus of subbase layer computed from FWD at Elmo Weedon road.

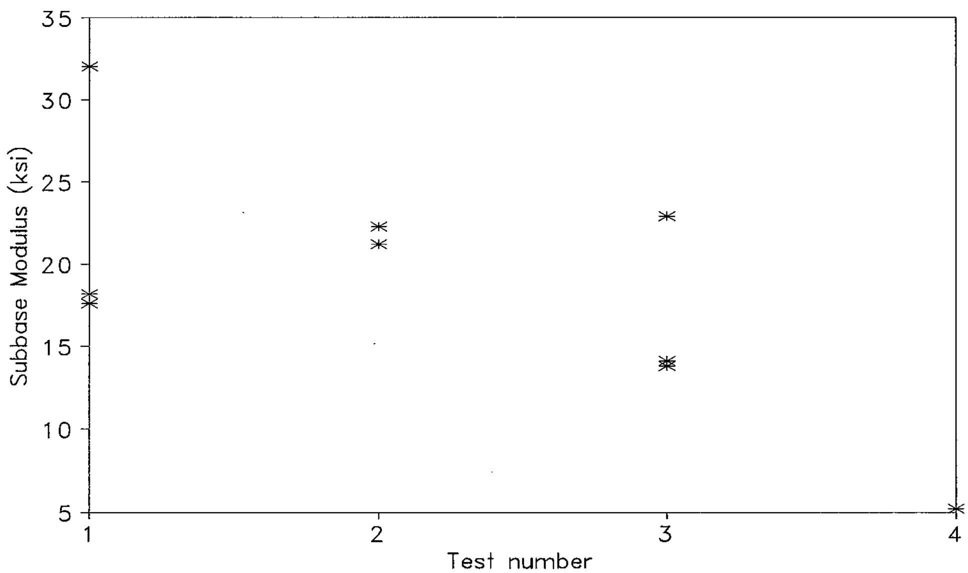


Figure C-8. Subbase modulus at Hardy Weedon road.

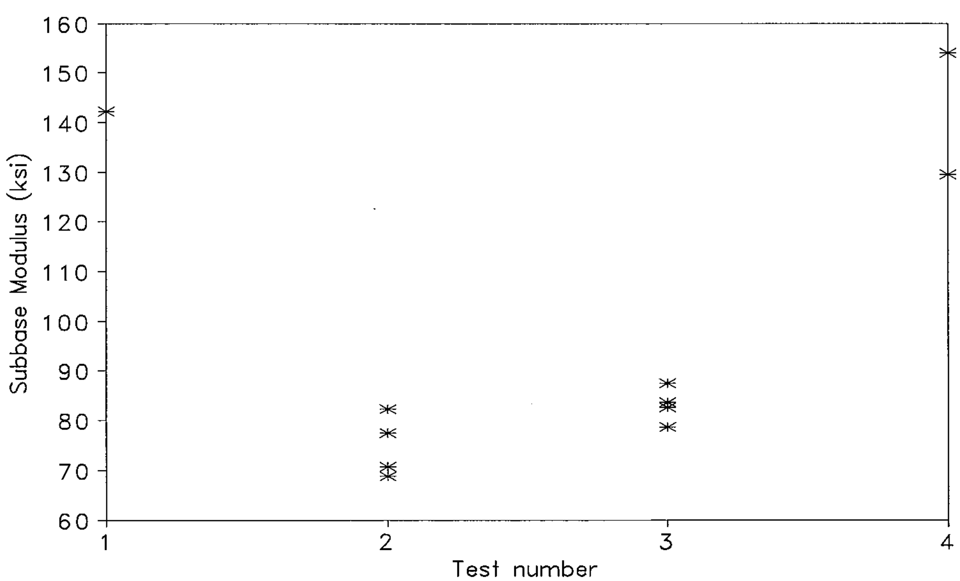


Figure C-9. Subbase modulus for State Highway 30.

One of the difficulties with many of the soils in eastern Texas is that they are expansive. This is a manifestation of moisture uptake in the pavement system. During the course of this study, periodic readings of the MDD sensors were taken. Increasing negative values for these readings indicate one of three possibilities: (1) upward movement of the sensor body with respect to the anchor, indicating swelling of the layer of interest with moisture increase, (2) shortening of the sensor core rod due to temperature decreases, or (3) instrumentation drift. Option (1) seems to be the most plausible explanation. Figures C-10 - C-12 illustrate the movement of the sensors over the period of the project. The date code on the plots is a computer generated date for which 34,114 corresponds to 25 May 1993 and 34,198 corresponds to 17 August 1993. Note that the movements of the sensors at Elmo Weedon, SH 30, and at the SDD sensors at Hardy Weedon are relatively small at approximately 0.03-0.05in (0.8-1.3mm). This is because these sensors are located in layers that are less susceptible to moisture variation. The SDDs at Elmo and Hardy were located between 3.5 and about 14.5 inches (8.9-36.9cm) below the surface of the pavement. As shown in the earlier table on pavement structures, this puts the measurement area through layers of reasonably moisture insensitive material (limestone, gravel, and stabilized soil). The sensors on SH 30 were placed 3.5, 14, and 22 inches (8.9, 36, and 56cm) below the surface. Therefore, these sensors are located in reasonably good quality base and stabilized materials in a pavement system that should be more resistant to moisture variations. The interesting plot is that of the MDD sensors at Hardy Weedon, Figure C-11. Some swelling apparently takes place below the stone base materials due to changing moisture conditions between the December and August tests. The small trend back toward the positive direction just before the August test may be an indication of drying conditions.

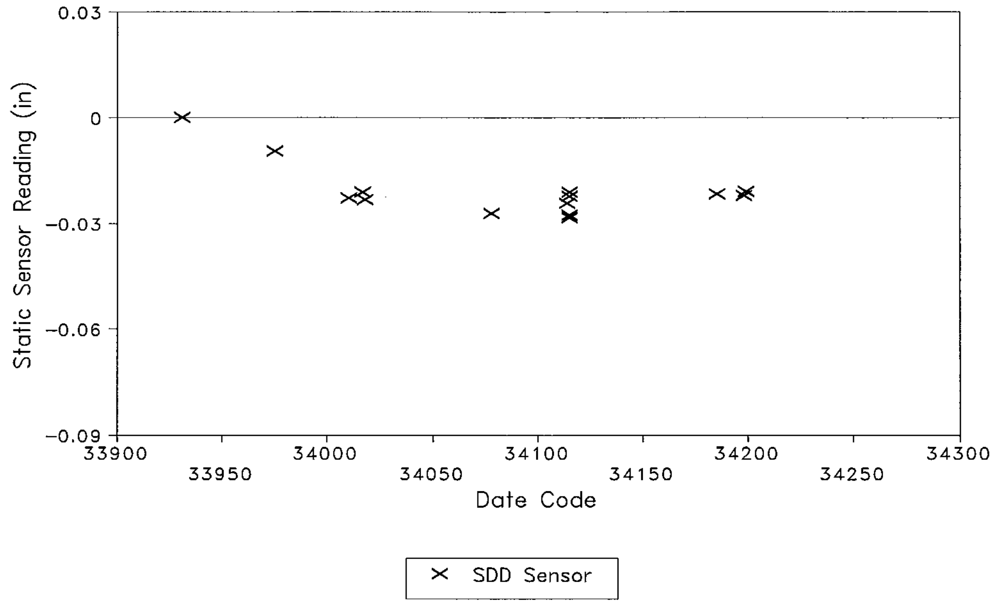


Figure C-10. Static SDD sensor readings at Elmo Weedon road.

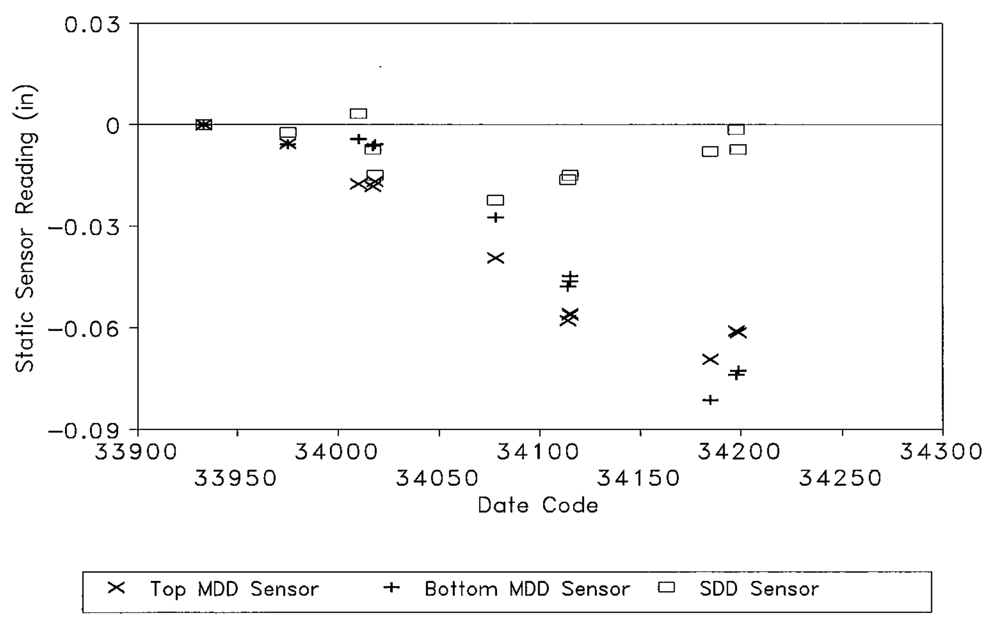


Figure C-11. Static readings for all sensors (SDD & MDD) at Hardy Weedon road.

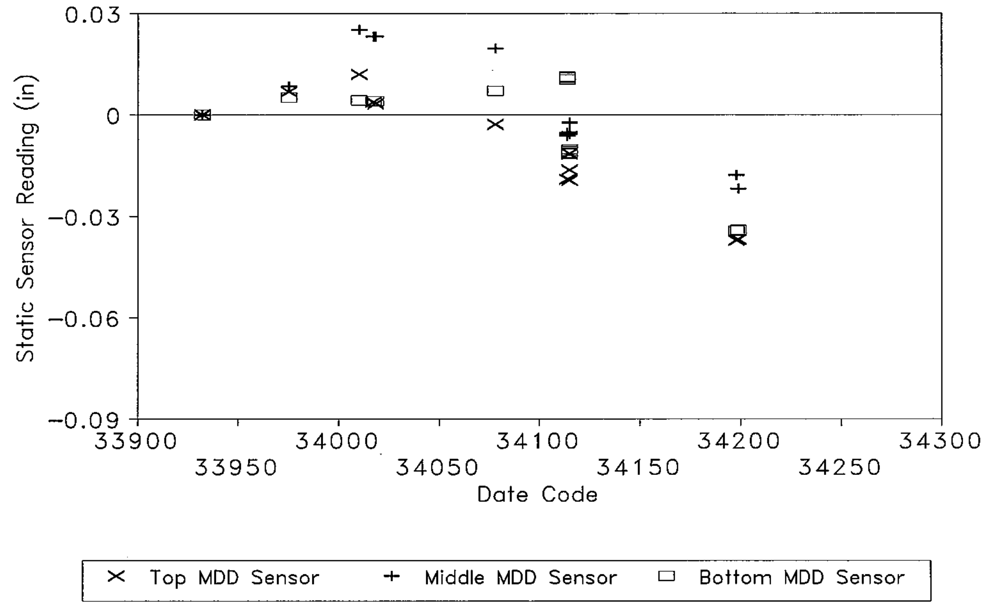


Figure C-12. Static readings at SH 30 MDD.

