1. Report No. **FHWA/LA.04/396**	2. Government Accession No.	Recipient Catalog No.
4. Title and Subtitle **DEVELOPMENT OF LABORATORY TESTING FACILITY FOR EVALUATION OF BASE-SOIL BEHAVIOR UNDER REPEATED LOADING: PHASE-1: FEASIBILITY STUDY**	5. Report Date **February 2005** 6. Performing Organization Code	
7. Author(s) **Murad Y. Abu-Farsakh, Ph.D., P.E.** **Izzaldin M. Almohd, Ph.D.**	8. Performing Organization Report No.	
9. Performing Organization Name and Address **Louisiana Transportation Research Center** **4101 Gourrier Avenue** **Baton Rouge, LA 70808**	10. Work Unit No 11. Contract or Grant No. **02-04GT**	
9. Sponsoring Agency Name and Address **Louisiana Transportation Research Center** **4101 Gourrier Avenue** **Baton Rouge, LA 70808**	13. Type of Report and period covered **Final Report** **03/01/2004 to 10/30/2004** **14. Sponsoring Agency Code**	
15. Supplementary Notes		

16. Abstract

Accelerated load testing of paved and unpaved roads is the application of a large number of load repetitions in a short period of time. This type of testing is an economic way to determine the behavior of roads and compare different materials, structures, and construction alternatives for the design of highways under a large number of load applications. Currently, numerous accelerated pavement testing (APT) facilities are being used worldwide. Heavy vehicle simulators (HVS) and the cyclic load actuators are the most commonly used facilities. Smaller scale model-testing facilities are also available.

This report presents a feasibility and cost-efficiency study for different accelerated load facilities to determine the most useful facility for conducting comparative studies and preliminary investigations on paved/unpaved roads along with the Accelerated Load Facility (ALF) at the Louisiana Transportation Research Center (LTRC). Heavy vehicle simulators (wheel beam assembly), cyclic load actuators, and the Model Mobile Load Simulator (MMLS) were reviewed and compared based on the literature findings, personal communication with researchers, and coordinating site visits to selected facilities. The comparisons included the applications, advantages, limitations, and costs of each of the three alternative facilities.

Based on the feasibility study, the MMLS was excluded due to its limited influence depth reasoned by the wheel size and wheel load. The HVS and the cyclic load actuators were found to be more useful for base, subbase, and subgrade related studies. Due to various applications, and based on the inherent advantages of both facilities (speed and cost), the cyclic load actuator facility has been recommended for research purposes at the LTRC. This facility can be used for wide range of research related to asphalt concrete layers, base course layers, subgrade layers, and the reinforcement layers. Its compact size and speed of testing will allow for more preliminary investigations prior to ALF testing.

17. Key Words **Accelerated load testing, accelerated pavement testing, heavy vehicle simulator, cyclic load actuator, model mobile load simulator, performance testing of pavements, feasibility study, cost-benefit.**		18. Distribution Statement	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages **60**	22. Price

DEVELOPMENT OF LABORATORY TESTING FACILITY FOR EVALUATION OF BASE-SOIL BEHAVIOR UNDER REPEATED LOADING PHASE 1: FEASIBILITY STUDY

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LTRC Report No.396

Conducted for Louisiana Department of Transportation and Development

Louisiana Transportation Research Center

February 2005

ABSTRACT

Accelerated load testing of paved and unpaved roads is the application of a large number of load repetitions in a short period of time. This type of testing is an economic way to determine the behavior of roads and compare different materials, structures, and construction alternatives for the design of highways under a large number of load applications. Currently, numerous accelerated pavement testing (APT) facilities are being used worldwide. Heavy vehicle simulators (HVS) and the cyclic load actuators are the most commonly used facilities. Smaller scale model-testing facilities are also available.

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ACKNOWLEDGMENTS

This research project was funded by the Louisiana Department of Transportation and Development (LA DOTD) (State Project No. 736-99-0998) and the Louisiana Transportation Research Center (LTRC Project No. 02-04GT). The authors appreciate the assistance and comments provided by the research review committee. The comments and suggestions of Mark Morvant, Pavement and Geotechnical Administrator at LTRC, are gratefully acknowledged. Much of the information provided in the report is based on personal communication with researchers who have had experiences with similar facilities and site visits to selected facilities. The authors express gratitude to all who contributed to the work presented herein, namely: Dr. Khalid Farrag of the Gas Technology Institute (GTI), Dr. Steven W. Perkins of the Western Transportation Institute at Montana State University, Dr. Imad Al-Qadi of the University of Illinois at Urbana, Mr. Dale Rand of the Texas Department of Transportation (TxDOT), and Mr. Jianren Wang of Geotesting Express in Georgia.

IMPLEMENTATION STATEMENT

This report presents phase one of the research project concerning the development of an accelerated load testing facility for evaluating pavement's behavior. The results of this study included comparisons and discussion of different alternatives for the proposed facility to be used at LTRC along with the full-scale ALF at the Pavement Research Facility (PRF) site of LTRC-LADOTD. The results and findings of this report are important to the selection of the desired facility to be used for future testing of pavements under different material, geometric, and environmental conditions.

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INTRODUCTION

Accelerated pavement testing (APT) facilities were developed to simulate years of traffic loading in a much shorter period of time. APT allows the collection of reliable pavement performance data in a much faster, effective, and economic manner. The application of well-controlled traffic at these facilities, along with laboratory test data, helps to develop mechanistic methods to design pavements, validate design assumptions, validate new construction technologies and materials, and evaluate the conditions of existing pavements. Currently, various test facilities are used throughout the United States to evaluate and/or predict pavement behavior. These facilities can be categorized, depending on their sizes and loading mechanisms, into three major types: (i) large-scale (wheel-beam) facilities, (ii) model (reduced-scale) facilities, and (iii) cyclic plate load (load-actuator) testing facilities. The selection of the type and specifications of the facility involves careful consideration of the inherent advantages and limitations of each facility. The technical and operational aspects of these facilities were reviewed along with the setup costs, maintenance requirements, and operational capacities (number of sections tested in a year). A cost efficiency study should consider the initial cost, maintenance costs, and test section preparation cost.

The large-scale facilities usually exceed 30 feet in length and are capable of simulating heavy truck loads. The model mobile load simulators (MMLS3) are much smaller devices with reduced wheel sizes and axle loads. Due to their small axle loads and tire sizes, they require either resizing the pavement layers (reducing the thicknesses of the constituting layers) or testing each of the pavement layers independently. Cyclic load actuators, on the other hand, are programmable and well-controlled devices that can apply numerous load-time functions at different frequencies and amplitudes. Despite the differences between the wheel and the cyclic plate, the cyclic plate load actuator is a common and reliable facility.

The Louisiana Transportation Research Center (LTRC) of the Louisiana Department of Transportation and Development (LADOTD) possesses a full-scale 100 foot long accelerated load facility (ALF) that has been intensively used and continuously scheduled for pavement research purposes since it was constructed in 1994. The cost of the pavement sections that are being tested by the LTRC-ALF average $60,000 to $80,000 per section. Accordingly, a smaller and less costly facility is needed for conducting preliminary and comparative studies that will enhance the existing LTRC-ALF. In this report, each one of these options will be considered in terms of reliability, advantages, limitations, and cost efficiency.

In general, the desired test facility should have the following minimum requirements:

1. Reliability of tests results: The test facility should be able to represent the actual heavy field traffic loads and speeds. This requires that the axle loads, influence depth, size of tires, and speed of loading are compatible with the heaviest vehicles on highways. The test sections must be repeatable, thus assuring that the same test section and approximately the same results can be obtained more than once. An essential feature of the test section is to enable comparisons between different designs or instructions.
2. Size of facility and paved test section: The facility should be large enough to conveniently predict the behavior of paved/unpaved sections. However, the size should not be excessively large, so as to enable the environmental control conditions of the test sections (controlling temperature and moisture conditions).
3. Cost efficiency: The facility should be cost effective. Cost efficiency involves considerations for (i) the initial cost, (ii) maintenance cost, (iii) section preparation cost, and (iv) number of test sections per year.

OBJECTIVES

The main objective of this study was to determine the most beneficial and cost effective accelerated load facility that could be used in conjunction with LTRC's ALF. The facility will be used primarily for conducting preliminary and comparative experimental studies which will have results and findings that can be implemented and used in developing the experimental program of the LTRC's full-scale ALF. This report provides an insight into the advantages, disadvantages and limitations, and the cost efficiency of the different types of facilities currently available for this purpose. The findings of this study will lead to a recommendation for the most beneficial and economic type of facility to best suit the needs of current and future pavement research and development in Louisiana.

SCOPE

This study was based on the results of a comprehensive literature review of available accelerated load testing facilities and communication with researchers who have experience with these facilities. Site visits along with demonstrations of the equipment and operation of different facilities were major factors contributing to the contents of this report. The advantages and disadvantages of the different types of facilities were compared.

METHODOLOGY

To accomplish the objectives of the study, the research methodology included the following major tasks:

1. A comprehensive literature survey to become familiar with other experiences regarding large-scale and full-scale testing and the published works relevant to the design and behavior of flexible pavements under cyclic loading. This included reviews of case studies involving different methods/equipment that are being used for full-scale testing, large-scale testing, and laboratory testing of flexible pavements with/without reinforced bases and treated bases or subgrades. Problems reported for different test facilities as well as the reliability, resemblance to real working conditions, and repeatability of tests sections were also investigated and compared for all alternatives.

2. Personal communication with different research and academic agencies, and researchers with expertise in full-scale, reduced-scale, and model testing of pavements sections. This helped us determine the advantages and disadvantages of the test facilities included in this report.

3. Following the personal communications, field visits were scheduled to observe the operation and preparation of selected test facilities. This also included demonstrative workshops and ongoing major projects.

4. The final report will include recommendations on the appropriate test facilities that can be deployed for future testing of flexible pavements. The recommendations will be based on a comparative study of the different testing facility options considering the reliability and resemblance to actual field conditions and loadings, as well as cost effectiveness (initial cost, maintenance cost, test duration, and personnel or workmanship).

DISCUSSION OF RESULTS

Many researchers and research agencies have tested indoor, full-scale, or pre-existing pavements to evaluate the condition of pavements, predict their anticipated performance, and validate new design methods, assumptions, or construction materials. To accomplish these objectives, different experimental approaches have been followed. One approach is the time-consuming process of real field testing using a driver vehicle and accelerated load testing (ALT). The inefficiency of this method urged researchers to seek alternate ways to shorten the test duration, yet still represent the actual field loading conditions. This was accomplished by using cyclic plate loading at high frequency, heavy vehicle simulators (wheel-beam assembly), and model load simulators. The three options were evaluated.

Cyclic Load Actuators

Stationary cyclic load actuators can reduce the test duration by applying thousands of load cycles in minutes rather than days. These actuators can be programmed to apply loads at different magnitudes (peaks), frequencies, and load-time functions (figure 1). The amplitudes (magnitude of load) are comparable to actual traffic loads, and the frequencies can be adjusted to represent up to 50 mph.

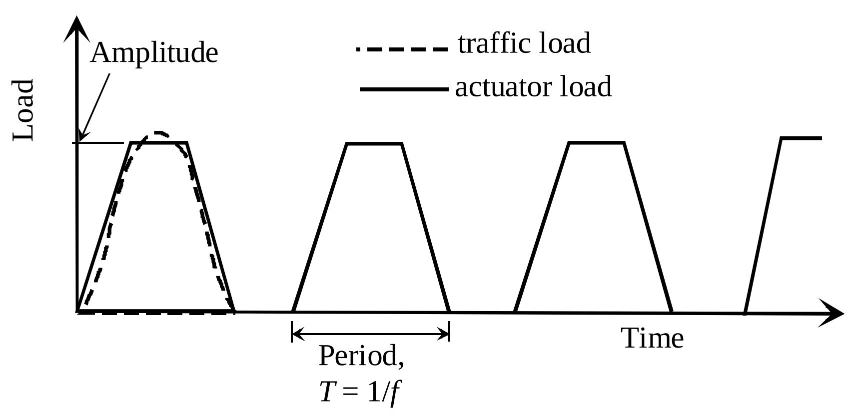


Figure 1
Load frequency applied by the cyclic load actuator compared to traffic load

Many researchers have used cyclic load actuators for testing reduced-scale pavement sections [*1*, *2*, *3*, *4*, *5*, and *6*]. Their work evaluated the benefits of using reinforcements within the base course layer. They also studied some of the design variables, such as the type, stiffness, and location of the reinforcement, the stiffness of the subgrade layer, the thickness of the base course layer, and the moisture effects.

Different sized test boxes and sections have been used in the literature. The appropriate box sizes are believed to be greater than 5 feet x 5 feet in plan, and about 5 feet in depth. An example of the test box and actuator facility is depicted in figures 2 and 3, which show schematics and images of the entire load actuator facility (box, frame, and actuator), and the load actuator and loading plate, respectively.