The more interesting portion of the study was the short term testing with the trucks on these roads. The response of the MDD sensors to various loads is shown in Figures C-13 - C-18. The response illustrated in Figure C-13 is from a falling weight deflectometer which imparted a load of 7,925lb (35kN) on the pavement. The first peak is associated with the drop of the weight. The other peaks show the impact of the weight as it bounces against the rubber bumpers on the trailer. The residual deformation at the end of the pulse is essentially meaningless because the vehicle and the plate are still applying a static load at that point. The edge of the plate of the FWD was within 3 inches (7.6cm) of the MDD sensor on this drop.

The horizontal offset distance of the loading device from the MDD is quite important. In this study, each pass of the truck was monitored visually and a horizontal offset position was recorded for the pass. This offset was given one of 9 values that described the location of the MDD with respect to a point on the rear axle midway between the dual tires on the right side of the trailer. During the data reduction process, this offset value was reduced to two categories -- either a tire rolled over the MDD or the MDD was between the two tires. Figure C-14 shows a typical example of the pavement responding to the passage of a 2060 permitted vehicle. This test was on 18 February 1993 and was chosen because it illustrates an interesting behavior. In this case, the tire rolled over the MDD. In the remainder of this section, reference will be made to *peak* and *permanent* deformations or strains. This terminology is identified in Figure C-14. The peak deformations include both elastic and plastic (or permanent) components.

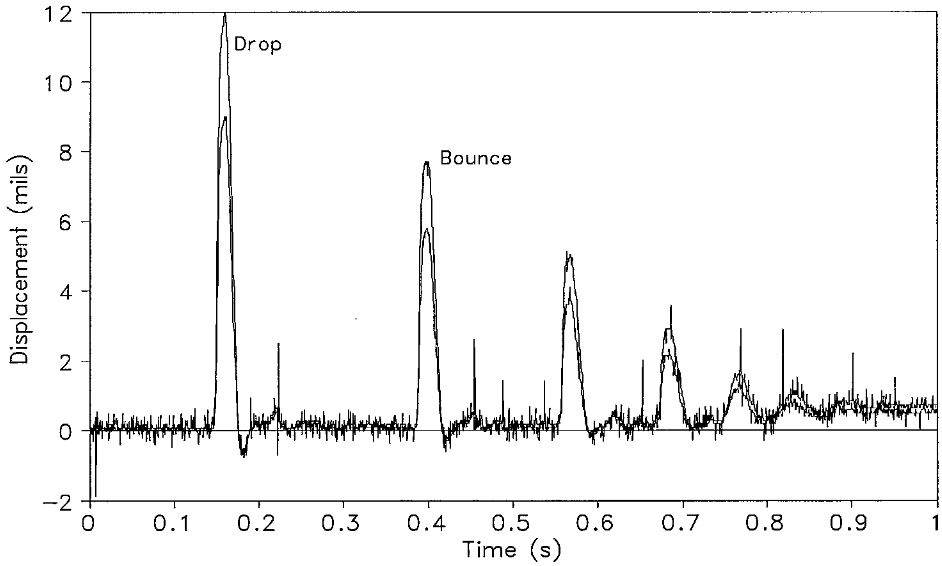


Figure C-13. FWD induced MDD response (Hardy Weedon road, top and bottom sensors).

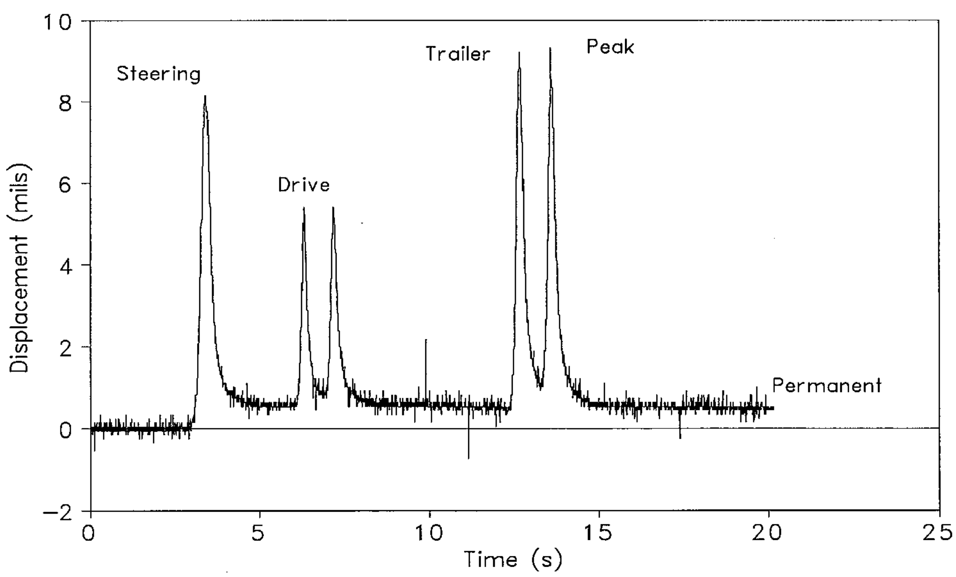


Figure C-14. Typical SDD response to 2060 permitted 5-axle truck (Elmo Weedon road).

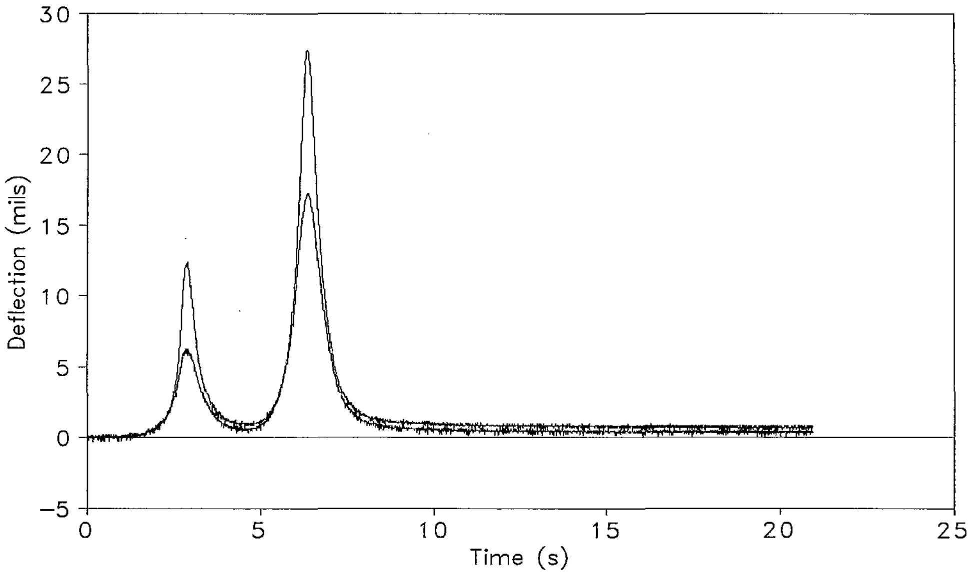


Figure C-15. Response to dump truck on Hardy Weedon road (17 February 1993).

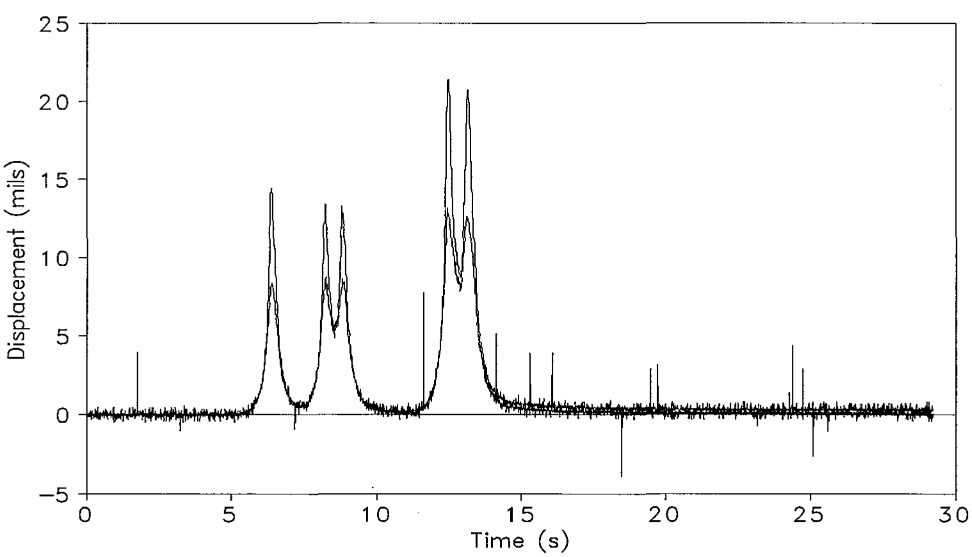


Figure C-16. MDD response to a 24.84kip (110kN) trailer axle load on Hardy Weedon road (25 May 1993).

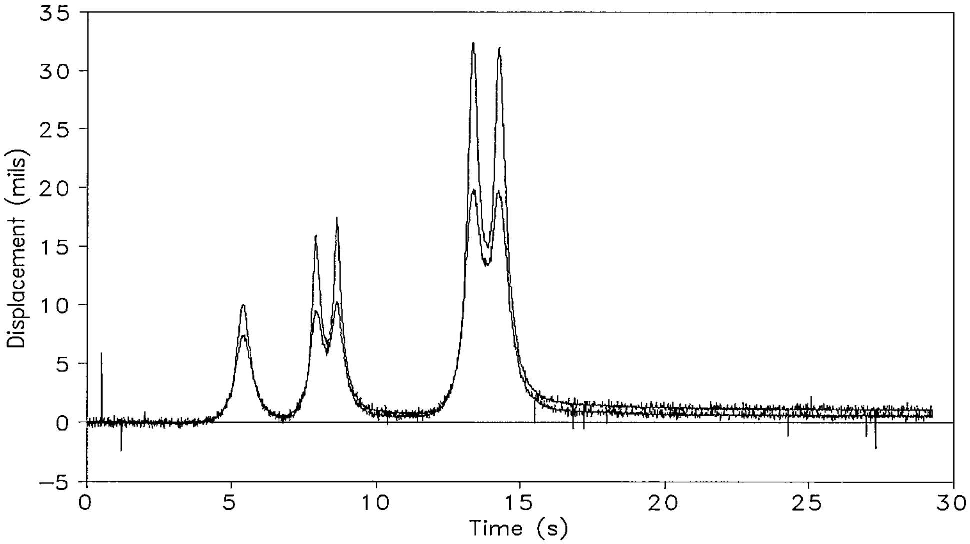


Figure C-17. MDD response to 34.8kip (155kN) trailer axle load on Hardy Weedon road (26 May 1993).

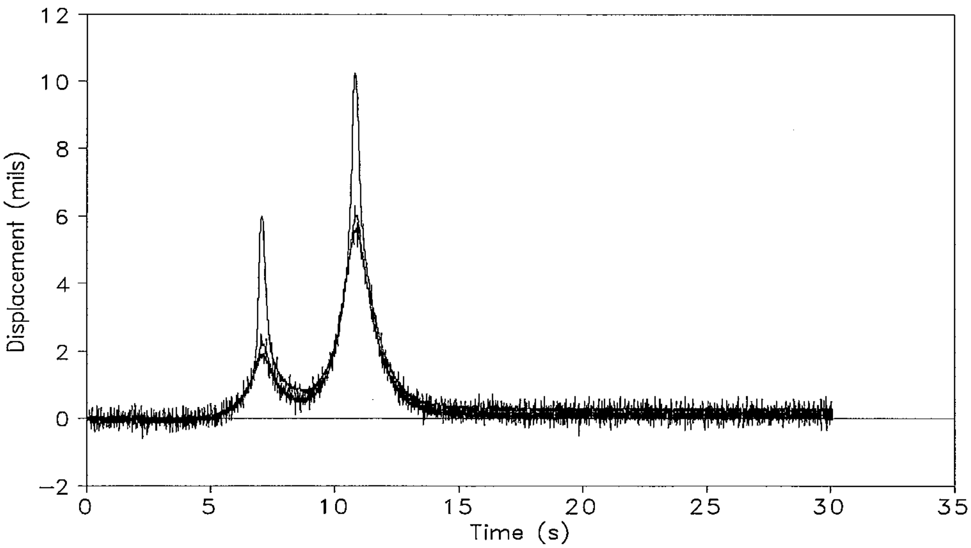


Figure C-18. MDD response to dump truck on SH 30 (17 August 1993, top, middle, and bottom sensor traces).

The peak and the permanent deformations are not necessarily linearly related, especially for pavement and other composite materials, so it is important to observe the permanent deformations directly when possible. The most interesting point concerning this plot is the fact that the steering axle induced almost as much total deformation as the tandem trailer axles. Since the rear tire rolled over the MDD, it can be concluded that the effect of the steering axle is significant here and could be due either to the static weight or to suspension dynamics as discussed in one of the articles in Appendix B (possibly bouncing of the tractor unit). Figures C-15 - C-18 show more typical responses and illustrate both single and multiple sensor responses as well as different vehicles.

The peak and permanent deformations from the experiment were calculated using an interactive computer program developed by the author. The trailer tandem axle was assumed to be associated with the peaks and the permanent deformation. Cases in which the steering axle peak was greater than the tandem trailer axle peak were limited; but in those cases, the peak associated with the trailer axle was selected. The permanent deformation was always associated with the trailer axle load for purposes of data reduction. Although several passes were conducted at each site during each test, the inability of the trucks to roll over the same spot on each pass limited the number of observations available for each treatment-level combination. Figures C-19 - C-21 document various degrees of damage in the form of permanent deformation. The lines plotted on these figures are the AASHTO damage predictions based on equation D-12, but with permanent strain substituted for rut depth. Data points above the lines indicate that more damage occurred in the test than the fourth power rule would suggest, while points below the line indicate that the fourth power rule overestimates the damage increment.

Figures C-19 and C-20 use the terminology *composite* strain, while Figure C-21 uses the term *layer* strain. Both terms refer to permanent strain, but they are calculated on the basis of different gage lengths. The term layer strain is used for the SDD because the only calculation that can be made with this sensor configuration is that relating to the strain in the layer between the sensor module and the lower anchor module. For the SDDs used

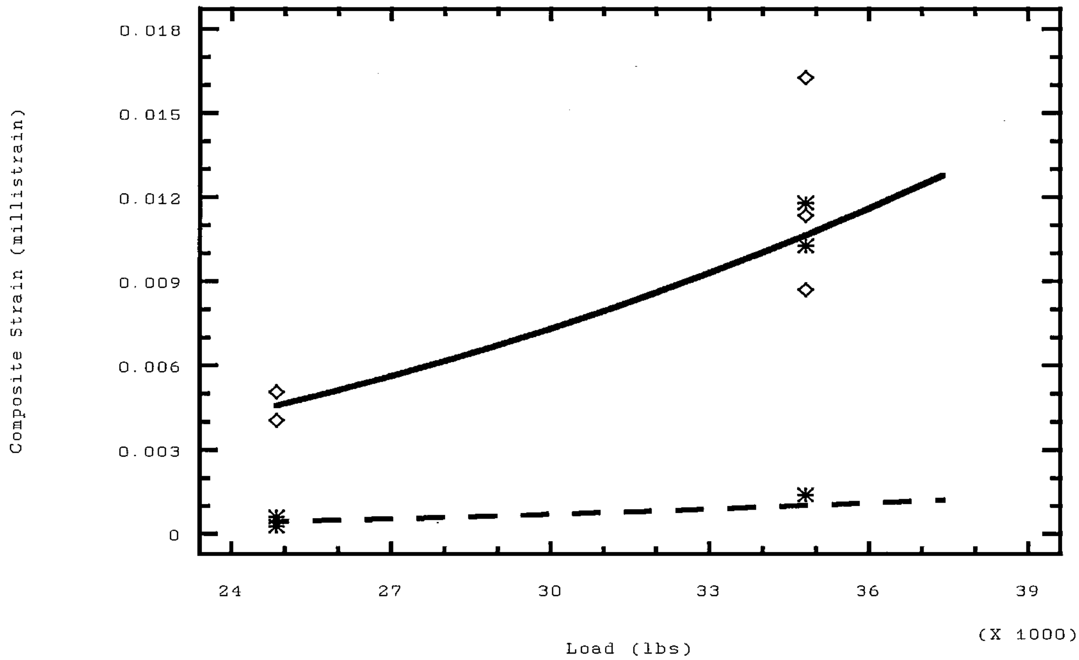


Figure C-19. Composite permanent strains at Hardy Weedon road (May test).

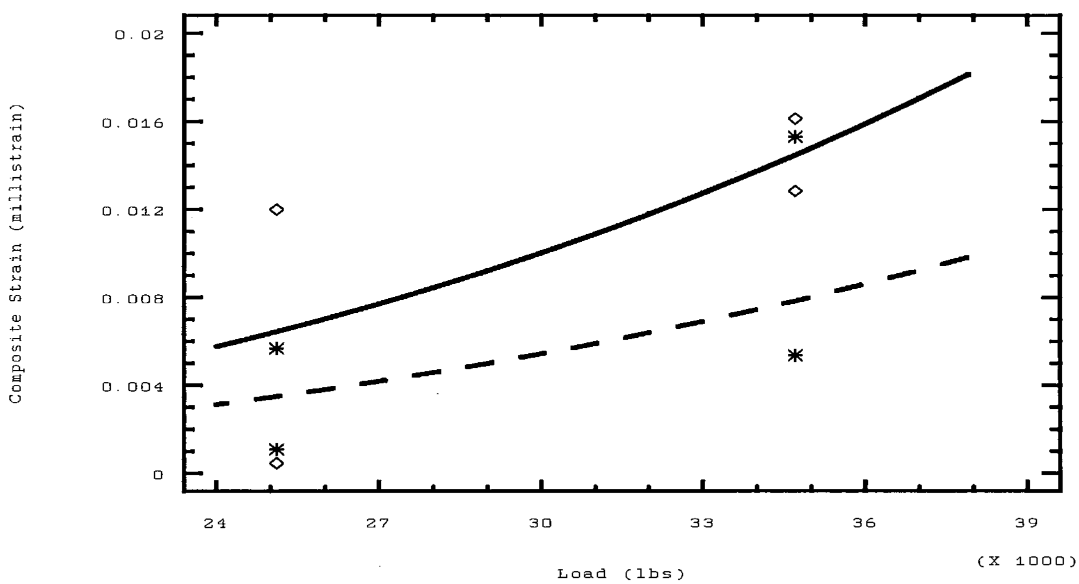


Figure C-20. Composite permanent strains for Hardy Weedon road (August test).

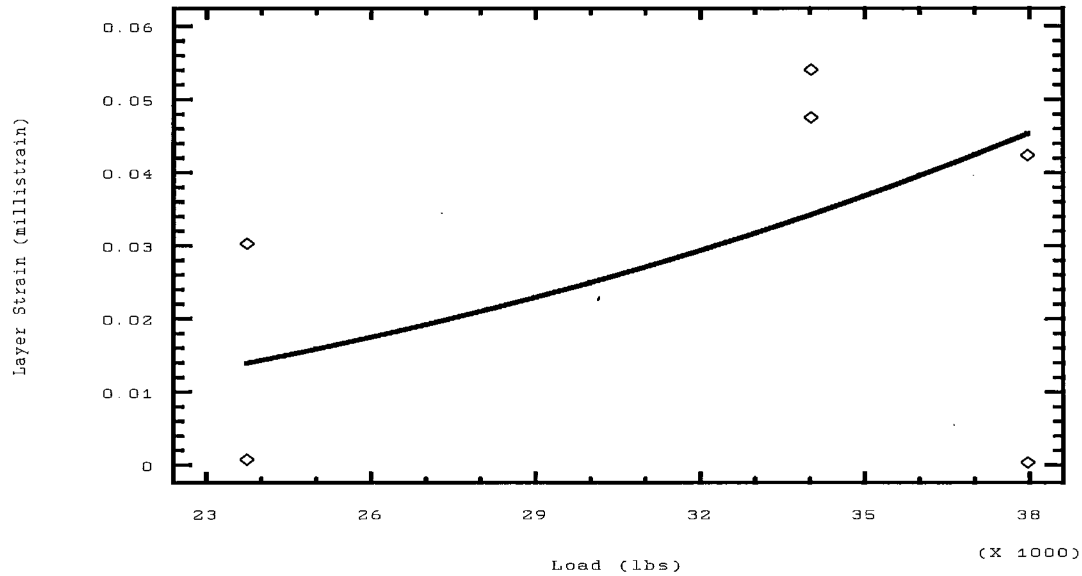


Figure C-21. Permanent layer strain in the Elmo Weedon SDD layer (February test).

SDDs used in this experiment, this layer is still a nonhomogeneous composite material because it really spans two improved materials that should have reasonably good vehicle support characteristics. For the MDD, a composite strain is computed on the basis of the gage length from the sensor to the anchor at the bottom of the MDD hole.

Based on the precipitation data, one might expect that May would be the month that would show the worst damage -- in fact, this is the case. Figure C-19 documents one of the worst cases in the experiment in terms of permanent deformation. The solid line is the prediction for the top sensor (associated with the diamond symbol for measured data), while the dashed line is for the lower sensor (asterisk data symbol). The data indicate that the fourth power rule generally underpredicts the damage that occurred in May. It is important that the lower sensor indicates so much more damage than the fourth power rule would suggest because this implies that the damage is penetrating deep into the pavement system.

Figure C-20 indicates that the damage at this site in August was approximately the same as the fourth power rule would suggest. The videotape portion of this report documents major surface deterioration at the time of the May and August tests which further supports the notion that the actual damage is worse than the fourth power rule suggests. The measurement for February at the Elmo Weedon SDD (Figure C-21) indicates general agreement with the rule, with the exception of one point indicating no appreciable damage.

In the final two figures of this section, Figures C-22 and C-23, the data for all months and offsets have been combined to obtain more points for study. This action makes the error term larger, but would give a minimum bound for damage. In these two figures, peak composite strains are used. Since Elmo Weedon road had only an SDD, no composite strains were available for that site. The maximum strain magnitudes were desired, so the data from the top sensors are presented. In contrast to the previous graphs, the line on these graphs is a regression line, not the AASHTO fourth power rule prediction. The regression was done so that the data could be used to specify a strain ratio and compare it to the AASHTO damage ratio. The regression yielded a peak strain ratio of approximately 1.8 which is somewhat less than that of 5.57 suggested by AASHTO. However, this strain ratio is based on total strain, not permanent strain, and the observed surface flushing distress which required an expensive repair of the test pavement is not considered in this data. An interesting, if serendipitous and perhaps irrelevant note, is that the 1.8 ratio for peak strains happens to be approximately the same as the ratio of incremental costs associated with the service of one oil well on a low volume, relatively light duty FM pavement (estimated at about 1.89 in *Mason 1983*).