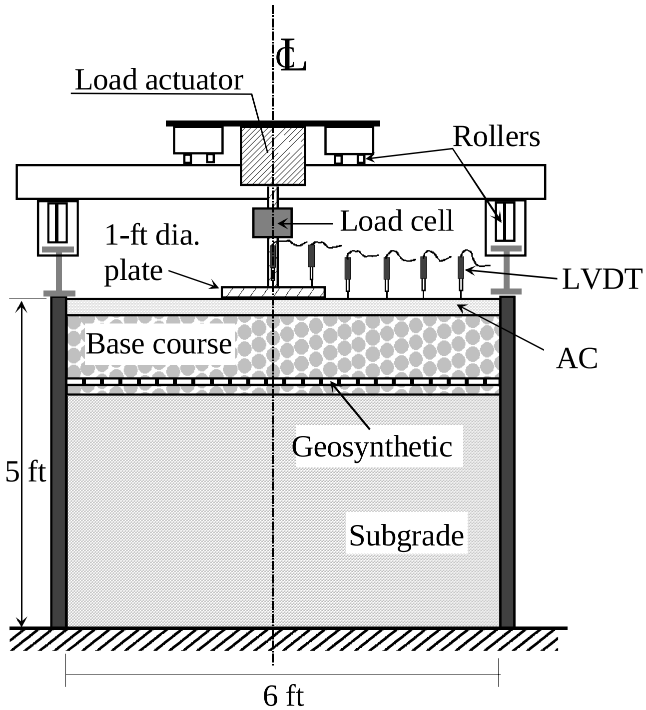
Due to the relatively small size of the sections that are tested using the actuators, a number of case studies were examined. The findings and results of some of the relevant studies demonstrated the adequacy, reliability, and capability of this type of facility. This examination included comparative studies and studies that featured repetitions of test sections to assure the repeatability of the results of identical sections.

Montanelli et al. conducted a series of laboratory accelerated load tests on pavement sections using a cyclic load actuator [*3*]. The sections were prepared in a 3 feet x 3 feet x 3 feet (90 cm x 90 cm x 90 cm) box, and consisted of asphalt, crushed limestone base course, and fine uniform sand as the subgrade. The results of this study showed that the cyclic load actuator can predict the trends and compare different design/construction alternatives (figure 4). The actuator results were also used in the development of the Italian Highway Department design chart (figure 5).

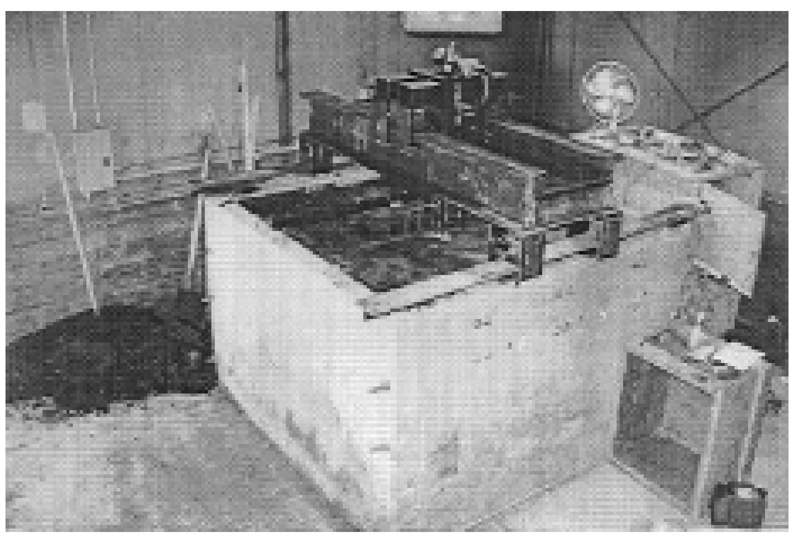
Al-Qadi et al. [*4*] studied the performance of geosynthetic reinforced pavements with weak subgrades. The use of geotextile separators and geogrid reinforcements was validated by conducting a series of accelerated loading tests using a cyclic load actuator on laboratory and field sections. The results of the cyclic load tests, shown in figure 6, clearly demonstrate the benefits of using a separator or reinforcement and increasing the thickness of the base layer.

Using the cyclic load actuator, Perkins conducted an experimental study to validate and compare the benefits of different types of geosynthetic reinforcements in base course layers [*5*]. Two types of geogrids and one geotextile were tested under different subgrade and base course conditions (strength and thickness). The position of the geogrid within the base course was also a variable. As shown in figure 7, the results of the cyclic load actuator had a very consistent trend. The type, stiffness, and position of the reinforcements were clearly identified and evaluated relative to the control (unreinforced sections). Perkins verified the repeatability of the test sections by comparing the measurements and results of two identical sections as shown in figure 8 [*7*]. The reliability of the results can also be verified by examining figure 9, which shows the differences in permanent deformations within the subgrade layer due to small changes in the thicknesses of the base course and subgrade layers at different load repetitions. Perkins conducted additional accelerated load testing of full-scale pavement sections using a heavy vehicle simulator [*7*]. Some of these sections were constructed using materials similar to those tested by the cyclic load actuator in Perkins [*5*]. Based on the comparisons of these sections, Perkins indicated that the results of reduced-scale sections, tested by the actuator, had the same trends as those of the full-scale facility [*7*].

Leng and Gabr represented the results of an experimental study of unpaved reinforced bases on soft subgrades [*6*]. In their study, two types of biaxial geogrids (BX1 and BX2) and two base course thicknesses were used. Sections were prepared in a 53 inch (1.35 m) deep, 5 ft (1.5 m) long and 5 ft (1.5 m) wide steel box. The tests were conducted twice to assure the repeatability of the results (figures 10 and 11). Referring to Figure 10a and 10b, for thin (152 mm deep) and thick (254 mm thick) base courses, respectively, the test sections had excellent repeatability in terms of the measured permanent deformation at any number of load cycles. Moreover, the results in this figure also demonstrate the benefit of using geogrids to reinforce the base course layers. The measured vertical stresses are also provided in figures 11a and 11b for thin and thick base courses. The reinforced sections are shown to perform better by distributing the vertical stress and producing a more uniform pressure than in the unreinforced cases.



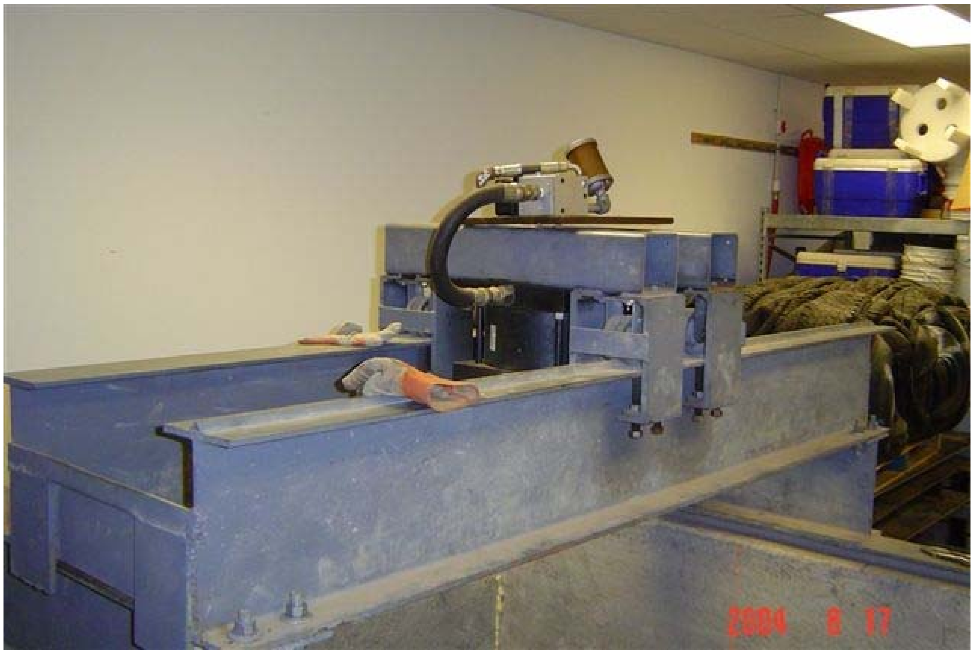
a) Schematic view



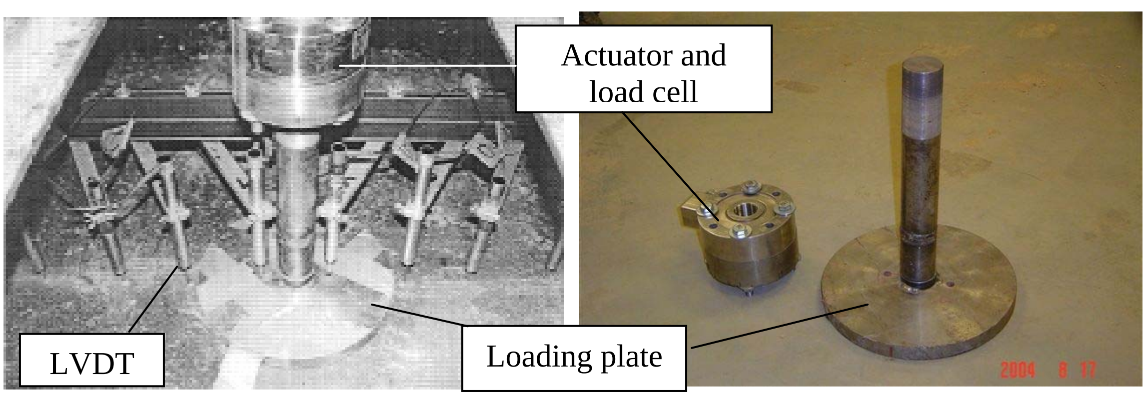
b) Photo Image

Figure 2

A schematic and an image of test box and actuator setup [*5*]



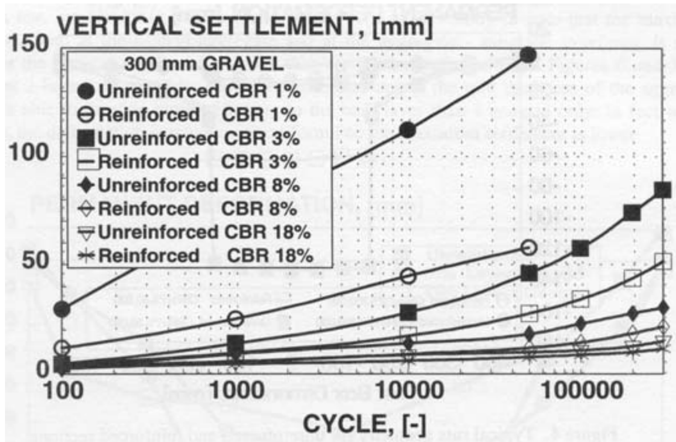
a) Reaction frame



b) Loading and rutting measurement

Figure 3

Loading and measurements: reaction frame, loading, and deformation measurement



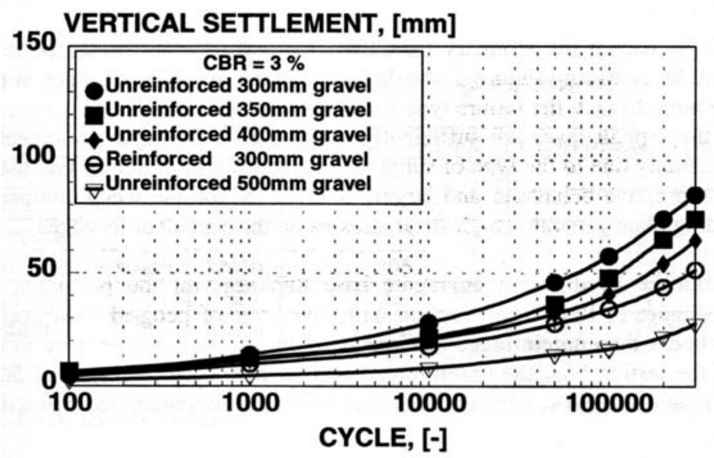


Figure 4
Permanent deformations at different load repetitions applied by the cyclic load actuator by Montanelli et al. [*3*]

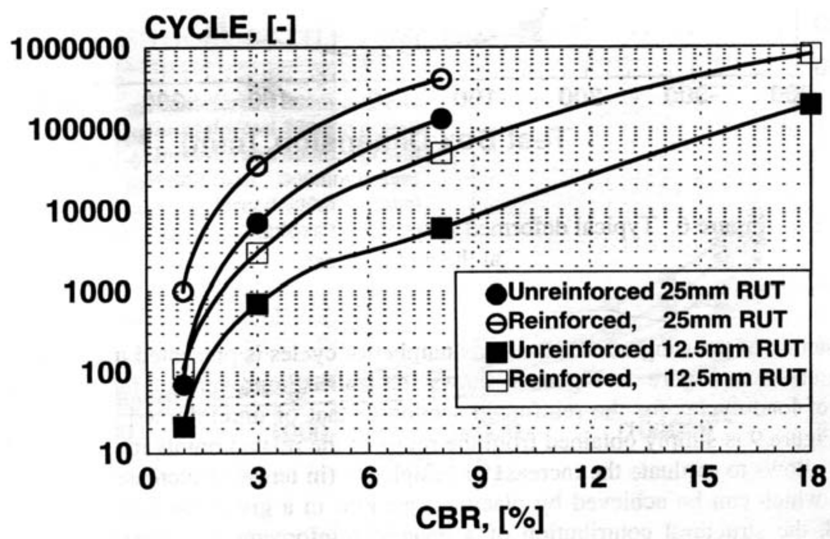


Figure 5

CBR values at different load repetitions for reinforced and unreinforced sections [3]