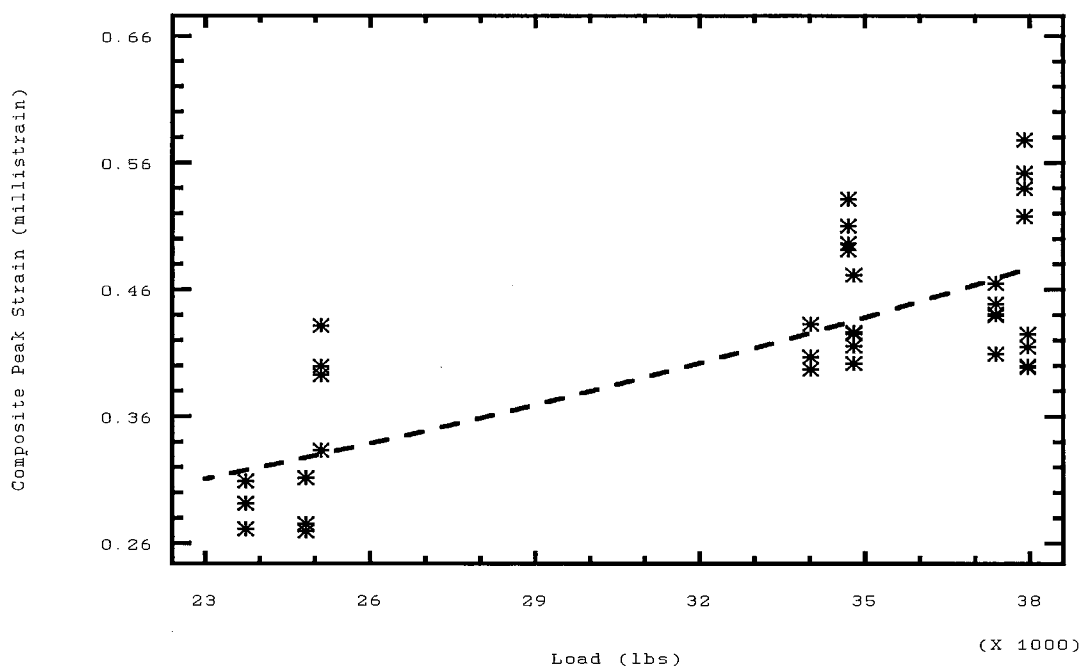


Figure C-22. Composite peak strains at the Hardy Weedon MDD.

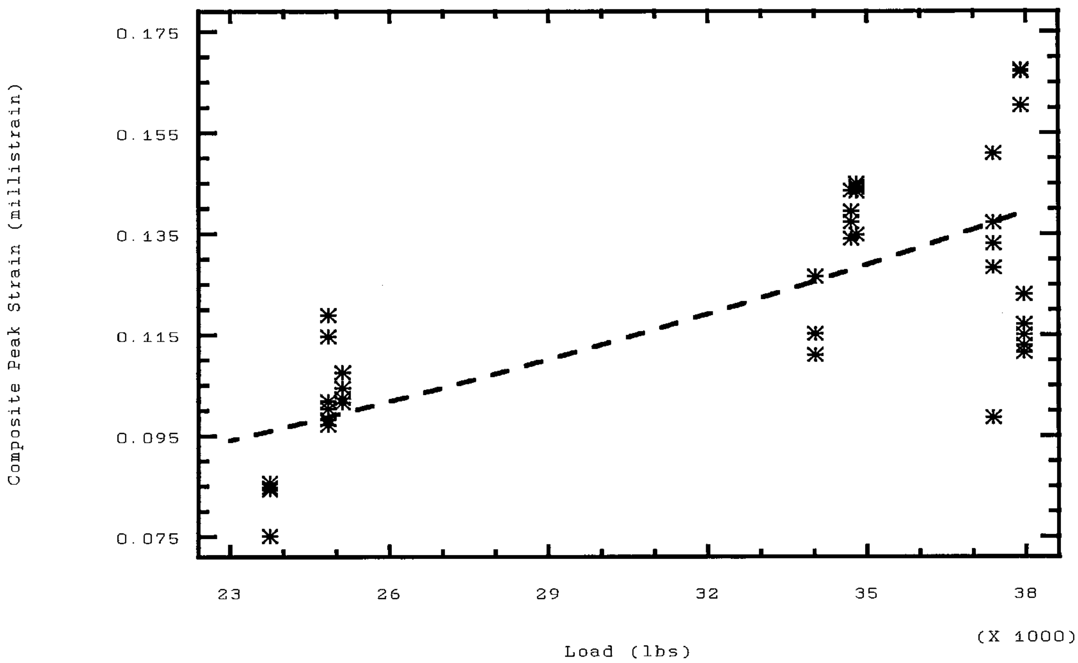


Figure C-23. Composite peak strain for SH 30.

Figures C-19 through C-23, in conjunction with visual observations during the field testing, provide the quantitative support necessary to establish a range of damage factors that might be expected with 2060 permitted vehicles operating on roads designed for 58,420lb (260kN) vehicles. That range is approximately 1.8 to 5.57, or about 2-5 or 2-6 in round figures. In fact, the maximum value of 5.57 has been shown to underestimate the damage in a limited number of cases.

APPENDIX D - DAMAGE ANALYSIS

AASHTO GUIDE

A fundamental question in this study was to determine what the impact of 2060 permitted vehicles would be on relatively light duty roads such as those load zoned for 58,420lb (260kN) vehicles. The AASHTO Guide for Design of Pavement structures provides a first approximation of the difference in damage that one might expect from the two types of vehicles through a concept called load equivalency factors. Basically, these factors relate the amount of damage expected from a given vehicle and axle configuration to the damage induced by a reference vehicle with a specified axle configuration. The data from the AASHTO Guide can be analyzed in such a way that a very simple formula for relative damage will result. This formula states that relative damage occurs approximately as the fourth power of the ratio of the axle loads. There is some discussion in the transportation community about the accuracy of the fourth power rule, but it seems to apply reasonably well to the problem addressed in this study as shown elsewhere in this report. For this Appendix, it is assumed that the fourth power rule is sufficiently accurate.

Relationship Between Damage and User Fees

A review of a Transportation Research Board publication and an application of the methodology to the 2060 problem is provided in this section of the report. The implications of the engineering analysis on fee structure is presented. Further details concerning damage and the serviceability concept are presented in the next subsection of this Appendix.

Nicholls, R. (1991). "Ratios of Pavement Damage to User Fees," *Pavement Management: Data Collection, Analysis, and Storage.* TRR 1311, pp. 277-285.

Nicholls has developed a method for computing ratios of pavement damage to user fees which provides an efficient means for all states to evaluate and adjust their road user fees for each class of vehicle. The method is based on the 1986 AASHTO Design Guide's concept of damage. One of the important observations that is not particularly new is that the damage varies approximately as the fourth power of axle load. Nicholls states, "Thus the 20-kip load is 8 times as damaging as the 12-kip load, i.e. $(20/12)^4$, and should arguably pay approximately 8 times as much per vehicle-mile in highway revenue. The power term varies only slightly with structural number (SN), pavement thickness (D), and terminal serviceability index (p_t) . . .".

The computation of the ratio of pavement damage cost to user fee is shown in the following equation.

The resulting ratio is to be interpreted in relationship to a reference vehicle. Therefore, a ratio of 20, for example, does not mean that the vehicle in question should pay 20 times as

$$Ratio = \frac{ESAL\ for\ the\ vehicle}{\left(\frac{Total\ user\ revenue\ per\ year}{Vehicle\ miles\ per\ year}\right)} \qquad \textbf{(D-1)}$$

much as the reference vehicle. Instead, it means that the vehicle in question should pay 20 times what it currently pays in user fees, assuming that the user fees for the reference vehicle remain unchanged.

An example of the application of this concept to the 2060 permit follows. We will arbitrarily establish two reference vehicles, one with a total weight of 80,000 pounds (356kN), and one with 58,420 pounds (260kN). For purposes of the example, one can assume that all vehicles are 5-axle, 18-wheel vehicles with the tandem axle pairs assumed to carry 42.5% of the total vehicle load. This means that the 80kip (356kN) tandem axle set will carry 34kip (151kN) while the 58.42kip (260kN) axle set will carry 24.83kip (110kN). House bill 2060 authorizes a 10% increase in the axle load and a 5% increase in the total load. Therefore, we can expect operations with 37.4kip (166kN) on the axle set of a vehicle weighing 84,000lb (374kN). Applying the fourth power rule of thumb to the tandem axle set, the damage induced on a road built for 58,420 lb (260kN) vehicles by the 84,000 lb vehicle would be $(37.4/24.83)^4$ or 5 times as much as the 58,420 lb (260kN) vehicle. Note that the relationship between the 37.4kip (166kN) and the 34kip (151kN) load is significantly less damaging (a factor of 1.5 increase in damage).

In order to evaluate the revenue apportionment, the revenue from the reference vehicles must be set. The 58.42kip (260kN) vehicle will pay $0.90/100lb ($0.90/445N in 1992 dollars) for registration plus $15.30 for the trailer. The total annual fee for this vehicle is $541.08. The 80kip (356kN) vehicle pays $1.00/100lb ($1.00/445N) plus $15.30, or $815.30. The overweight permitted vehicles will pay $815.30+$75.00 or $890.30. For the sake of the example, each vehicle is assumed to travel 1 mile on the fee so that the fee is also the fee per mile. The steering axles are assumed to support the appropriate remaining portion of the vehicle weight so that the 80kip (356kN) vehicle will have 12kip (53kN) on that axle, the 84kip (374kN) will have 9.2kip (41kN), and the 58.42kip (260kN) will have 8.76kip (39kN) on the steering axle. The total ESAL (equivalent single axle load) will be the sum of the ESAL of the steering and the 2 tandem axles. For roads built for 58,420lb (260kN) loading, a terminal serviceability index of 2.0 is a reasonable choice for the design. Using the low volume road design catalog in the 1986 AASHTO Guide for Design of Pavement Structures, a structural number of 2.5 is chosen for a typical pavement of this type. This assumes the design is for a low traffic level, fair quality of roadbed soil, and covers climatic regions I, II, and IV. The ESALs for this combination of parameters are shown in Table D-1.

Table D-1. Axle Load Equivalency Factors.

Truck	Steering	Tandem	Tandem	Total
58.42kip (260kN)	0.055	0.293	0.293	0.641
80kip (356kN)	0.183	1.075	1.075	2.333
84kip (374kN)	0.067	1.632	1.632	3.331

The ratios of interest are the ratios computed according to equation D-1 above (assume unit mileage and $541.08 for the total user revenue for the reference vehicle). The ratios for the 58.42kip (260kN), 80kip (356kN), and 84kip (374kN) vehicles are 0.00118, 0.00286, and 0.00374, respectively. These ratios, in turn, must be used to relate the ratio to the reference vehicles. The results are summarized below. In relation to the two reference vehicles, the permitted vehicle should be paying 3.2 (=0.00374/0.00118) times its current rate on roads designed for 58.42kip (260kN) vehicles and 1.3 times its current rate on roads designed for 80kip (356kN) vehicles. On the county road system, the 3.2 factor would apply. Assuming that the factor computed from the logic in this publication applies to the total fee, the fee would then become 3.2($890.30) or $2,848.96. This would raise the overweight permit fee from $75 to $2,033.66. Since this is the amount required to cover damage *only* (assuming equal distances for each vehicle type), the fee would need to be increased above this amount to cover permit administration and enforcement. In the literature, enforcement is estimated at 9% of damages, which would increase the cost of the permit to $2,216.69.

Details of Serviceability and Damage Components

To illustrate how the fourth power rule of thumb comes about for the specific case under study, consider the permitted and load zoned vehicle data shown in Table D-1. The values of 1.632 and 0.293 shown in that table for the tandem axles on these two vehicles were computed using linear interpolation in Table D-5 of the AASHTO Guide publication (*AASHTO 1986*). By simply taking the ratio of these two values (1.632/0.293 = 5.57), the relative damage factor is determined to be slightly over five. The damage factor can be related to the ratio of the axle loads as follows, where it is shown that the exponent on the power function is slightly more than four for this particular case.

$$5.57 = \left(\frac{37.4}{24.83}\right)^x$$

$$x = \frac{\ln 5.57}{\ln(37.4/24.83)} = 4.19$$

In the AASHTO Guide, a serviceability index is used as an indicator of damage. An initial and a terminal serviceability are used in pavement design. This damage concept is implicit in the load equivalencies discussed above. The serviceability at any given time can be expressed as the present serviceability index (PSI) as shown in equation D-2 in which the numbers are basically regression coefficients (*Yoder & Witczak 1975*). The equation shown is for flexible pavement types which make up the majority of the county and farm to market systems. There is a separate equation for rigid pavements.

$$PSI = 5.03 - 1.9\log_{10}(1+SV) - 0.01\sqrt{C+P} - 1.38RD^2 \qquad \textbf{(D-2)}$$

In this equation, SV is the slope variance, C is a measure of cracking, P is a measure of patching, and RD is a measure of rut depth. In the field experiment discussed in Appendix C, the measurements of most interest were the deflections in the pavement structures when they were loaded with the trucks. In the PSI equation, rut depth (RD) relates to the field deflection measurements conducted in this study. Since the fourth power rule relates to a composite index based on all the types of distress found in the PSI equation, it is necessary to formulate the relative damage in terms of rut depth only, so that a relatively direct comparison with deflection measurements may be made. The discussion in the previous paragraph showed that the relative damage, R_e, is taken to be the ratio of the load equivalency factors, $e_{37.4}/e_{24.83}$. The load equivalency factor is $e_x = w_{t18}/w_{tx}$, where w_{tx} is the number of load applications of a given load and axle configuration, and w_{t18} is essentially the number of AASHTO reference 18kip (80kN) single axle loads that would cause the same damage as w_{tx}. Assuming that the number of load applications is the same for both the 2060 permitted vehicle, $w_{t37.4}$, and the load zoned vehicle, $w_{t24.83}$, the following equation results.

$$R_e = \frac{e_{37.4}}{e_{24.83}} = \frac{w_{t18(37.4)}\, w_{t24.83}}{w_{t37.4}\, w_{t18(24.83)}} = \frac{w_{t18(37.4)}}{w_{t18(24.83)}} \qquad \textbf{(D-3)}$$

In this equation, $w_{t18(x)}$ is used to indicate the number of 18kip (80kN) loads that would be equivalent to w_{tx}. From this point, we desire to formulate a relationship between R_e and the rut depth. The approach goes back to the AASHTO design equation for flexible pavements shown in equation D-4 since it involves PSI which, in turn, involves rut depth. The AASHTO design equation is

$$\log_{10} w_{t18} = Z_R S_o + 9.36\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40+1094/(SN+1)^{5.19}} + 2.32\log_{10} M_R \quad \textbf{(D-4)}$$

where *SN* is the structural number which is assumed to be 3.0 for this problem, M_R is the effective roadbed soil resilient modulus, S_0 is the overall standard deviation which is assumed to be 0.35 for this problem, and Z_R indicates the reliability which is set at 50% reliability for this situation and this results in a value of zero for Z_R. The effective roadbed soil resilient modulus is generally considered to be in the 7,000-10,000psi (48-69MPa) range. However, falling weight deflectometer (FWD) and dynamic cone penetrometer (DCP) data were obtained at the test locations and these results indicate that a value of 15,000psi (103MPa) approximates the condition at the test sites for much of the experiment. Using these assumed values, equation D-4 reduces to equation D-5.

$$\log_{10} w_{t18x} = 6.7 + 0.819\log_{10}\Delta PSI \quad \textbf{(D-5)}$$

Assuming that the road is new at the start of the problem, it would be acceptable to assume that SV and C+P are both zero, in which case, equation D-2 reduces to equation D-6.

$$PSI = 5.03 - 1.38RD^2 \quad \textbf{(D-6)}$$

The change in PSI, ΔPSI, is the difference between the starting and ending PSI. At the starting PSI, the rut depth, RD_s may be assumed to be zero. Equation D-5 can now be reduced to equation D-7.

$$\begin{aligned} \log_{10} w_{t18x} &= 6.7 + 0.819\log_{10}(5.03-1.38RD^2{}_S-5.03+1.38RD^2{}_E) \\ &= 6.815 + 0.819\log_{10} RD^2{}_E \end{aligned} \quad \textbf{(D-7)}$$

Equation D-7 establishes the basic relationship between rut depth and 18kip (80kN) equivalent single axle loads. In order to establish the relationship between load and rut depth, it is necessary to introduce the equation used to generate the load equivalency factor tables as shown in equation D-8.

$$\log_{10}\left(\frac{w_{tx}}{w_{t18x}}\right) = 4.79\log_{10}(18+1) - 4.79\log_{10}(L_x+L_2) + 4.33\log_{10}L_2 + \left(\frac{G_t}{\beta_x}\right) - \left(\frac{G_t}{\beta_{18x}}\right)$$

where

$$G_t = \log_{10}\left(\frac{4.2-p_t}{4.2-1.5}\right)$$

and

$$\beta_x = 0.40 + \frac{0.081(L_x+L_2)^{3.23}}{(SN+1)^{5.19}L_2^{\,3.23}}$$

(D-8)

In this equation, p_t is the terminal (ending) serviceability which is assumed to be 2.0 for this derivation, L_2 is 2 for a tandem axle and 1 for a single axle, L_x is the load on the single or tandem axle set as applicable (kips), and β_{18} is the value of β_x when L_x is 18 and L_2 is 1. By making the appropriate entries in equation D-8, equation D-9 can be produced to relate equivalency factor to the load.

$$\log_{10}\left(\frac{w_{tx}}{w_{t18x}}\right) = 7.429 - 4.79\log_{10}(L_x+2) + \frac{0.0889}{\beta_{18x}} - \frac{0.0889}{\beta_x} \equiv f(L_x)$$

(D-9)

$$\Rightarrow \frac{w_{tx}}{w_{t18x}} = 10^{f(L_x)}$$

Making the appropriate substitutions using equations D-9 and D-3, equation D-10 results.

$$\left(\frac{w_{t18(37.4)}}{w_{t18(24.83)}}\right) = \frac{10^{f(L_{24.83})}}{10^{f(L_{37.4})}}$$

(D-10)

$$\Rightarrow 10^{(6.815+0.819\log_{10}RD^2{}_{37.4}-6.815-0.819\log_{10}RD^2{}_{24.83})} = 10^{f(L_{24.83}-f(L_{37.4})}$$

Equation D-10 can be reduced further to yield the fundamental result of this analysis shown in equation D-11.

$$\frac{RD_{37.4}}{RD_{24.83}} = 10^{0.61\Delta f(L_x)} \qquad \textbf{(D-11)}$$

Finally, substitution of the value for $f(L_{24.83})$ in equation D-11 yields the equation D-12 for the ratio of the rut depths as a function of the tandem axle load on the interval between 24.83kips (110kN) and 37.4kips (166kN). According to this formula, the rut depth induced by a 2060 permitted vehicle should be approximately 2.8 times that produced by a 58.42kip (260kN) vehicle. A plot of the function is shown in Figure D-1.

$$\frac{RD_x}{RD_{24.83}} = 10^{\left[-4.25+2.92\log_{10}(L_x+2)+\left(\frac{0.054}{0.4+0.00006078\left(\frac{L_x}{2}+1\right)^{3.23}}\right)\right]} \qquad \textbf{(D-12)}$$

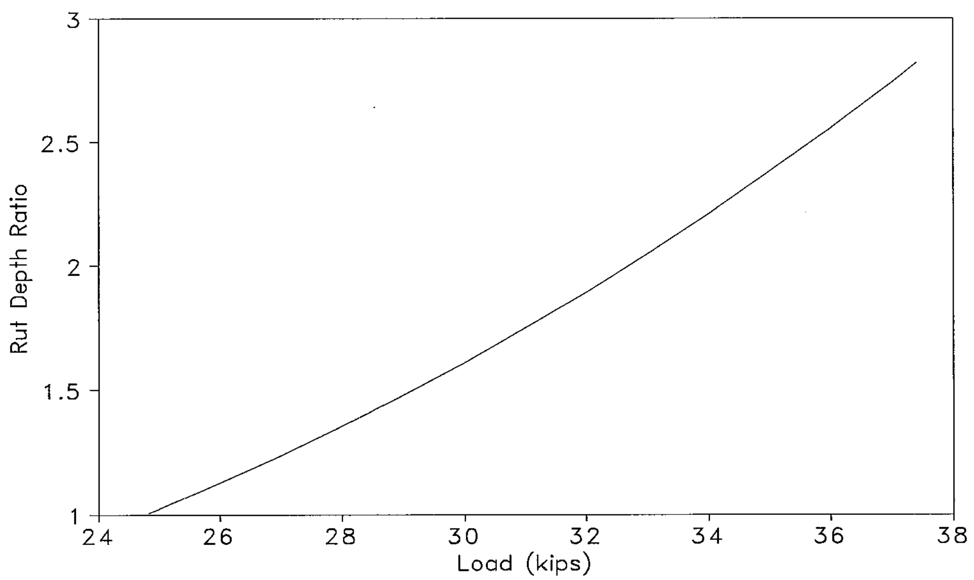


Figure D-1. Rut depth equation.