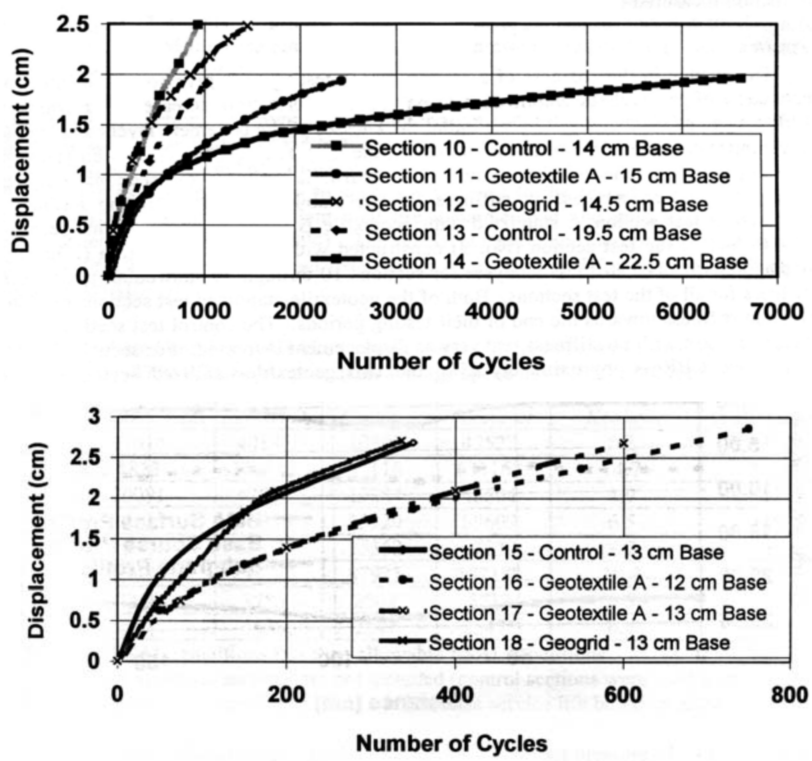
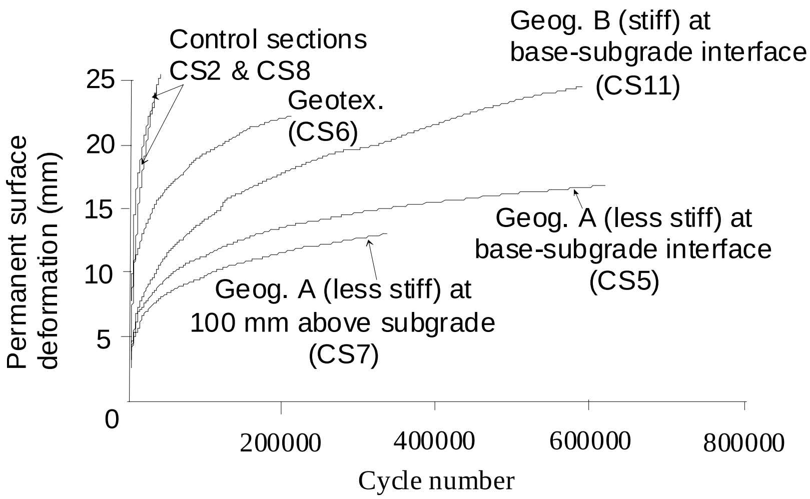
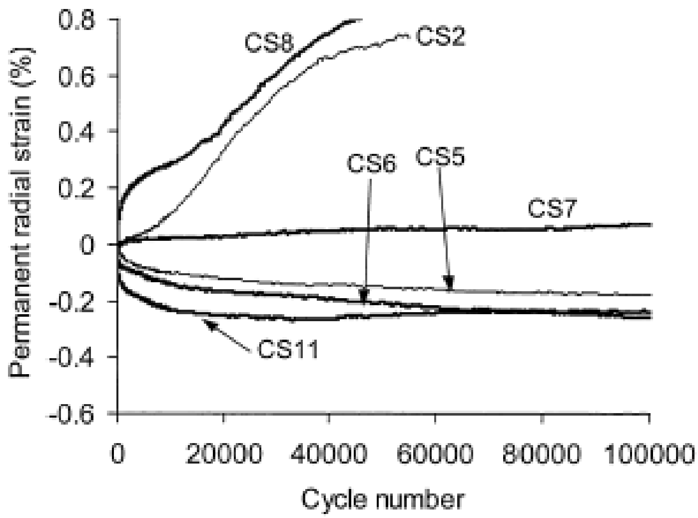


Figure 6

Measured permanent deformations at different load repetitions for pavements with subgrade CBR-values of: a) 4%, b) 2% [*4*]

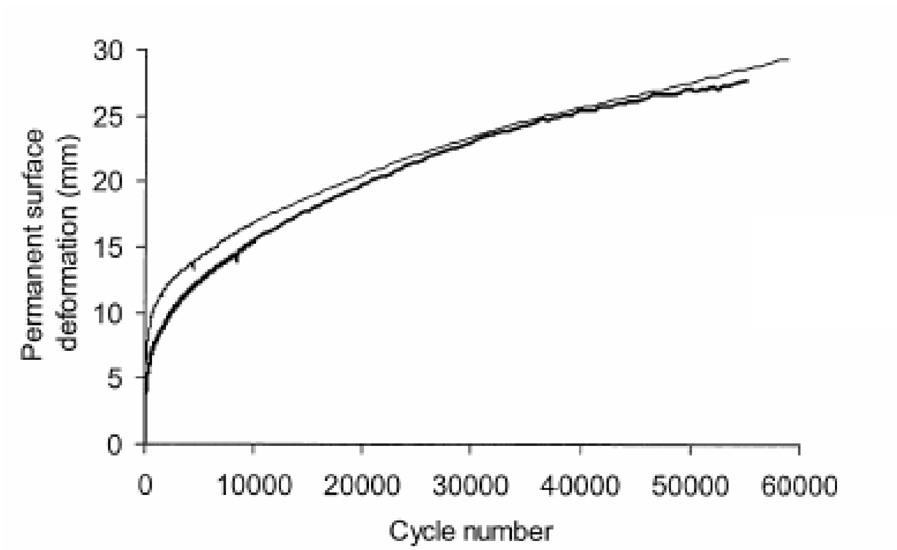


a) Permanent surface strain

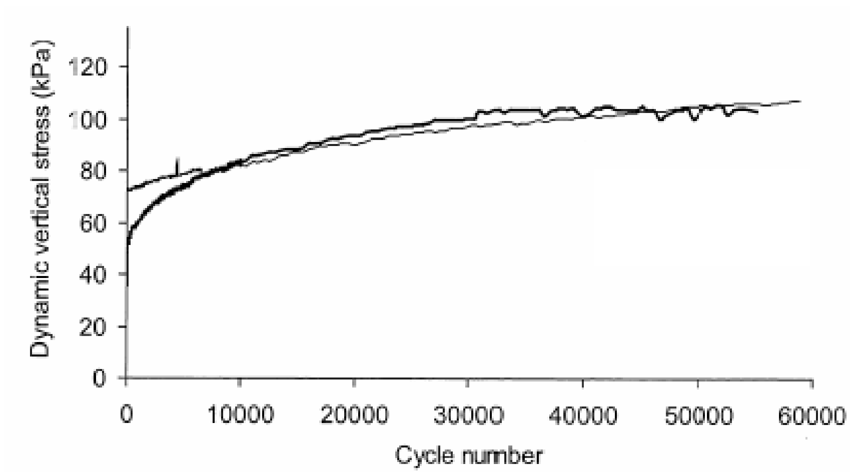


b) Permanent radial strain

Figure 7
The influence of different reinforcement types and reinforcement variables on pavements' responses in terms of: a) Permanent surface strain, and b) Permanent radial strain [*5*]



a) Permanent deformation



b) Dynamic vertical stress

Figure 8

Repeatability of the results of identical test section in terms of: a) Permanent deformation and b) Dynamic vertical stress [5]

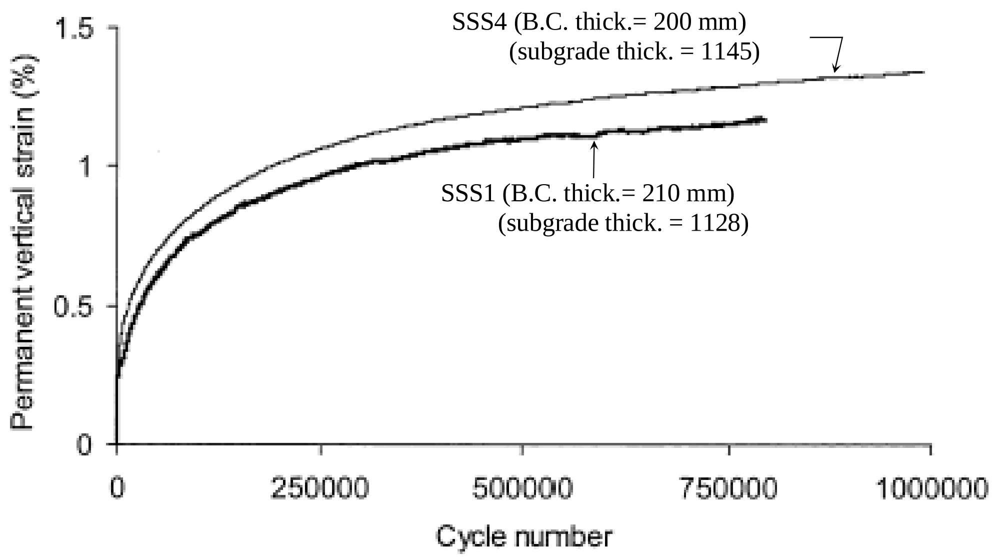


Figure 9

Effect of base course thickness on permanent strain in subgrades based on cyclic load actuator results [*5*]

	152-mm ABC tests			254-mm ABC tests		
a/h1	1			0.6		
Geogrid reinforcement	without	BX1	BX2	without	BX1	BX2
Vertical stress σ_c, kPa	360	330	220	200	180	130
Stress ratio σ_c/q	0.65	0.60	0.40	0.36	0.33	0.24
Modulus ratio E_1/E_2	1	1.6	5	1.2	1.8	4.8