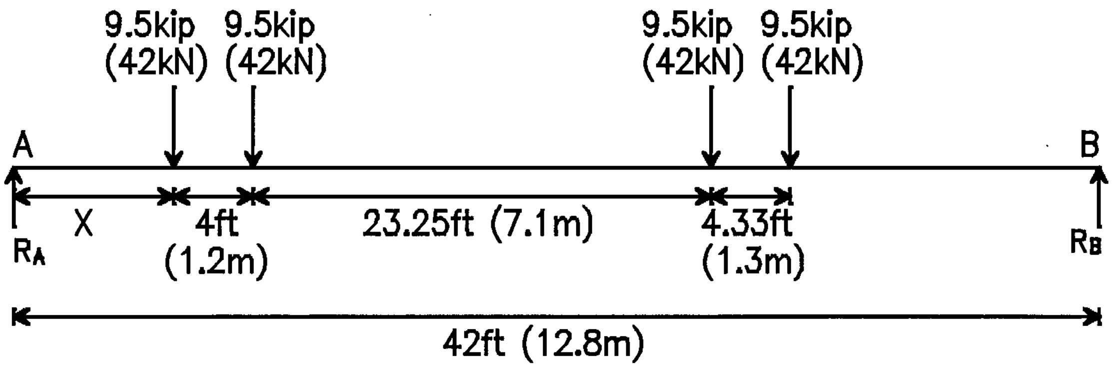
BRIDGE FRACTURE

A limited study of Brazos County bridge number 175-002 was conducted during this project. This bridge is a composite (steel and wood) structure spanning 42ft (12.8m). The longitudinal stringers were steel, while the piling support structure and decking were treated wood. The pilings were approximately 13in (33cm) in diameter. A subjective assessment of the bridge led to the conclusion that the most likely failures would be failures of one or more of the wooden deck planks or rotations of the pilings due to erosion of the soil at the edge of the water. These rotations would occur around the lower portion of the pilings and would result in one end of the bridge falling into the ravine. In this appendix, an analysis of a less likely, but potentially more dangerous failure is presented. The analysis is based on fatigue and fracture mechanics of the longitudinal steel stringers. Hopefully, the members would not fail by fracture, but would deform plastically, and the impending failure would be noticed in time to repair the bridge. However, the fracture scenario is not impossible. On the bridge, the decking and adjacent stringers help to distribute the load. However, for this illustration, the problem has been simplified to a single member simply supported on each end, the flanges are assumed to be cracked before the problem starts, the web is assumed to be approximately 24in (61cm) deep by 0.5in (1.3cm) thick, environmental effects are assumed to be negligible, and the system is assumed to have no mass. The purpose of this exercise is to determine the amount of time that would pass between the time: (1) a 2060 permitted truck passed over the bridge damaging it to the maximum extent possible without actually failing it, and (2) the time a 36,180lb (161kN) vehicle such as a school bus or farm vehicle would extend the damage to failure. The assumptions in Table D-2 are made with respect to shape and material properties (*Rolfe & Barsom 1977*).

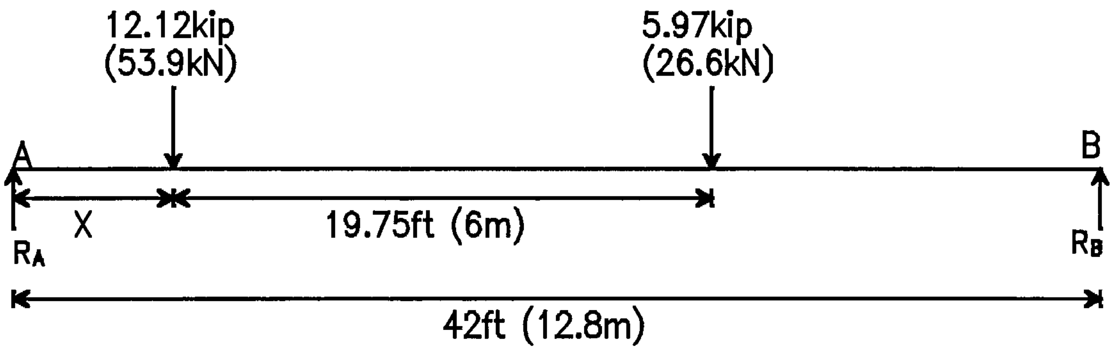
Table D-2 Properties of Steel Bridge Stringer.

ITEM	PROPERTY
Steel type	A36
Steel shape	W24X68
Plane strain fracture toughness, K_{Ic}	100ksi√in (110MPa√m)
Fatigue crack growth parameters, A,n (for ΔK_I in ksi√in)	3.6×10^{-10}, 3.0

Figure D-2 illustrates the loading condition. Since the 2060 permitted vehicle was longer than the bridge, only the drive axles and the trailer axles were on the bridge in the worst case condition.



18 Wheeler



Bus type vehicle

Figure D-2. Statics problem for bridge loading.

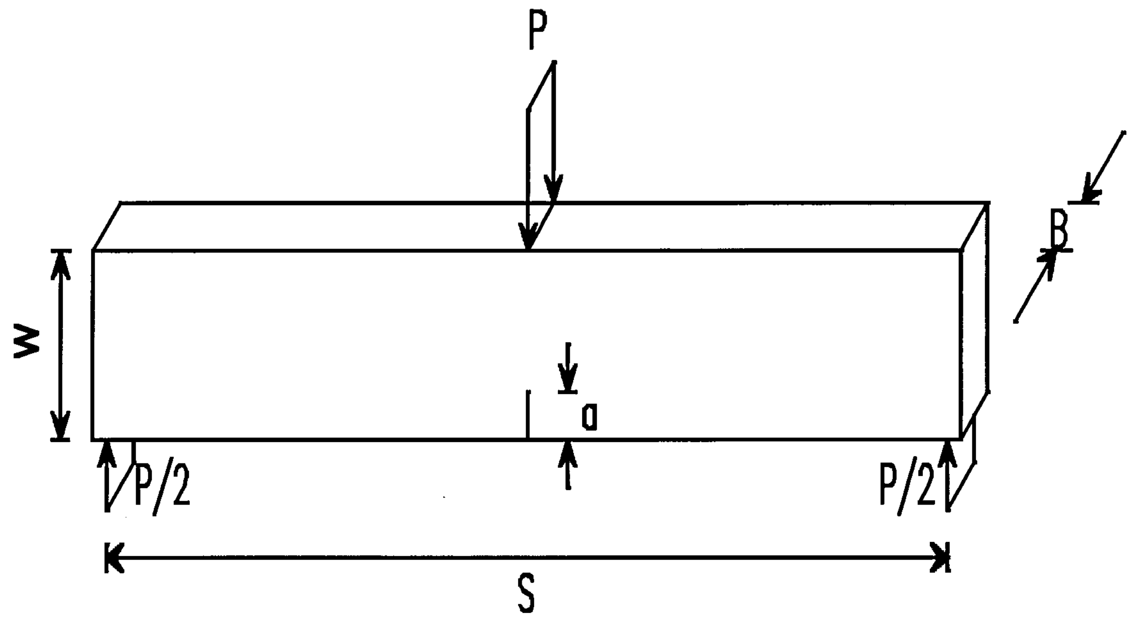


Figure D-3. Notched beam dimensions.

The steps in the solution are as follows. First, the critical crack length for failure of the beam is computed for both the 2060 permitted vehicle and the 58.42kip (260kN) vehicles. Obviously, the critical crack length for the 2060 vehicle will be the shorter of the two. Once the 2060 vehicle has extended a preexisting crack to its critical length, it is assumed that no more 2060 vehicles will pass over the bridge. From that point forward, it is assumed that only 36.18kip (161kN) vehicles will pass over the bridge. An axle configuration for a bus is used for this type of vehicle. The solution to the problem is obtained by computing the number of passes of the bus that will extend the crack from the critical length found for the 2060 permitted vehicle to the critical crack length for the bus.

Equation D-13 is the equation used to compute critical crack length, a_{crit} (*Broek 1982*). The various dimensions used in the equation are illustrated in Figure D-3. Equation D-14 describes the propagation of the crack from the critical value for the 2060 truck to the bus in terms of the number of load applications, N (*Rolfe & Barsom 1977*).

$$K_I = \left(\frac{PS}{BW^{3/2}}\right)\left[2.9\left(\frac{a}{W}\right)^{1/2} - 4.6\left(\frac{a}{W}\right)^{3/2} + 21.8\left(\frac{a}{W}\right)^{5/2} - 37.6\left(\frac{a}{W}\right)^{7/2} + 38.7\left(\frac{a}{W}\right)^{9/2}\right] \quad \textbf{(D-13)}$$

Table D-3 Solution to the bridge beam loading problem.

PARAMETER	2060 TRUCK	BUS CLASS VEHICLE
x	11.146ft (3.4m)	17.741ft (5.4m)
R_A	13.7kip (61kN)	7.64kip (34kN)
R_B	24.3kip (108kN)	10.45kip (46kN)
M_{max}	169.5ft-kip (230m-kN)	135.53ft-kip (184m-kN)

$$\frac{da}{dN} = 3.6x10^{-10}\ \Delta K_I^{3.0} \qquad \textbf{(D-14)}$$

The first step in the solution calculates the position at which the vehicle produces the absolute maximum live moment in the beam. The following rule is used in this portion of the solution: ". . . the maximum moment directly beneath one of a series of concentrated live loads that are applied to a simple end-supported beam occurs when the center of the span is halfway between that particular load and the resultant of all loads on the span" (*Norris et al. 1976, p. 159*). The solution for the maximum moment, M_{max}, the distance from one support to the nearest vehicle tire, x, and the reactions, R_A and R_B is given in Table D-3. Once the maximum moment in the beam is found, the problem becomes one of converting to an equivalent system of loads in a three point bend configuration as shown in Figure D-3. This was accomplished by solving for the concentrated forces that would be necessary to cause the maximum moment in the three-point bend configuration to be equal to that induced by the vehicles in the bridge situation. Once the value for the load, P, has been computed in this manner, all of the parameters in equation D-13 are known, with the exception of the crack length, a. Solving for the critical crack length in equation D-13 can be accomplished by one of several types of numerical methods. However, a simple method is to rearrange the equation making the left side equal to zero and then plot the function over a range of crack lengths. The plot can be used to bracket the zero of the function and then linear interpolation can be used to solve for a good estimate of the solution. This process can be accomplished on any good spreadsheet program. Using this approach, the critical crack lengths for the 2060 permit holder and the bus were found to be 1.76in (4.5cm) and 2.89in (7.3cm), respectively.

Once the critical crack lengths are determined, the somewhat more difficult task of integrating equation D-14 must be accomplished. Equations D-15 and D-16 describe the process. Integration of equation D-16 is somewhat difficult to do analytically as an indefinite integral. Therefore, the equation was integrated numerically as a definite integral using a Hewlett-Packard 48SX calculator which yielded a solution of 4,361 passes.

$$\frac{da}{dN} = 3.6x10^{-10}\Delta K^{3.0}$$

$$\int dN = \int \frac{da}{3.6x10^{-10}\Delta K^{3.0}} \qquad \textbf{(D-15)}$$

$$N = 2049.878 \int_{1.76}^{2.89} (0.592a^{0.5} - 0.039a^{1.5} + 0.0077a^{2.5} - 0.000555a^{3.5} + 0.0000238a^{4.5})^{-3}\, da \qquad \textbf{(D-16)}$$

Figure D-4 illustrates a practical application of the solution to this integration problem. A bridge inspection interval can be established based on the graph. For instance, 50 vehicles per day (VPD) over a five day week could extend the crack from the critical length for 2060 vehicles to the critical length for busses in a period of just over 17 weeks. Obviously, the inspection interval would need to be shorter than 17 weeks. During this study, Brazos county estimated that the total number of vehicles per day on Elmo Weedon and Hardy Weedon roads was 984 VPD and 1,118 VPD, respectively. These totals include a mix of oil field, agricultural, and passenger vehicles. If only 20% of the traffic mix were in the 36kip (160kN) range, the required inspection interval would be reduced to approximately 4 weeks. Monthly bridge inspections suggested by this scenario are beyond the capabilities of many counties because of personnel and budget limitations.