a) 152 mm ABC tests

b) 254 mm ABC tests

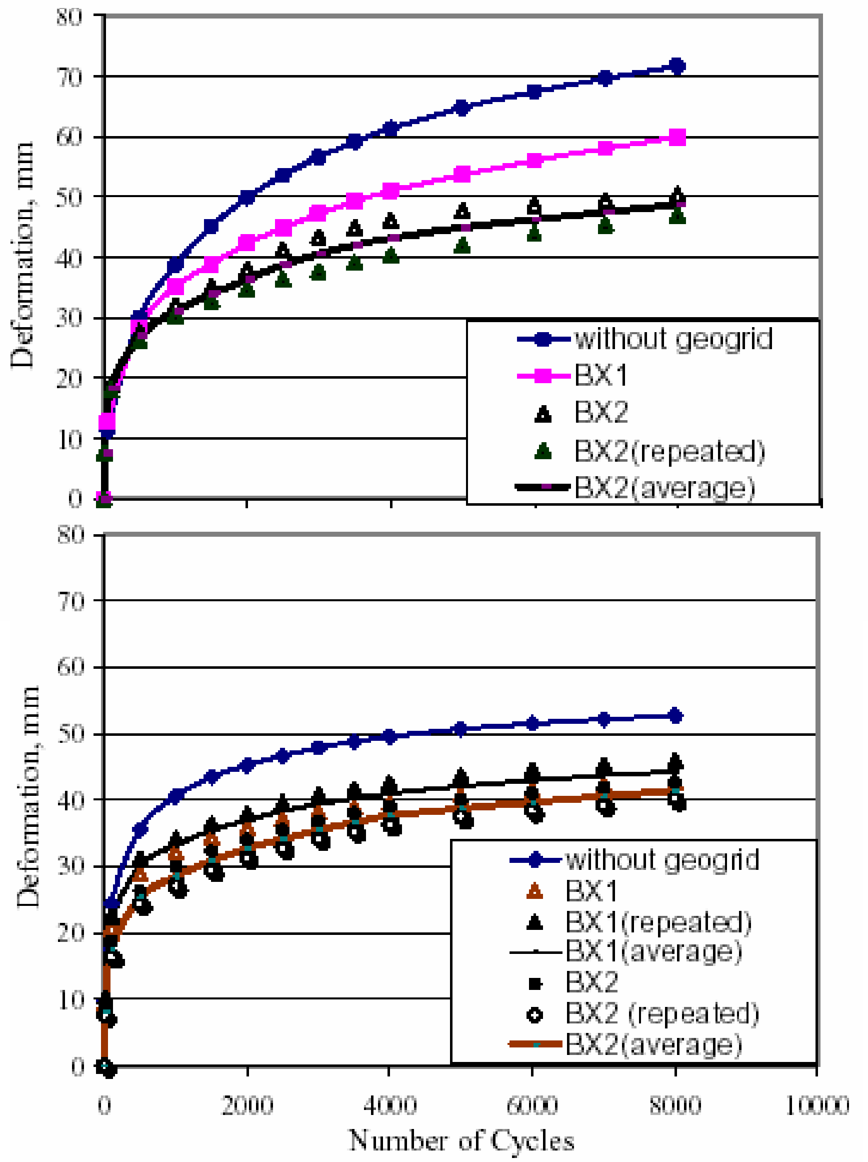
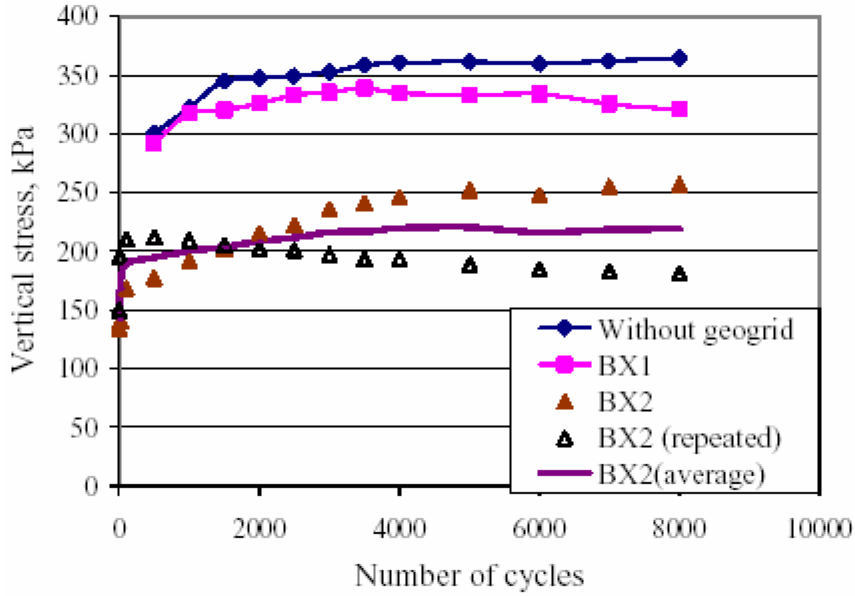


Figure 10

Measured surface deformations due to cyclic load actuator [*6*]

a) 152 mm
ABC tests



b) 254 mm
ABC tests

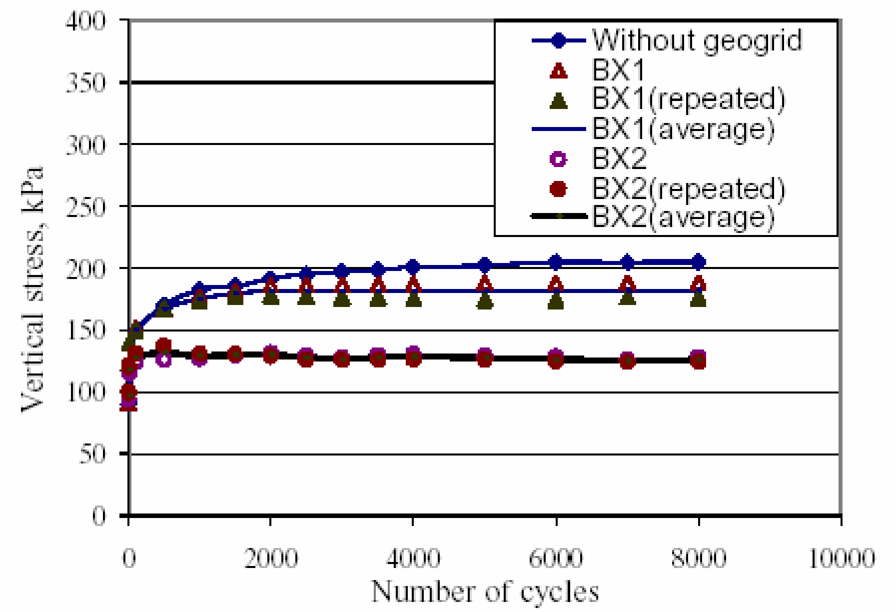


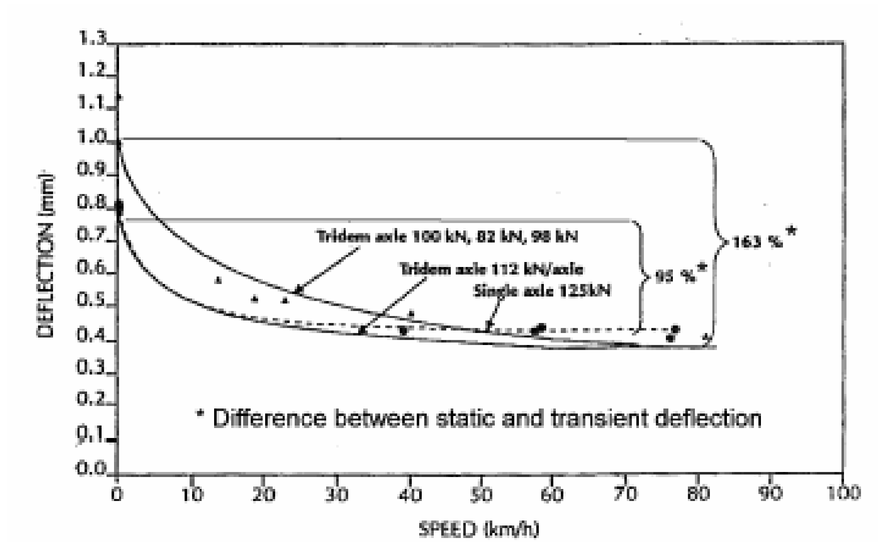
Figure 11

Measured vertical stresses under cyclic loads [*6*]

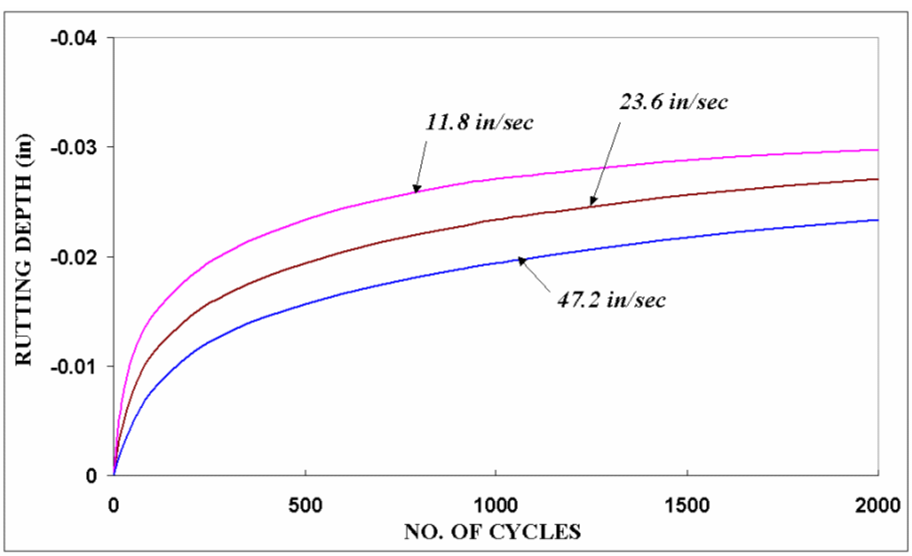
Vehicle Simulators (Wheel-Beam Assembly)

Heavy vehicle simulators (HVS) produce axle loads that represent traffic loads during shorter time durations. In general, they consist of a rotating wheel, supported by a beam (wheel-beam assembly), sliding along a portion of the test section to resemble the real traffic. HVS facilities are usually used as a reference for validating new construction materials or technologies, design theories, or new testing facilities. One of the limitations of these facilities is the wheel speed, which is usually limited to between 5 and 11 mph (8.1 to 17.8 km/h). Wheel speed, axle load, and environmental conditions (moisture and temperature) significantly influence the pavement performance and rutting responses. Based on the field measurements by Lourens and the finite element study by Al Qablan increasing the speed of vehicles resulted in less rutting at the same number of wheel passes (figure 12) [*8*,*9*]. The effect of the temperature on the rutting of the pavement is depicted in figure 13.

The Accelerated Load Facility (ALF) at the Pavement Research Facility (PRF) has been a valuable tool for LADOTD and LTRC since 1994. Similar facilities are available, including the following: Texas Mobile Load Simulator, CSIR Transportek, Berkeley Pavement Research Center at the University of California, University of Illinois- ATLaS, Accelerated Pavement Load Facility (ORITE- APLF), TRL's APT Facility, Accelerated Pavement Testing machine at the Florida Department of Transportation, U.S. Army Corp of Engineers Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Corp of Engineers Waterways Experiment Station, Indiana Department of Transportation Accelerated Pavement Testing (APT) Facility, The Turner Fairbank Highway Research Center (TFHRC) of the Pavement Testing Facility, Civil Infrastructure Systems Laboratory of Kansas State University, and the Pavement Test Track at National Center for Asphalt Technology (NCAT). Appendix A provides more information about some of these HVS facilities.



a) Experimental results [*8*]



b) Finite element analysis [*9*]

Figure 12
Effect of wheel speed on the rutting depth of pavement

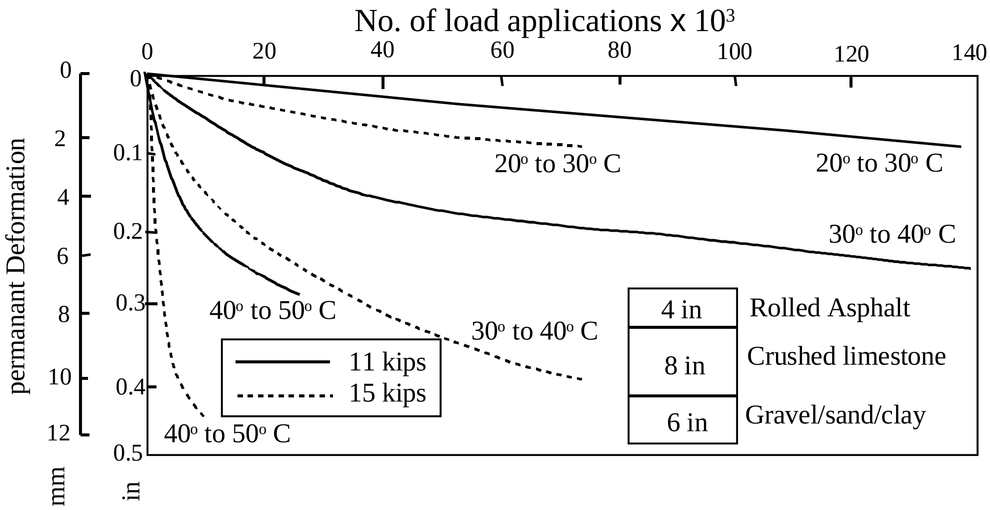


Figure 13

Effects of wheel load and temperature on the permanent rutting [*10*]

Despite the reliability of their results and findings, the wheel-beam simulator facilities are costly to purchase, construct (test sections), operate, and maintain. Other limitations include large test areas, long test times (even though accelerated), and limited and costly mobility. The setup cost for HVS facilities ranges from $0.3 million to well over $2 million, with $10 to $40 thousand in maintenance spending, depending on the size of the facility. The long test times are mainly attributed to the mechanism of loading and wheel movement. For one load cycle, the loaded wheel accelerates to reach a maximum speed of 5 to 11 mph and maintain speed along the measurement length, and then it decelerates back to zero. The acceleration and deceleration lengths are usually 10 to 20 feet, increasing the test duration significantly.

Model Mobile Load Simulator (MMLS3)

A compact, relatively fast, and less costly facility is the Model Mobile Load Simulator (MMLS3). This facility was introduced primarily to test the surface layer of pavements, since it has a shallow influence depth. Referring to the schematics of the MMLS3 facility (figure 14), the wheels circulate in the vertical direction and maintain a constant speed up to a maximum of 5.6 MPH. A picture and specification are provided in figure 15 and table 1, respectively.