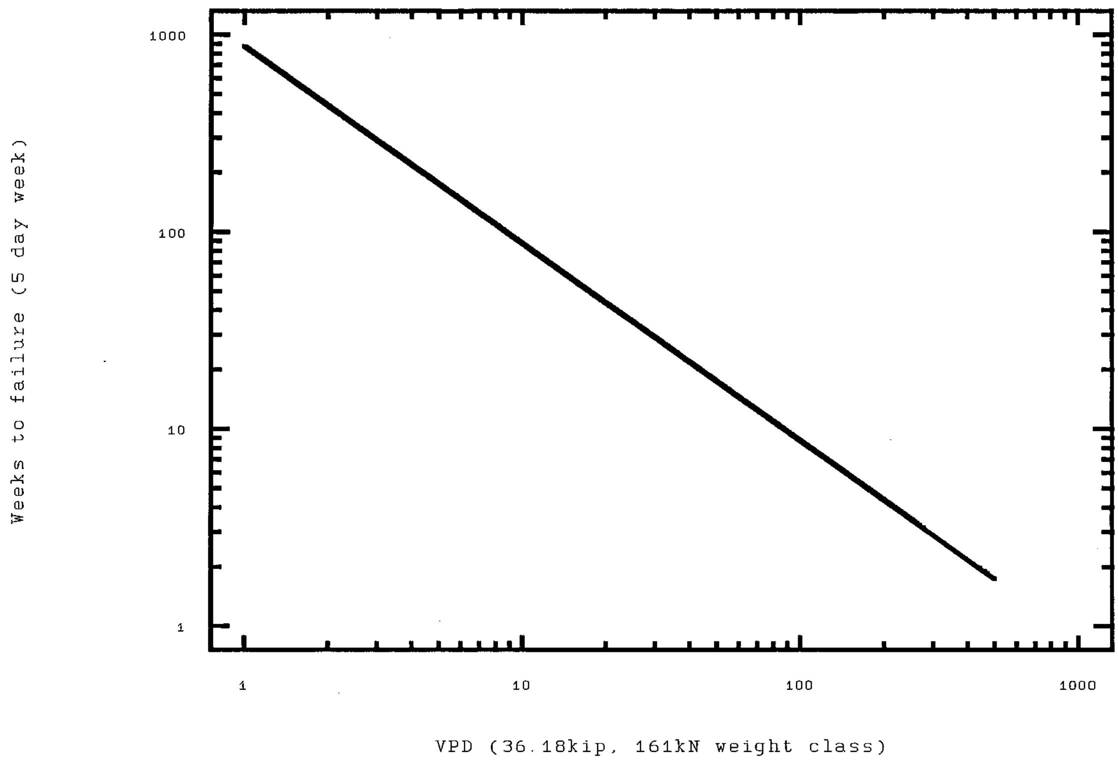


Figure D-4. Bridge inspection interval based on steel fracture.

APPENDIX E - VIDEOTAPE SCRIPT

The movement of goods on our surface transportation infrastructure is an important factor in the economic health of Texas. Trucking productivity is a key element in this movement. For productivity's sake, there is often a trade-off between vehicle weight and pavement management policies.

In 1989, the Texas legislature authorized the issuance of annual permits allowing commercial motor vehicle operators to drive non-agricultural vehicles exceeding the mandated axle weight by 10% and the allowable gross vehicle weight by 5%. Transporters of raw agricultural products can carry even heavier loads.

The $75 permit and $15,000 bond allow operation on state and county roads, except the Interstate system. This has been interpreted to allow 84,000 pound vehicles to travel on roads designed for 58,420 pound vehicles.

These light duty roads include much of the Ranch, Farm-to-Market, and county road systems. These roads constitute over half of the road system in Texas.

House Bill 2060 established these tolerances. The associated permit fee is divided between the state and counties. The state receives $25, the counties $50. The funds are apportioned by mileage in each county.

There is a delicate balance between end-use consumer cost and government taxation of those consumers. The impact of House Bill 2060 on infrastructure costs related to road and bridge maintenance is unknown.

For this reason, the Texas Transportation Institute conducted a study to assess these trade-offs and the potential impact of this legislation on the infrastructure. The field portion of the study was conducted in Brazos County on two county roads and a state highway.

Detailed documentation of the research is available in the final report for Research Project 1323.

In the late 1950's, AASHTO conducted an extensive field test in Illinois, resulting in pavement design procedures still in use today. Pavement performance is evaluated by a single number, the Serviceability Index. The index incorporates roughness and various forms of distress such as cracking and rutting.

This Serviceability Index can be used as an indicator of damage. The study found that thousands of average weight automobiles cause the same damage as one legal 80,000 pound truck with a standard axle and tire configuration.

Doubling vehicle axle weight caused much more than twice the damage. An 84,000 pound permitted vehicle should cause five times the damage produced by a 58,420 pound vehicle. The result is a five-fold increase in pavement and bridge maintenance costs.

A 1991 Transportation Research Board publication used the AASHTO damage concept to establish equitable user fees for various classes of vehicles. Using this technique, the 2060 permit fee should be increased from $75 to $2033.66.

This is the amount required to cover damage only, assuming equal distances for each vehicle type. The actual fee must be higher to cover permit administration and enforcement.

Pavement damage usually occurs gradually. Development of a 0.5 inch rut may require thousands of passes. Pavements are seldom instrumented with automated quantitative measurement devices to detect damage. Therefore, it is often difficult to trace damage to a single vehicle.

Enforcement is a key element in protecting our infrastructure. Enforcement costs are significant, but taxpayer involvement sometimes helps in the enforcement process.

News Footage Documenting Enforcement Action
Tony Cornett, KBTX-TV
Bryan, Texas

Reasonably skilled drivers may be able to handle the safety problems associated with gradual pavement damage. Bridges are another issue.

Damage may accumulate gradually in a bridge structure. A single heavy truck may be the final straw that causes catastrophic failure. It will be obvious which vehicle caused the damage. Or will it?

What if that heavy truck is the next-to-the-last straw in the process, with some lighter vehicle like a full school bus becoming the last straw? The resulting failure could be truly catastrophic.

In fiscal year 1992, the total distribution of 2060 permit fee receipts to the counties was approximately $380,500. Brazos County received $1,088 for its 470 mile (756 km) road system.

During the research period, one of the roads in the study required a surface treatment repair. The county estimated the costs at $30,000 per mile ($18,645 per km).

The State of Texas estimates the cost of surface treatment repairs at $10,000 per mile. Costs can go as high as $75,000 per mile to repair more serious damage. New bridges appropriate to this type of road cost an estimated $300,000.

These costs restore the road to its previous design capacity. They do not upgrade its load carrying capacity for the purpose of supporting heavier axle loads. Further repairs will be frequent if the traffic that caused the initial damage is allowed to continue. Upgrading to state highway standards would increase repair costs 2 to 5 times.

It is clear that a $75.00 permit and the method of distributing the receipts is inadequate. It is equally clear that there are only two other repair options: do nothing and let the vehicles traveling the road endure the damage; or increase taxes.

The purpose of the surface treatment repair during this study was to correct a bleeding or flushing and a rock pick-up problem. The cause was heavy oil field and agricultural traffic during the hot part of the year. The asphalt application rate was originally specified for lighter traffic.

The surface treatment was nearly new in December 1992. Very little surface distress was apparent in February. By May, problems began to develop.

During testing, the axle load for a 58,420 pound vehicle did not cause significant flushing or pick-up problems. The axle load for an 84,000 pound 2060-permitted vehicle caused significant visible flushing and pickup after only 6 passes.

Prior to repair in August, the surface rock and its beneficial contribution to skid resistance and ride quality had been lost to flushing and pick-up.

During repairs, the county reduced the asphalt application rate in an attempt to stop the flushing. Skid resistance was restored, but some flushing reappeared after 6 passes. Turning operations often resulted in visible damage.

Contributions to reduction in serviceability other than flushing were evaluated in the research project. Rutting, or permanent deformation, was also evaluated.

The three pavements studied were equipped with sensors to measure deflection under surface loading at depths from 3.5 inches to 22 inches.

Studies were conducted with a falling weight deflectometer to evaluate the engineering properties of the pavement systems. An automated road analysis vehicle measured surface ruts.

The goal was to determine if AASHTO findings apply to these types of Texas roads. Does permanent deformation, which is only part of the serviceability index, mirror AASHTO non-proportional damage findings? If so, 2060 infrastructure costs will be at least as severe as predicted by AASHTO experience.

Pavement loading was performed by two types of trucks: a TTI dump truck with a single rear axle and dual tires, and a county haul truck with tandem axles and dual tires on the rear of the trailer.

The trailer was loaded so that only the back pair of axles carried the desired weight. The overall truck gross weight was less than 84,000 pounds, but rear axle weight represented an 84,000 pound load on each set of tandem axles.

Weights were moved between tests so that axle loads for 58,420, 80,000, and 84,000 pound vehicles could be attained.

The AASHTO concept of non-proportional damage seems to apply reasonably well to these pavements. During wet portions of the year, rutting may be a significant component of serviceability reduction.

In hot, dry months, the underlying substructure of the pavement typically stiffens-up and the contribution to surface rutting from those lower pavement layers is reduced.

Heat also contributes to maximum rutting in the asphalt layer. A thin seal coat or surface treatment exhibits a drop in the viscosity of the asphalt due to high temperatures. This may cause several problems, including the flushing observed during this experiment.

The impact of 2060 legislation on infrastructure costs varies. Expect expenditures to increase 2-to-5 times to maintain status quo on roads limited to 58,420 pound vehicles. Costs will increase if 84,000 pound vehicles are accommodated on a routine basis.

Increased industrial activity may be indirectly indicated by a rise in 2060 permits. Such activity may signal increasing weights on existing traffic. It may also suggest additional heavy traffic. In either case, maintenance costs will be higher.

Safety costs include hazards associated with pavement and bridge damage, plus center of gravity and braking requirements of heavier vehicles.

Tire design, inflation pressure, and axle configurations can be altered to allow the same total weight per vehicle while limiting pavement damage. Unless legislation mandates these alterations, permit fees must be increased.

Counties that actually incur damage from permit holder vehicles must be provided with funds to repair infrastructure damage. Redistribution formulas must reflect this policy.

A fee based on miles traveled by the operator is one possibility. An alternate method might be issuance of a base permit for primary operation within one specific county. Extra fees are levied for each additional county where the permit holder wants to operate.

The object is simple -- make sure that permit income supports the infrastructure that carries permitted vehicles while continuing to encourage the economic activity and growth fostered by permitted vehicles. Permit income is vital for necessary maintenance, repair, and upgrade of the physical facilities. It also provides for equally important preventive measures, like effective law enforcement, without requiring large tax increases. Safe roads to carry the Texas economy forward require both.

Special thanks to Brazos County Road & Bridge for providing a suitable study location plus a 2060 permitted truck and driver for pavement tests. Additional thanks to TxDOT's Bryan District for traffic control.

APPENDIX F - HB 2060 INFORMATION

ARTICLE 6701d-11 TEXAS TRAFFIC LAWS

Sec. 1A. Manufactured housing exemption. "Manufactured Housing" as defined by the Texas Manufactured Housing Standards Act (Article 5221f, Vernon's Texas Civil Statutes) is not a "vehicle" subject to this Act.

Sec. 2. Weights and loads of vehicles; special permits; municipal regulation.

(a) Except as otherwise provided by law, no person may drive, operate, or move, nor may the owner cause or permit to be driven, operated or moved, on any highway, any vehicle or vehicles of a size or weight exceeding the limitations stated in this Act, or any vehicle or vehicles which are not constructed or equipped as required by this Act, or transport thereon any load or loads exceeding the dimensions or weight prescribed in this Act.

(b)(1) The Commissioners Courts through the County Judges of the several counties of this State may issue permits limited to periods of ninety (90) days or less for the transportation over highways of their respective counties other than State Highways and public roads within the boundaries of an incorporated municipality, overweight or oversize or overlength commodities which cannot be reasonably dismantled, or for the operation over these highways of superheavy or oversize equipment for the transportation of oversize or overweight or overlength commodities which cannot be reasonably dismantled, or for the operation over these highways of vehicles or combinations of vehicles that exceed the weights authorized under Section 5 or Section 51/2 of this Act. If a vehicle has a permit issued under Section 5B of this Act, a commissioners court may not issue a permit under this subsection, charge any additional fee for, or otherwise regulate or restrict the operation of the vehicle with a gross weight or axle weight that exceeds the weights authorized by Section 5 or Section 51/2 of this Act, or require the owner or operator to execute or comply with a road use agreement or indemnity agreement, to make any filings or applications, or to provide a bond or letter of credit other than the bond or letter of credit provided for in Section 5B.

(2) Not later than the 14th day after the date a person receives a permit under Section 5B of this Act, the person shall notify by certified or registered mail, return receipt requested, the county clerk of each county in which the person intends to operate or cause to be operated the vehicle. The notification must include:

(A) the name and address of the registered owner or operator of the vehicle

(B) the vehicle identification number and license plate number of the vehicle;

(C) a statement that the person intends to operate or cause to be operated the vehicle on, over, or across the county roads, bridges, and culverts with a gross weight, axle weight, or wheel load that exceeds the limitations established under Section 5 or Section 51/2 of this Act, and

(D) a statement that the notification is given pursuant to this subsection.

(3) A copy of the permit issued and bond or letter of credit required under Section 5B of this Act shall accompany the notification required under Subdivision (2) of this subsection.

(4) The notification under Subdivision (2) of this subsection may be given by an officer of a corporation or by a general partner in a partnership.

(5) The owner or operator of a vehicle that has a permit issued under Section 5B of this Act, who has filed the bond or letter of credit required under Section 5B of this Act, and who has filed the notification required by this subsection is liable to the county only for the actual damages to the county roads, bridges, or culverts with load limitations established under Section 5 or Section 51/2 of this Act caused by the operation of the vehicle in excess of those limitations. If a County Judge, County Commissioner, County Road Supervisor, or County Traffic Officer requires such vehicle to travel over a designated route, it shall be presumed that such designated route, including any bridges or culverts located thereon, is of sufficient strength and design to carry and withstand the weight of the vehicle traveling over such designated route.

(6) The liability of an owner or operator for damage to county roads shall not be limited to the amount of the bond or letter of credit required under Section 5B. A county may recover on the bond or letter of credit only by a suit against the owner or operator of the vehicle and the issuer of the bond or letter of credit filed in district court. Venue for a suit brought by a county to recover on the bond or letter of credit is in district court in the county in which the defendant resides, except that if the defendant is a corporation or partnership, venue is in the county in which the defendant has its principal place of business in this state. If a corporation or partnership does not have a principal place of business in this state, venue is in district court in the county in which the damage occurred.

(7) A County Judge may, in the same manner provided by Subdivision (1) of this section, issue an annual permit to a dealer in implements of husbandry to allow the dealer to use vehicles that exceed the width limitations in this Act and are not exempt under Subdivision (5) of Subsection (a) of Section 3 of this Act to transport the implements on the highways. A County Judge may exercise authority independently of the Commissioners Court until the Commissioners Court takes action on each request.

TXDOT INFORMATION SHEET

Form 1754, Rev. - 02/90

H.B. 2060 AUTHORIZES THE ISSUANCE OF A TOLERANCE PERMIT TO COMMERCIAL MOTOR VEHICLES (TRUCKS OR TRUCK/TRACTORS IN COMBINATION WITH TRAILERS AND/OR SEMITRAILERS) TO OPERATE WITH WEIGHT THAT EXCEEDS THE ALLOWABLE AXLE OR GROSS WEIGHT FOR THOSE VEHICLES. SUCH TOLERANCE PERMIT WILL BE ISSUED TO ONLY THE POWER UNIT.

1. PERMIT AUTHORIZES THE OPERATION OF VEHICLES TRANSPORTING NONAGRICULTURAL PRODUCTS AT A WEIGHT THAT EXCEEDS THE ALLOWABLE AXLE WEIGHT BY A TOLERANCE ALLOWANCE OF 10% AND EXCEEDS THE ALLOWABLE GROSS WEIGHT BY A TOLERANCE OF 5%. THIS PERMIT IS VALID ON THE STATE HIGHWAY SYSTEM, ALL COUNTY ROADS, AND ON LOAD ZONED ROADS.

2. PERMIT IS NOT VALID ON THE INTERSTATE SYSTEM. THIS PERMIT LIMITS THE OPERATION OF VEHICLES ON LOAD ZONED BRIDGES TO NOT MORE THAN 5% OVER THE POSTED LIMITS OF THE BRIDGE.

3. VEHICLES MUST BE REGISTERED FOR THE MAXIMUM ALLOWABLE WEIGHT FOR THAT PARTICULAR VEHICLE, BUT IN NO CASE TO EXCEED 80,000 POUNDS. THIS PERMIT DOES NOT INCREASE THE REGISTERED WEIGHT LIMIT, BUT ONLY ALLOWS A TOLERANCE ABOVE THE REGISTERED MAXIMUM WEIGHT.

4. PERMIT IS VALID FOR ONE YEAR AND MUST BE CARRIED IN THE VEHICLE FOR WHICH IT WAS ISSUED. COST OF THE ANNUAL PERMIT IS $75.00. CASHIER'S CHECK OR MONEY ORDER IS REQUIRED; PERSONAL CHECKS AND COMPANY CHECKS WILL NOT BE ACCEPTED.

5. AN APPLICANT FOR A PERMIT SHALL FILE WITH THE DEPARTMENT A BOND OR AN IRREVOCABLE LETTER OF CREDIT ISSUED BY A FINANCIAL INSTITUTION WHOSE DEPOSITS ARE GUARANTEED BY THE FEDERAL DEPOSIT INSURANCE CORPORATION IN THE AMOUNT OF $15,000, PAYABLE TO THE DEPARTMENT AND TO THE COUNTIES OF THIS STATE.

6. APPLICANTS OPERATING A VEHICLE THAT IS LOADED WITH TIMBER, PULP WOOD, WOOD CHIPS, COTTON OR AGRICULTURAL PRODUCTS, IN THEIR NATURAL STATE, MAY EXCEED THE ALLOWABLE AXLE WEIGHT BY A TOLERANCE ALLOWANCE OF 12% WITHOUT PURCHASING THIS PERMIT, BUT TO BE ELIGIBLE FOR THE GROSS WEIGHT TOLERANCE OF 5%, THE APPLICANT MUST OBTAIN THIS PERMIT. NO LETTER OF CREDIT OR BOND IS REQUIRED FOR AGRICULTURAL PRODUCTS.

7. THE OWNER/OPERATOR OF A VEHICLE THAT WILL BE OPERATED ON COUNTY ROADS MUST NOTIFY THE COUNTY CLERK OF EACH COUNTY WITHIN 14 DAYS OF RECEIPT OF THE PERMIT, BY CERTIFIED OR REGISTERED MAIL, RETURN RECEIPT REQUESTED. THE NOTIFICATION TO THOSE COUNTIES MUST INCLUDE:

    A. THE NAME AND ADDRESS OF THE REGISTERED OWNER OR OPERATOR OF THE VEHICLE.

B. MAKE AND MODEL OF THE VEHICLE, IDENTIFICATION NUMBER AND LICENSE PLATE NUMBER.

C. A COPY OF THE PERMIT ISSUED AND BOND OR LETTER OF CREDIT REQUIRED UNDER THIS ACT SHALL ACCOMPANY THE NOTIFICATION REQUIRED.

D. THE NOTIFICATION MAY BE GIVEN BY AN OFFICER OF A CORPORATION OR BY A GENERAL PARTNER IN A PARTNERSHIP.

8. THE OWNER OR OPERATOR OF A VEHICLE OPERATING WITH A PERMIT ISSUED UNDER THIS ACT, IS LIABLE TO THE COUNTY ONLY FOR THE ACTUAL DAMAGES TO THE COUNTY ROADS, BRIDGES, OR CULVERTS WITH LOAD LIMITATIONS ESTABLISHED UNDER THIS ACT CAUSED BY THE OPERATION OF THE VEHICLE. LIKEWISE, SUCH OWNER OR OPERATOR IS LIABLE TO THE DEPARTMENT FOR THE ACTUAL DAMAGES TO THE STATE HIGHWAY SYSTEM CAUSED BY THE PERMITTED VEHICLE.

9. LIABILITY OF AN OWNER OR OPERATOR FOR DAMAGES SHALL NOT BE LIMITED TO THE AMOUNT OF THE BOND OR LETTER OF CREDIT.

10. A SEMITRAILER BEARING A TOKEN PLATE OR AN APPORTIONED TRAILER PLATE, WHEN OPERATED IN COMBINATION WITH A TRUCK TRACTOR FOR WHICH A PERMIT HAS BEEN ISSUED, WILL BE REQUIRED TO INCREASE THE TOKEN FEE FROM $15 TO $30 UPON RECEIPT OF A PERMIT ISSUED UNDER THIS LAW.

11. IT SHALL BE UNLAWFUL AND CONSTITUTE A MISDEMEANOR FOR ANY PERSON TO VIOLATE ANY OF THE PROVISIONS OF THIS ACT. ANY PERSON, CORPORATION, OR RECEIVER WHO VIOLATES ANY PROVISION OF THIS ACT SHALL, UPON CONVICTION, BE PUNISHED BY A FINE OF NOT MORE THAN $200.00; FOR A SECOND CONVICTION WITHIN ONE YEAR SUCH PERSON SHALL BE PUNISHED BY A FINE OF NOT MORE THAN $500.00, OR BY IMPRISONMENT IN THE COUNTY JAIL FOR NOT MORE THAN 60 DAYS, OR BY BOTH SUCH FINE AND IMPRISONMENT; AND UPON A THIRD AND SUBSEQUENT CONVICTION WITHIN ONE YEAR SUCH PERSON SHALL BE PUNISHED BY A FINE OF NOT MORE THAN $1,000.00, OR BY IMPRISONMENT IN THE COUNTY JAIL FOR NOT MORE THAN 6 MONTHS, OR BY BOTH SUCH FINE AND IMPRISONMENT. PROVISIONS HEREOF WITH RESPECT TO IMPRISONMENT SHALL NOT BE APPLICABLE TO CORPORATIONS, BUT DOUBLE THE FINES HEREIN PROVIDED FOR, MAY BE IMPOSED AGAINST THEM IN LIEU OF IMPRISONMENT.

12. ANY INDIVIDUAL, PARTNERSHIP OR CORPORATION THAT DESIRES TO OBTAIN THIS PERMIT UNDER H.B. 2060 MUST SUBMIT THE FOLLOWING:

A. COMPLETED APPLICATION FORM PRESCRIBED BY THE DEPARTMENT.

B. PHOTO COPY OF THE REGISTRATION RECEIPT OF ALL POWER UNITS TO BE ISSUED THE PERMIT.

C. ORIGINAL BOND OR IRREVOCABLE LETTER OF CREDIT.

D. LIST OF THE COUNTIES IN WHICH THIS VEHICLE IS TO BE OPERATED.

E. CASHIER'S CHECK OR MONEY ORDER IN THE AMOUNT OF $75.00 FOR EACH POWER UNIT (TRUCK OR TRUCK/TRACTOR).