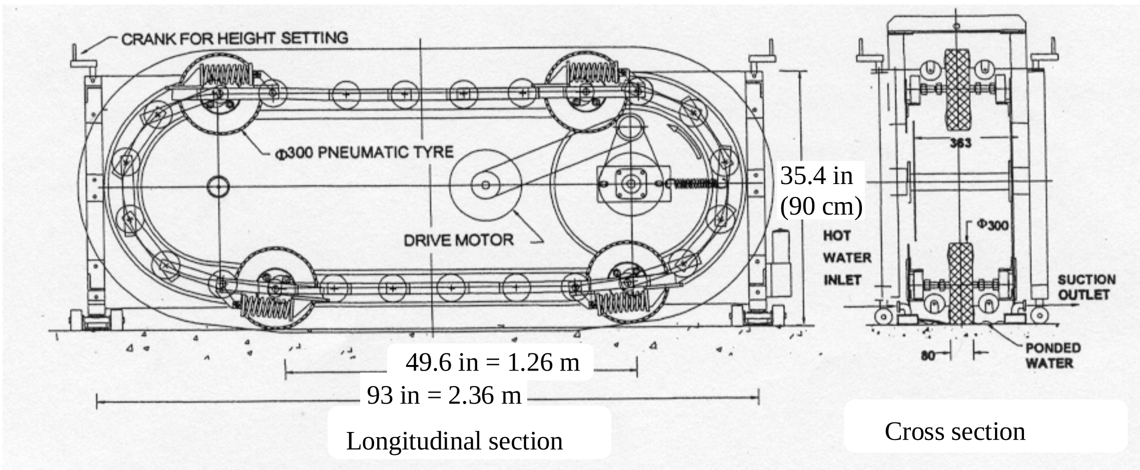


Figure 14
Schematics of the MMLS3 test facility

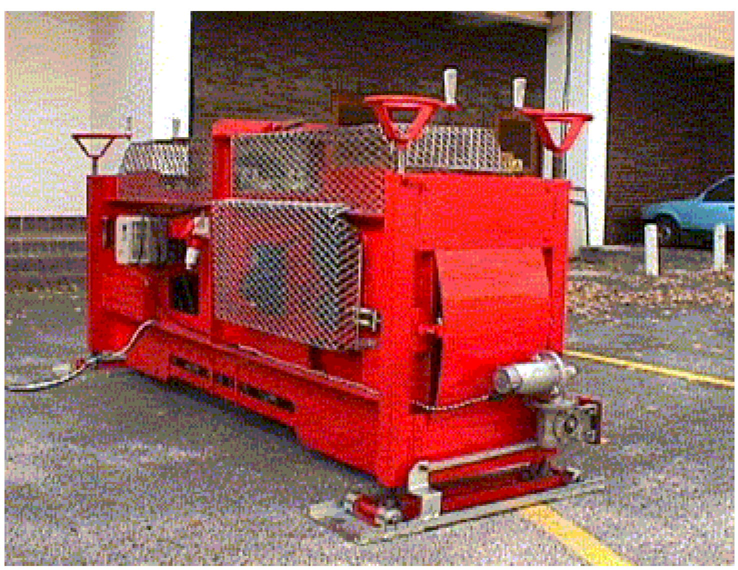


Figure 15
Texas MMLS3 [*11*]

Table 1
Specifications for the MMLS3 [*16*]

Number of Bogies	4
Wheel Diameter	1 ft (30.0 cm)
Load per wheel	427~600 lb (190~275 kg = 1.9~2.7 kN)
Tire pressure	$\leq$ 115 psi ($\leq$ 800 kPa)
Nominal speed	5.6 MPH (9 km/h)
Passes per hour (per second)	7200 (2)
Equivalent load frequency	4 Hz

The size of the tire contact area (3-inch wide tires) and the magnitude of axle load for the MMLS3 are less than actual traffic values, which is a major concern. Two approaches have been used to solve this problem. The first approach is to resize the pavement layers to make up for the differences in loads and contact areas. In this approach, it is hypothesized that the asphalt concrete and base course layer thicknesses of the test section should be reduced. In fact, the MMLS3 was referred to as a one-third scale facility due to the reduced size of tires and wheel loads [*11, 12, 13, 14, 15, and 16]*. The equivalent single axle load (ESAL) also needs to be reduced. This approach involves an assumption regarding the linearity and nonlinearity of the pressure distributions within the pavement layers, thus ignoring the shear modulus of these layers. Although this approach might work in some cases for evaluating asphalt layer, and possibly a thin base layer, it is impossible to evaluate the subgrades due to shallow influence depths. In addition, it is very difficult to scale the reinforcement in case of evaluating reinforced sections.

In the second approach, described by Walubita et al., the MMLS3 is run on each of the pavement layers; e.g., on top of the base course and after the placement of the AC layer [*15*]. The amount of rutting in each layer is then factored and combined with the other rutting values to estimate the total rutting of the pavement section. Testing each layer increases the testing time, making this approach impractical. Moreover, the rutting of the pavement section is not necessarily linearly related to the rutting values of all constituting layers. Although this approach may work in some cases, such as evaluating asphalt layers and possibly the base course layer, it is impossible to evaluate the subgrade due to the shallow influence depth. In addition, it is very difficult to scale the reinforcement when evaluating reinforced bases and subgrade.

Walubita et al. conducted an experimental study, with laboratory tests and the full-scale Texas Mobile Load Simulator (TxMLS), to evaluate the performance of rehabilitated aggregates using a reduced-scale MMLS3 [*15*] (see figure 16). The purpose of this study was to evaluate the performance of US 281 in Jacksboro, Texas, under different environmental conditions (wet, dry, and different temperatures). Walubita et al. indicated that the rut depths measured using the MMLS3 could be related to those of the TxMLS (figure 17) [*15*]. Based on the results of the finite element analysis, Walubita et al. indicated that the pressures due to the MMLS3 at different depths can approximate the actual (full-scale) pressure distribution of the traffic (figure 18) [*15*]. However, the authors believe that the shallow influence depth, which was less than 6 inches, and the non-linearity of the materials' behavior, question the reliability and applicability of MMLS3, especially for the cases of soft subgrades and in reinforced sections.

Hugo et al. investigated the stress distributions due to the TxMLS and MMLS3 wheel loads using ELSYM5 F software [*16*]. They used the second approach described by Walubita et al. for the MMLS3 [*15*]. The results of their analytical study indicated that the pressure distribution based on the MMLS3 was similar in shape to that of the TxMLS, yet they had different magnitudes. They also indicated that the MMLS3 can be used as a supplemental tool to the full-scale TxMLS, despite the limitations imposed by stiff pavement surfacing layers. This conclusion was based only on numerical modeling and was not supported by a large sample of experimental data.

a)

b)

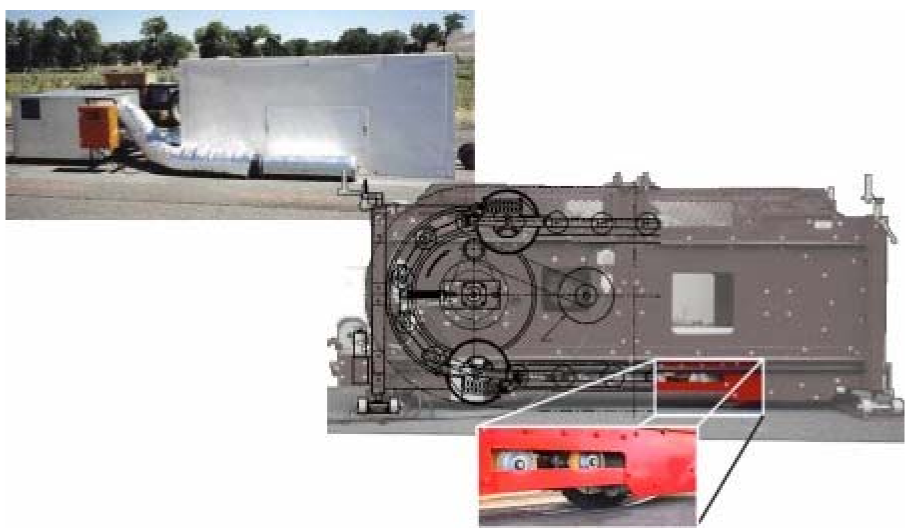


Figure 16
Model mobile load simulator (MMLS3): a) Wet pavement heating, b) Environmental chamber

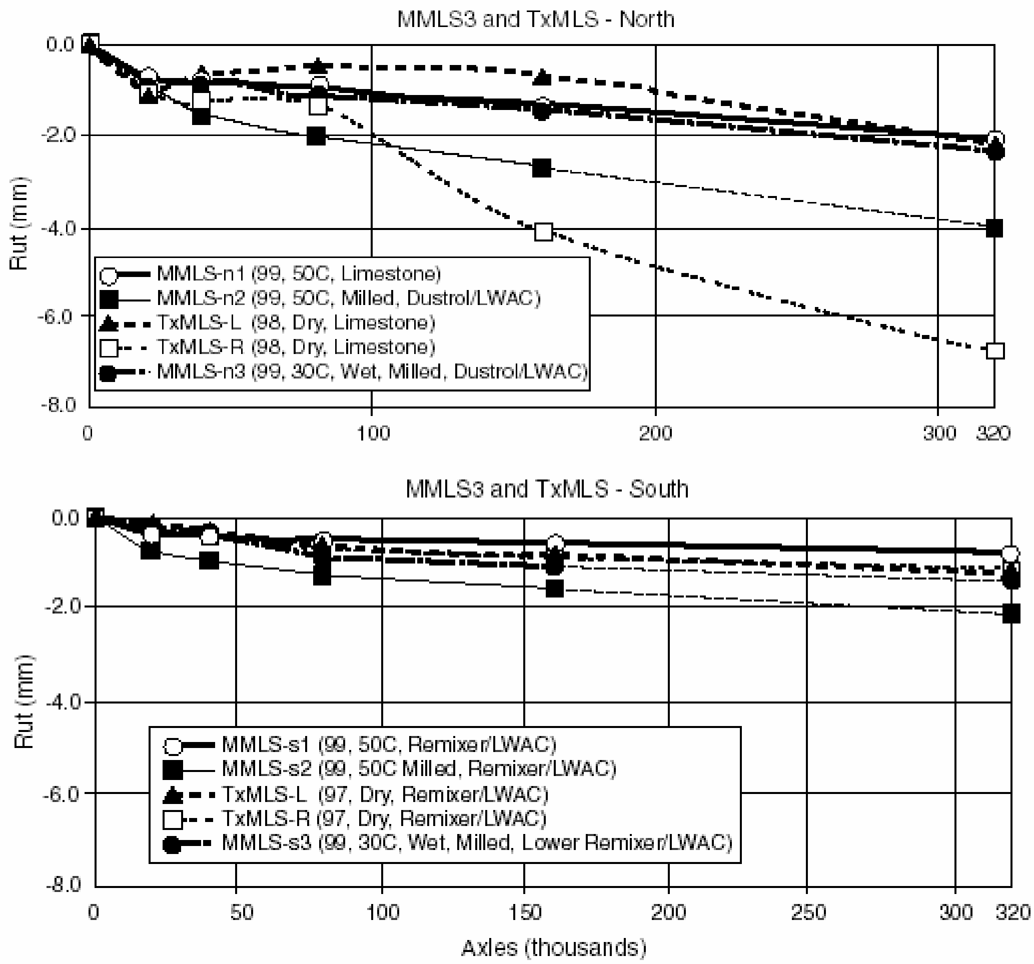


Figure 17

Comparisons between the MMLS3 and the TxMLS rut depths [*15*]

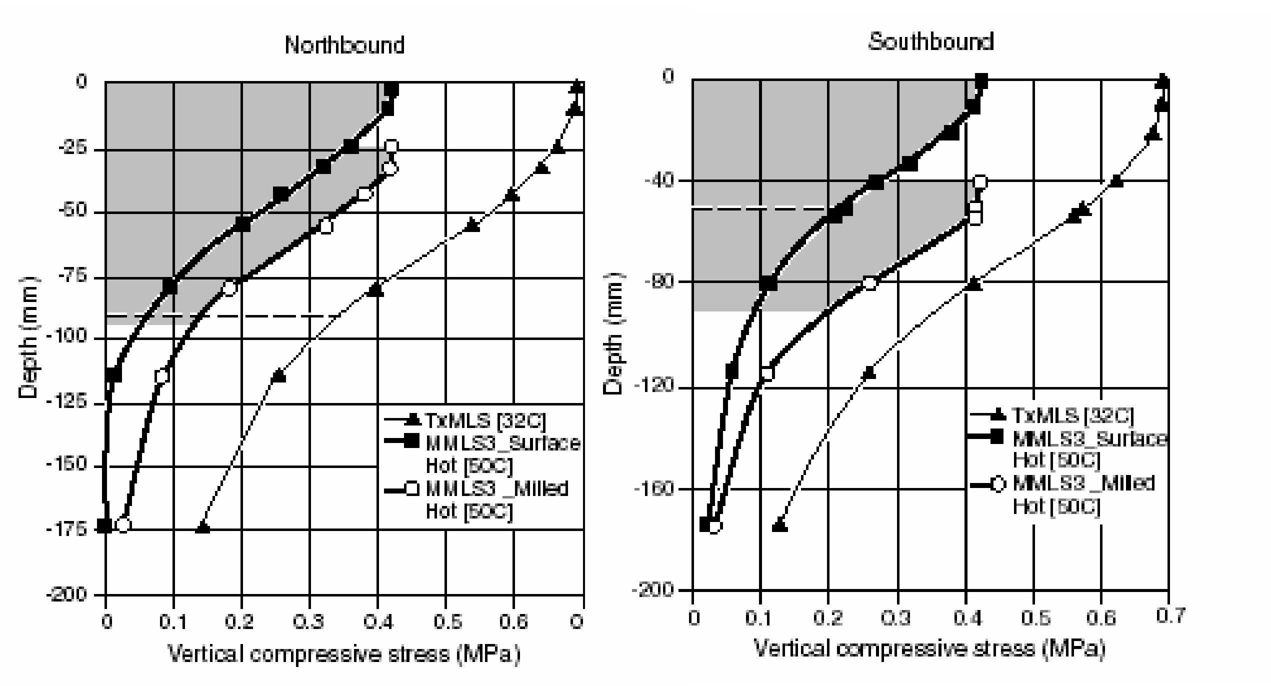


Figure 18
MMLS3 and TxMLS vertical pressure profiles [*15*]

Epps et al. compared the results of reduced-scale testing using the MMLS3 with those of the full-scale TxMLS [*11*]. They validated the MMLS3 by comparing the theoretical rutting ratio (*TRR*), using the MMLS3, with the field rutting ratio (*FRR*), using the TxMLS. The ratio of *(TRR)* to the *(FRR)* defines the rutting performance ratio (PR_{rut}). The PR_{rut} is an indication of acceptance for the MMLS3 measurement. A PR_{rut} value equal to one indicates the best predictability of the MMLS3. Based on their results and comparisons, Epps et al. showed that the actual rutting performance can be related to the MMLS3, given that further considerations should be made towards evaluating the effects of the viscoelatic behavior of the AC layer and the differences in the contact and shear stresses between the actual traffic load and the MMLS3 conditions [*11*].

In another study, Smit et al. indicated that the MMLS3 may be used to estimate full-scale rutting performance [*12*]. Smit et al. reported that the correlations used to predict the actual rutting based on the MMLS3 may exceed the actual field rut depths and that the environmental conditions should be investigated and accounted for in the formula to calculate the actual rut depth [*12*].

FEASIBILITY AND COST EFFICIENCY

Louisiana owns one of the largest accelerated load facilities in the United States. This facility has been effectively used for various pavement performance applications. The selection of the most beneficial facility, which will be used for preliminary and comparative studies prior to using the LTRC-ALF, will be determined based on the following considerations:

1. *Benefits of the facility*. The facility should be convenient for conducting preliminary and comparative evaluations of pavements with different designs, construction methods, and/or materials. A smaller, more cost effective facility would allow more sections to be tested initially, which would subsequently reduce the number of more expensive tests using the LTRC-ALF. The results and findings of the proposed facility could also be correlated to those of the full-scale pavement sections, obtained either from LTRC-ALF or real traffic data.
2. *Cost efficiency*. The cost benefits of the new facility will be determined based on the following factors:
   a) Setup cost, which is the sum of initial cost, site preparation cost, and the cost of housing for the facility. The setup cost for different facilities currently available vary based on the type of facility, the size of facility, and the additional equipment needed. The initial cost of the model load simulator or the cyclic load actuator is considerably less than that of the heavy vehicle simulator.
   b) Cost of preparation of test sections. This will primarily depend upon the type and size of the facility and whether the pavements are laboratory (reduced-scale) or full-scale. The number of test sections that can be tested at the same time will also be considered in this analysis.
   c) Maintenance requirements. The maintenance cost will be estimated based on the experiences of other research agencies that already posses these facilities. The maintenance spending will be based on the average maintenance dollars spent for at least 10 years of operation.

Provided the objectives and targeted benefits of the proposed facility are met, the following three types of facilities will be considered in the feasibility study: (i) the cyclic plate and load actuator test facility, (ii) model mobile load simulator (MMLS3), and (iii) the moderate size (length) heavy vehicle simulators (ATLaS type). Recommendations as to which device will best suit LTRC's interests will be made based on two considerations: (i) cost efficiency, and (ii) compliance with LTRC goals.

Benefits of Accelerated Load Facilities

The usability of the accelerated load facility for different pavement research objectives and the reliability of the results will be the major two concerns in the development of the facility. This report emphasized the evaluation of the rutting performance pavements with a wide range of construction materials and technologies, as well as different environmental conditions. The reliability of the results of the vehicle load simulators depends on how well the simulator facility duplicates actual traffic. Accordingly, an understanding of the real life loading mechanisms and variables that prevail under actual traffic is essential for conducting the comparative study. These mechanisms are:

1. Axle or wheel loads and the area and shape of the wheel-pavement interface. The influence of the magnitude and shape of applied surface load on the rutting or deformation of a material can be shown by the relationship relating the permanent deformation ($\Delta\varepsilon$) of a material to the load (stress) applied for certain time duration (Δt) or certain number of cycles using the characteristic constants of the material (B, n`), as follows:

   $$\frac{\Delta\varepsilon}{\Delta t} = B\sigma^{n'} \tag{1}$$

   Moreover, the shape of the applied load (square, rectangular, circular, elliptical, etc.) determines the shape of the pressure distribution within the pavement structure or ground, thus influencing the amount of rutting.
2. Speed of loading (speed of wheel movement). As described earlier, the results of the finite element (FE) analyses and the field measurements (shown earlier in figures 12a and 12b, respectively), have indicated that increasing the speed of traffic results in less rutting for the same number of wheel passes (cycles).
3. Traffic wander. The deviations and inconsistencies in the path of vehicle passage contribute to the reliability and precision of the predictions of the pavement rutting for a certain pavement service life.
4. Tire pavement stresses. These include normal and shear stresses within the pavement structure, as well as friction (skid) stresses along the upper surface of the pavement.
5. Environmental conditions. Accommodating the climatic and ground water variations is essential to the prediction of real-life pavement performance. The moisture and ground water variations significantly alter the rutting performance of pavements. Increasing the temperature of asphalt pavement, on the other

hand, would increase the rate of rutting development of the pavement. This can be explained by the following equation relating the rate of permanent deformation (rutting) to the temperature of the material, and the characteristic constants (*A* and β) of the material under a given maintained load:

$$\frac{\Delta\varepsilon}{\Delta t} = Ae^{\beta / T} \qquad (2)$$

Controlled environmental conditions require that the test section and test facility be isolated and housed inside a chamber or building that enables the control of temperature and moisture throughout the test.

The first major feasibility concern of this study was the capability of different pavement testing facilities to represent the above mentioned mechanisms and factors so as to resemble real-life traffic. Stationary cyclic load actuators, vehicle load simulators, and model load simulators are considered in this part of the report.

Cyclic Load Actuators

The advantages of the cyclic load actuators include:

1. They perform testing faster than other alternatives and enable more test sections to be conducted.
2. Cyclic load actuators can be programmed to represent different load-time scenarios. Different traffic speeds (up to 55mph), load magnitudes, and tire contact areas can be assessed.
3. Due to their compact size, environmentally controlled conditions can be easily accommodated and applied.
4. They can be used for conducting comparative studies for a variety of purposes such as:
   a. Paved and unpaved roads, different asphalt pavement mixtures, reinforced and unreinforced top layers.
   b. Base course and/or subbase: material compositions (crushed stone or recycled product), grading, different treatment/stabilization methods, reinforced and unreinforced conditions.
   c. Subgrade materials and conditions: weak and stiff subgrades, different subgrade treatment methods, subgrade compaction methods, and subgrade moisture content and ground water conditions.
   d. The use of geosynthetics in pavement construction: pavements with reinforced and unreinforced base courses, pavements with reinforced subgrades, pavements with reinforced top layers, pavements with

separation layers at the subgrade-base course interfaces, and pavements with geosynthetic drainage control layers.

e. Geosynthetic reinforcements' variables: type of reinforcement, reinforcement geometry, reinforcement stiffness, and location of reinforcement within pavement layers.

f. Environmental conditions: different moisture and water table conditions and different test temperatures.

g. Test loads: different load magnitudes, different load frequencies (speeds), and different load repetitions (number of loading cycles).

h. Design methods: comparing the reliability and acceptance of new methods for design of paved and unpaved roads.

i. Validation of new developments: Future developments pertaining to construction materials, advances in soil treatment of pavement layers, construction technologies, and new design methods can be validated using the cycli load actuator device.

j. They can be used for other experimental studies under actual confinement conditions, such as in-situ triaxial and resilient modulus, in-situ creep load tests and bearing capacities of model footings.

5. They can be correlated and calibrated to the full-scale PRF-ALF facility.
6. They allow for future upgrades and modifications of the type of load and load functions as well as the shape or material of the loading plate, thus becoming usable for different applications or testing purposes.

The disadvantages of the cyclic load actuators may be summarized as:

1. Cyclic load actuators can not represent traffic wander.
2. The relatively small section sizes might raise concerns about repeatability of sections and variance in properties. However, communications with other research agencies experienced with similar facilities indicated that section repeatability is a minor concern. They indicated that a section can be repeated with reasonable accuracy.
3. They can not simulate the friction stresses caused by the wheel rotation on pavement (skid).
4. Although the cyclic load actuator can apply loads approximately the same as of the actual traffic, it may not represent the actual tire-pavement stress distribution produced. The loads that can be applied by the load actuators are uniform within the entire contact area, which is equal to the area of the plate. However, in real-life traffic, the vertical and lateral stresses are not uniform

in both directions (the lateral and longitudinal directions) of the wheels. A study by Pottinger and McIntyre showed that distributions of the contact stresses along both directions (figures 19 and 20, respectively) are not uniform [*17*]. The non-uniformity of the contact stresses in the lateral direction (figure 19) is less than the longitudinal direction (figure 20).

The cyclic load actuator device could be as a very useful and valuable method for conducting preliminary and comparative performance studies. It can be used for testing paved and unpaved sections with variety of material options and loading scenarios. An essential step preceding the use of this facility, however, is to correlate its results and findings to those of the full-scale PRF-ALF, this alleviating the concern about the errors caused by the differences in the shape of the loaded area (uniform or no-uniform stress) and mechanism of load application (cyclic versus moving load mechanisms). To this date, the effects of these variables on the performance of pavements have not been determined. Correlating the results of cyclic load actuators to the PRF-ALF can be accomplished by comparing the results of identical sections tested using both facilities.

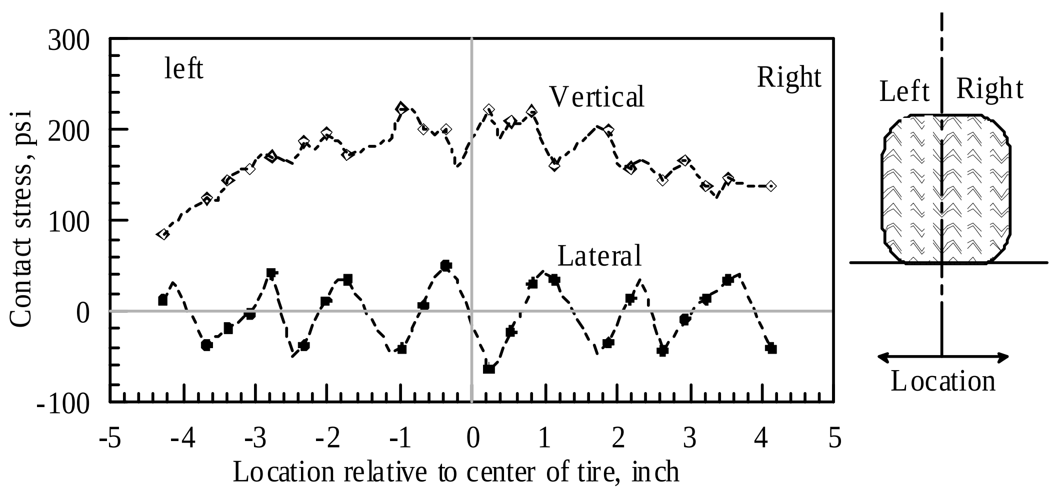


Figure 19

Vertical contact stresses measured along the lateral direction of the tire (after Pottinger and McIntyre [*17*])

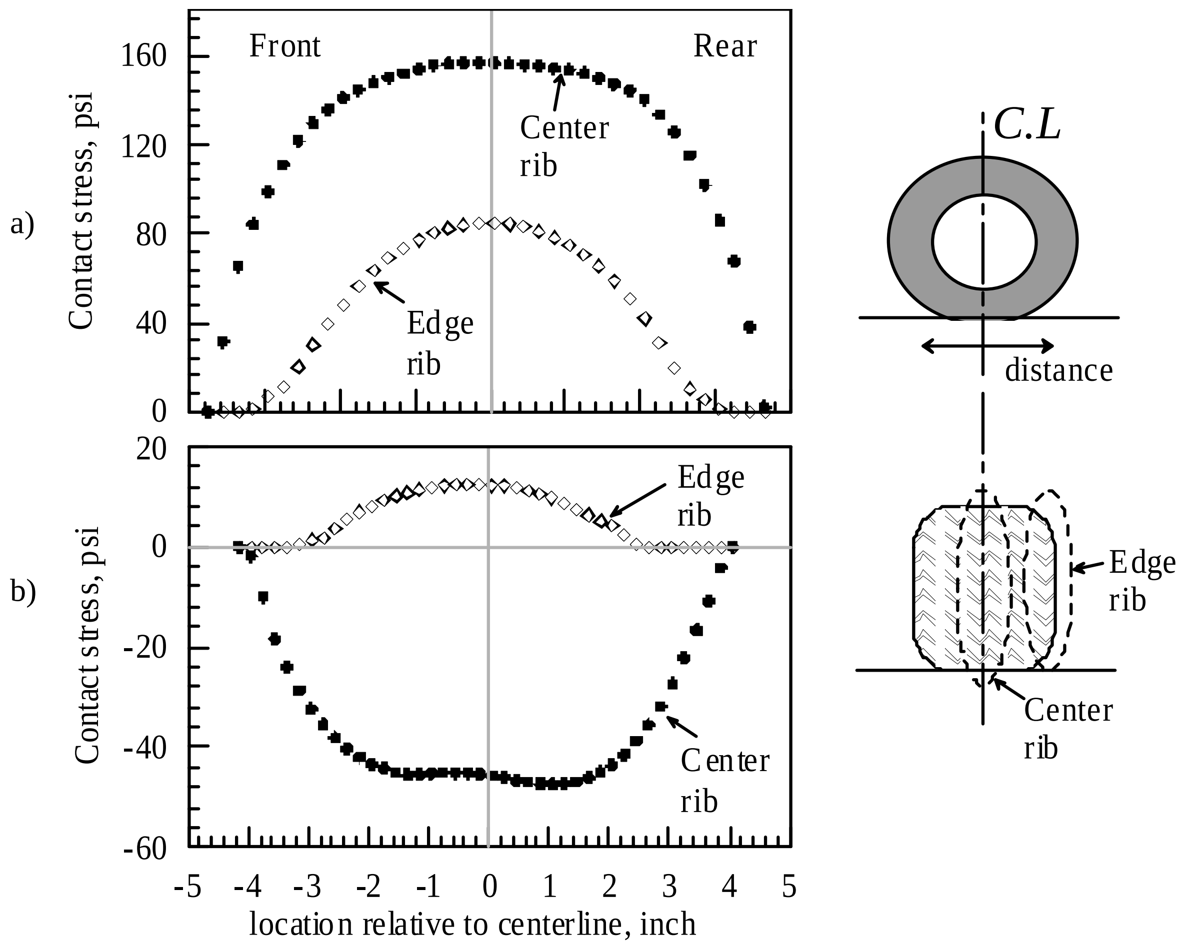


Figure 20
Variations in the measured contact stresses in the longitudinal direction along the edge of a radial truck tire: a) vertical stresses, and b) lateral stresses (reproduced from Pottinger and McIntyre [*17*])

Vehicle Simulator (ATLaS type)

The best simulation of the magnitude and shape of real-life surface (traffic) loads, traffic wander, tire-pavement stresses, and load transition effects may be obtained by using the large scale (wheel-beam assembly) vehicle simulators, similar to the LTRC-ALF. Within this category, a variety of sizes are available, ranging from compact (30 to 40 feet long), similar the Kansas-APT and ATLaS-20, to large (more than 80 feet long) facilities. Only compact vehicle simulators will be considered in the feasibility and cost-benefit study.

The main advantage of this type of facility is the resemblance of the traffic loading as indicated above. However, the disadvantages of this type of facility are:

1. The wheel speed limitations (5 to 10 mph),
2. test duration; it is a time consuming test compared to the MMLS3 or load actuators,
3. The size of test section is larger than that of the other two categories (30 feet long and 8 feet wide, minimum),
4. Size of facility housing, in case of environmentally controlled house; also larger than the housing required for the other two categories (50 feet long, 15 feet wide, and 15 feet high, minimum). It also requires additional housing for the compressor, and
5. The setup and maintenance costs are considerably larger than those of the other alternatives (cyclic load actuator). Moreover, the LTRC already possesses a bigger facility of the same type (LTRC-ALF) at the pavement research facility site. Having a compact facility of the same type that has longer test duration may not be a wise alternative. The proposed facility should be fast and reliable so that it can be effectively deployed in preliminary and comparative studies.

Model Mobile Load Actuator (MMLS3)

The MMLS3 device is relatively light weight, portable, and fast compared to the larger wheel-beam assemblies. Its compact size and loading mechanism allow indoor and outdoor sections to be tested relatively faster than on heavy vehicle simulators.

The disadvantages of this facility can be summarized as follow:

1. The MMLS3 facility was originally developed for testing the AC layer due to the dimensions of the device, the size of tire, and the magnitude of the wheel loads, which affects its influence depth.

2. Although the published works by Hugo et al., Walubita et al., Epps et al., and Smit et al. have shown that the findings of the MMLS3 could be correlated to the actual field performance of pavements, more research and full scale testing is needed to verify the adequacy of this device in predicting the performance of full pavement structures*[16,15,11,12]*. The effect of the influence depth limits MMLS3 applications to the AC layer and sometimes the top base layer.
3. The two approaches described earlier for testing using the MMLS3 have the following major concerns:
    a) In the first approach, the layer thicknesses and loads are reduced to make up for the small contact area and wheel load. For this to happen, the stress, contact area, and thickness (or depth) should be linearly related. The material properties are also assumed not to influence the stress distribution within the depth of a given layer. These are unrealistic and questionable assumptions that would definitely lead to major discrepancies. The transformation of the full-scale sections into reduced test sections is a rather complicated process that involves many variables, such as the test load compared to the actual traffic load, the effects of the material properties, the thicknesses of different pavement layers, the presence of ground water or suction heads, and the use of fabrics or reinforcing members within the AC, base course, or subgrade layers.
    b) In the second approach, a full pavement structure is tested by running the MMLS3 more than once after the completion of each of the constituting layers. This approach is time consuming and not yet proven to be adequately accurate or reliable. This approach also ignores the effects of the size of the load area on the pressure distribution and the resulting permanent deformation.

Based on the characteristics and limitations of this facility, the MMLS3 device may only be recommended for testing the surface (AC) layer. It may not be a wise choice for the proposed facility since it does not fit the objectives of the proposed research study. Therefore, it was eliminated and it will not be considered in the cost-benefit analysis in the next section of the report.

Cost Efficiency

Only the cyclic load actuator and vehicle simulator were considered in the cost-benefit study. The MMLS3 was ruled out since it did not fit the objective of the proposed research study. The cost of each alternative includes the setup cost, operational and maintenance costs, and the costs of test sections. The total setup costs of any of these facilities is the sum of the setup cost, maintenance spending, cost of preparing test sections, and the cost of workmanship and labor. Tables 2 and 3 provide the total setup costs for the two facilities and the average annual maintenance and construction costs, respectively. The costs of the actuator facility were provided by Mr. Jianren Wang of Geotesting Express in Atlanta, Georgia, which posseses the actuator facility that was earlier used by Perkins [*5*]. The costs of the vehicle simulator in these tables were provided by Dr. Khalid Farrag of the Gas Technology Institute (GTI) in Des Plaines, Illinois, which owns the ATLaS-20 vehicle simulator.

A cost-benefit analysis was conducted for these two alternatives based on their setup costs, operational and maintenance costs, and the costs of test sections. The cost-benefit analysis was conducted as follow:

1. The average maintenance and operational spending was evaluated. Operational costs include the labor and power supply (utilities) necessary for running these tests. The operational and maintenance spending is taken as an average value cost over a 10-year period.
2. The duration of the tests and the number of sections tested per year were examined. For a given load frequency, the objective of the test and the failure criteria determines the test duration. In many instances, depending on the construction materials or test objectives, the test may be completed after running 100,000 to 1,000,000 load passes. This is usually convenient when comparative studies are needed on different design or construction material alternatives. Another more frequently used criteria is the predetermined permanent deformation (rutting) value at which the test is stopped which is usually when one-half inch of rut is reached. According to these variables, the test duration is given as the range, as shown in Table 3.
3. The actual metered cost (cost/sections) of facility was evaluated. Due to the differences in the capacities of the two devices (sections tested by each facility per year), the actual metered costs were considered as follow:
    a. The average cost per section, per year (cost/sec.yr), considering maintenance, is calculated as the sum of the average section cost ($US/section) and the maintenance needs for one section, given that

the maintenance cost is distributed evenly on all sections tested throughout the year, i.e;

Cost/(sec.yr) = (cost/section) + maintenance/section/year

b. The cost of testing any number of sections, also considering the maintenance cost, is calculated as:

Cost/n-sections = n x [$US/section + maintenance/sections/year]

The total cost, as a function of the number of sections, is shown in Figure 21 for both devices. The shaded area indicates a range in costs due to the range of embedded costs of materials, instruments used, etc. This figure clearly shows that the cost of an actuator test section is considerably less than that of the vehicle simulator. Moreover, as the number of sections increases, the difference between the two facilities becomes larger, and the two facilities become incomparable. This is due to the differences in the number of sections per year and the differences in maintenance and operational cost requirements.

4. The normalized benefit/cost (B/C) ratio was determined. The actual benefit/cost ratio of any facility (B/C_i) is expressed as:

$$B/C_i = \frac{savings\ on\ highway\ and\ traffic\ system}{Cost_i} \tag{3}$$

where the subscript (*i*) dictates the facility type. B/C_A and B/C_T represent the benefit/cost ratio of the actuator and the vehicle simulator, respectively. The implementation and findings of these facilities the anticipated to create savings in highway construction and maintenance (longer highway design service life), improvement in vehicle fuel consumption, etc. The calculation of these benefits involves many uncertainties in a rather complicated process, potentially resulting in a wide range of savings (benefits). A simpler approach was to use a normalized B/C ratio, in which the benefit of a given facility is given with respect to the B/C ratio of the other facilities. Assuming that all three facilities have about the same reliability, and usefulness, and about the same benefits on the highway system, the B/C ratio of any two alternatives (*i* and *j*) is given as:

$$\frac{B/C_i}{B/C_j} = \frac{\dfrac{savings\ on\ highway\ and\ traffic\ system}{Cost_i}}{\dfrac{savings\ on\ highway\ and\ traffic\ system}{Cost_j}} = \frac{Cost_j}{Cost_i} = b/c_{ij} \tag{4}$$

where b/c_{ij} is be referred to as the normalized benefit. According to this equation, the benefit of any given facility is equal to the ratio of the cost of the other alternative divided by the cost of the current alternative. The facility with the highest normalized ratio (B/C) can be considered as the most beneficial facility based on the cost analysis. A summary of the benefit cost analysis, including the normalized benefit/cost ratios for the two facilities, is provided in table 3, which shows that the cyclic load actuator has a better B/C ratio than the vehicle simulator.

Table 2
Setup costs for the proposed facilities

Item	Actuator[(1)]	Vehicle Simulator[(2)]
Initial	70,000	350,000
Frame, Housing & Foundation	20,000	30,000
Temp. & Moisture Controls	10,000	8,500
Additional Equip.	10,000	35,000
Total setup cost	**110,000**	**398,500**

[(1)] Based on communications with Wang, J. of Geotesting Express, Atlanta, GA.
[(2)] Based on communications with Farrag, K. of Gas Technology Institute (GTI) at Des Plaines, IL (www.gastechnology.org).

Table 3
Anticipated average annual maintenance and test construction costs for the proposed facilities

Item		Actuator	Vehicle Simulator
Cost			
Maintenance		$5,000	$20,000
Test section	Preparation time	*W week*	*1 month*
	Test duration [(1)]	*3 weeks*	*3 months*
	Sections/year	*12*	*3*
	$US/section[(2)]	*$3,000~$6000*	*$20,000~$40,000*
	Average cost $US/section	$4,500	$20,000
Cost/(sec.yr)[(3)]		**$4,900**	**$26,500**
Total setup cost		$110,000	$398,500
Normalized benefit-cost (B/C) ratio With respect to:			
Actuator[(4)]		1	0.2
Vehicle Simulator		4.9	1

[(1)] Including section preparation. [(2)] Including labor.
[(3)] Cost/(sec.yr) = (cost/section) + maintenance/(section/year).
[(4)] B/C ratio considering the cost/(sec.yr) of the actuator as the benefit, given that a different alternative is selected for the proposed facility.

a)

b)

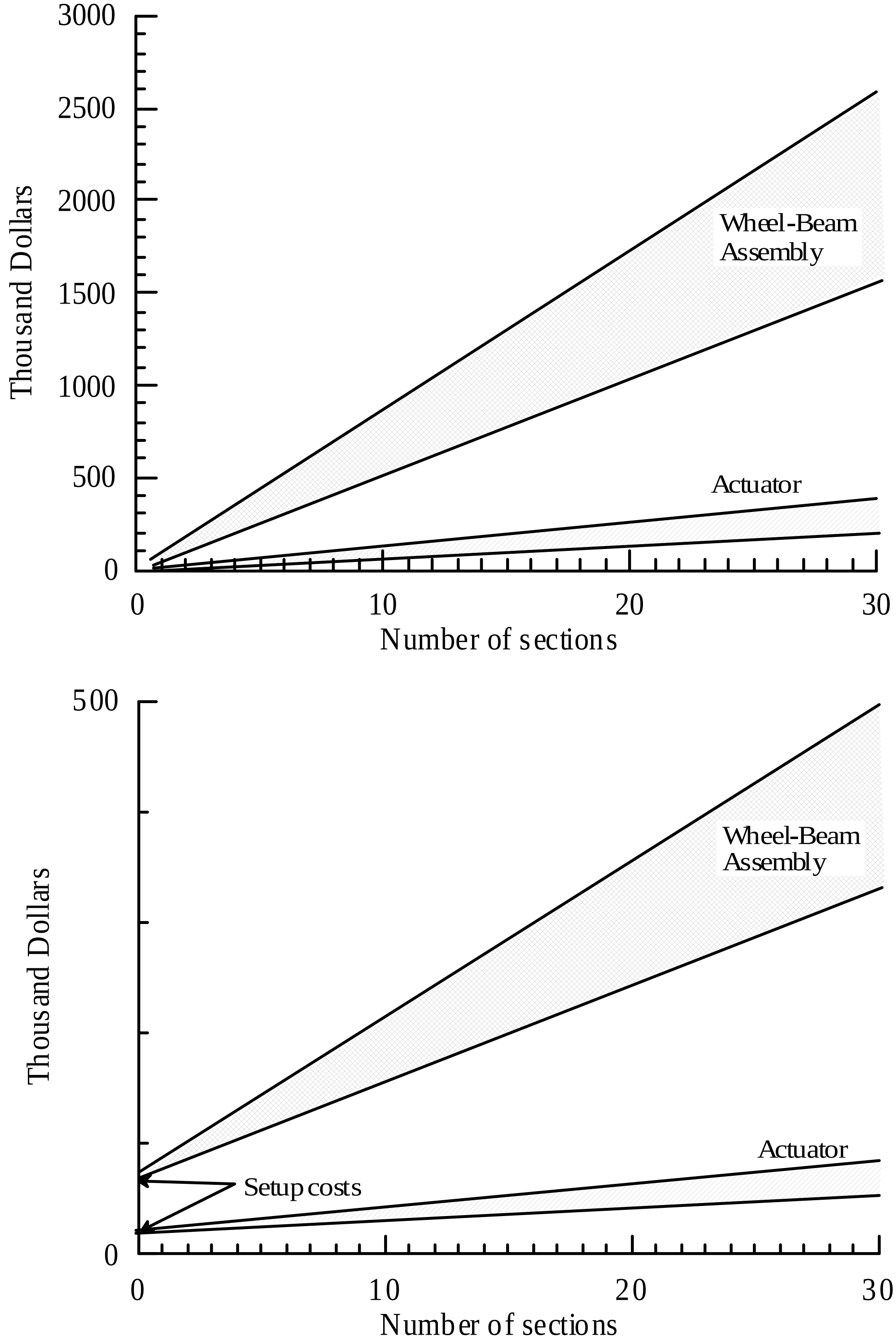


Figure 21

Cost as a function of the number of sections: a) Operational and maintenance cost, and b) Operational and maintenance and setup costs

SUMMARY AND CONCLUSIONS

A feasibility study was conducted to evaluate the performance of different accelerated pavement testing (APT) devices and determine the most appropriate device to be used for research purposes in conjunction with the LTRC-ALF at the Pavement Research Facility. The study was limited to small-to moderate-size accelerated pavement testing devices. The following three alternatives were considered: cyclic load actuator, MMLS3, and a wheel-beam assembly (vehicle simulator). This report was based on a thorough review of relevant literature, oral communications with other research agencies possessing similar facilities, and site visits for selected facilities.

Based on the feasibility study conducted herein, the following conclusions on the reliability and usefulness of these facilities were made concerning the advantages, shortcomings, and benefits of each of the three facilities:

1. The vehicle simulator and the cyclic load actuator can be conveniently used to conduct comparative performance studies of different designs, construction materials or new technologies pertaining to highway and pavement engineering.
2. Given LTRC's current needs, the cyclic load actuator is the most effective and beneficial device. This device can be used in conjunction with the LTRC-ALF to enrich the database of accelerated load test results.
3. The cyclic load actuator device is a powerful tool to conduct preliminary and comparative studies, due to its inherent advantages of speed (frequency of load application), test duration, and the possibility of applying various load-time functions to resemble different traffic loading scenarios. This device may also be used for other various research studies such as resilient modulus, triaxial testing, and CBR testing under actual confinement conditions. Moreover, the cyclic load actuator can be modified to obtain a closer resemblance to actual field traffic by altering the plate shape and possibly adopting a wheel-like assembly instead of the steel loading plate.
4. Despite the advantages (size, speed, and controlled conditions) of the MMLS3 device, it is only recommended for testing the surface layer. It is not recommended for the purpose of accelerated load testing of full pavement structures. The two approaches used to relate the results of the MMLS3 to the full-scale pavements are based on questionable assumptions and are not yet validated.
5. Based on its operational specifications, the MMLS3 was eliminated and was not considered in the benefit-cost analysis.

A normalized (relative) benefit-cost analysis was conducted. Based on the results of this analysis, the following conclusions were made:

1. The setup cost and spending (section preparation, labor, maintenance, power, etc.) of the vehicle simulator were incomparably high. Despite the reliability of this type of device, LTRC already possesses one, and has used it intensively for research purposes. Based on LTRC's current objectives and the budget limit, this type of facility may not be recommended.
2. The benefit cost analysis indicated that the cyclic load actuator is significantly more cost effective than the vehicle simulator. The difference in costs between the two facilities increases with the number of test sections.

RECOMMENDATIONS

Considering the designated objectives of the proposed facility along with the advantages, drawbacks and limitations, specifications and capabilities, and the benefit-cost ratios of each device, the cyclic load actuator is recommended for consideration as the most appropriate device at this time. This device can be further improved to enhance its predictability and reliability, in future research studies.

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APPENDIX A
HEAVY VEHICLE SIMULATOR FACILITIES

LTRC-ALF

The Louisiana Transportation Research Center (LTRC) of the Louisiana Department of Transportation and Development (LaDOTD) owns one of the largest active accelerated load facilities at the Pavement Research Facility (PRF). This facility, shown in Figure A1, consists of 94.8-Foot long beams supporting the single/dual wheels traveling at a speed of 11 mph (equivalent for 356 cycles/hour) on a 38-foot long section, simulating 20 years of loading in a single month under continuous 24 hours of operation. This facility can apply axle loads ranging from 10 to 21 kips and can be programmed to simulate the traffic wheel wander.

Figure A1
LTRC-PRF accelerated load facility

One of the earliest accelerated pavement testing facilities is the Turner Fairbank Highway Research Center (TFHRC) facility established in 1986 (figure A2). This is a 95-foot long facility that enables testing of 32-foot long sections under axle loads of 10 to 22.5 kips, with a maximum wheel speed of 11.5 mph, and the ability to simulate the traffic wander.

A similar facility is the Ohio Research Institute for Transportation and the Environment Accelerated Pavement Load Facility (ORITE-APLF) at the Ohio State University. The facility is 80 feet long, 40 feet wide, and 18 feet high, and it can test 45-foot long and 38-foot wide sections. The facility can apply axle loads ranging from 9 to 30 kips, with a ± 10 inch wander, at a maximum speed of 5 mph, which is constant within a 35-foot long portion of the section. Single and dual wheel assemblies can be used for unidirectional or bidirectional testing.

Figure A2
TFHRC-accelerated load facility

A number of smaller accelerated pavement testing facilities have been introduced recently. The size of these facilities ranges from 25 to 50 feet in length. One of these facilities is the Accelerated Pavement Testing (APT) facility developed by Purdue University for the Indiana Department of Transportation INDOT (figure A3), and constructed in 1989-1991. This facility was used to test prototype scale pavement sections that were installed in test pit in the facility building. The APT loading system is capable of applying moving wheel loads to the pavement test sections measuring a minimum of 20 feet wide by 20 feet long and up to 6 feet high. The facility is housed inside a 30-foot long and 11-foot high building. This allows the placement of full depth pavements.

Figure A3
Indiana APT facility

The loading mechanism of the INDOT facility uses a spring and scissors type action which supplies and maintains a constant force up to 20 kips (89 kN). The force can be increased to about 40 kips (178 kN) and can be applied on a dual or super single wheel assembly. The load carriage travels at 6 mph (10 km/h). Traffic can be applied repeatedly in the same wheel path or with wander. With wander, the wheel path is randomly selected to achieve a normal wander distribution over a 10 inch (250 mm) width. Traffic applied by this facility can either be in one or two directions. The facility building includes a heating system that uses hot water pumped and air heating. A chilling system can also be added for cold weather testing. Figure A4 contains more images for the INDOT-APT facility, showing the wheel load mechanism, calibration, and cable drive.

The Gas Technology Institute (GTI) in Chicago, Illinois posseses an APT facility used for testing/evaluation of paved sections. This facility, shown in figure A5, is called the Accelerated Transportation Loading System (ATLaS). The specifications and features of this facility are summarized in table A1 for the three ATLaS brands: ATLaS 20, ATLaS 30, and ATLaS 80. The numbers (20, 30, and 80) indicate the maximum wheel (contact) load in thousands of pounds (kips). For pavement testing, a contact load of 9 kips is usually used. ATLaS 20 can be used for testing sections that are at least 35 feet long with a minimum lane width of 6 feet. Considering the maintenance requirements, and due to its pneumatic loading mechanism, the ATLaS 20 might have the advantage of lower maintenance costs compared to the hydraulic ATLaS 30 and ATLaS 80. It can operate at a maximum testing speed of 7.5 mph (12 km/hr) within the 15 feet length that has a constant speed. This corresponds to about 550 cycles/hr (13,200 cycles/day) using unidirectional testing and 1100 cycles/hr (26,400 cycles/day) under two-way testing.

a) Wheel load mechanism

b) Wheel load calibration

c) Cable drive mechanism
Figure A4
Indiana APT facility (http://rebar.ecn.purdue.edu/APT)

Figure A5
GTI-ATLaS facility

Table A1
Specifications for ATLaS facilities

Description	ATLaS 20	ATLaS 30	ATLaS 80
Max. wheel load, kips (kN)	20 (89)	30 (133)	80 (356)
Load type	Pneumatic	Hydraulic	Hydraulic
Max. Travel length, ft (m)	25 (7.6)	53 (13.7)	85 (25.9)
Constant Speed length, ft (m)	15 (4.6)	35 (10.7)	65 (19.8)
Acc./dec. length, ft/ft (m/m)	5/5 (1.5/1.5)	9/9 (2.7/2.7)	10/10 (1.5/1.5)
Max. Speed, mph (km/h)	7.5 (12)	7.5 (12)	10 (16)
Total wheel wander, in (cm)	None	20 (50)	36 (90)

The accelerated load testing facility constructed by Kansas State University in 1989-1991 is one of the early moderate sized facilities. This facility, shown in figure A6, consists of 42-foot long, 12-foot wide beams capable of simulating traffic loading as well as applying stationary cyclic loads at a point. Traffic loads up to 40 kips can be applied through the tandem single axle wheels traveling at a maximum speed of 7 mph along the 18 foot test (middle) portion of the pavement. The facility can apply up to 313 cycles/hour for one-way loading, and twice this number for two-way loading with no traffic wander.

The Kansas accelerated load facility can also be used for cyclic load testing using two load actuators (shown in figure A7). The actuators are supported by the same frame along which the wheels move and are operated using a hydraulic system capable of applying up to 40 kips of cyclic load that alternates between the two actuators. The dead load (bogie) is moved to one end of the frame to provide the necessary reaction load. The cyclic load can be applied at a maximum load frequency of 5 Hz, which is equivalent to a 0.2 seconds simulating one truck pass per second.

The Danish Road Institute (DRI) and the Institute of Planning for the University of Denmark (DTU/IFP) Road Testing Machine (RTM), shown in figure 8, is another accelerated load testing facility. The RTM is enclosed in a climate chamber, 13.1 ft (4 m) wide and 12.5 ft (3.8 m) in height. This chamber can maintain a temperature range of 14 °F (-10 °C) to 104 °F (40 °C) and is capable of controlling the ground water level. Schematics of the facility showing the dimensions of the chamber and test sections are provided in figure A9. The 29 ft (9 m) long and 6.6 ft (2 m) deep portion around the center of the facility constitutes the test section.

A maximum load of 14.6 kips (65 kN) can be applied on the dual wheels moving at a maximum speed of 15.4 mph (25 km/h), equivalent to 416.7 cycles/hour (10000 cycles/day). This corresponds to approximately 4,000 passages of a standard 80 kN axle load. The lateral position of the wheel can be automatically changed during testing to give a desired transverse wheel load distribution (wander).

Figure A6
Kansas accelerated load facility

Figure A7
Cyclic load actuators and reaction beams for Kansas accelerated load facility.

Figure A8
Danish RTM facility

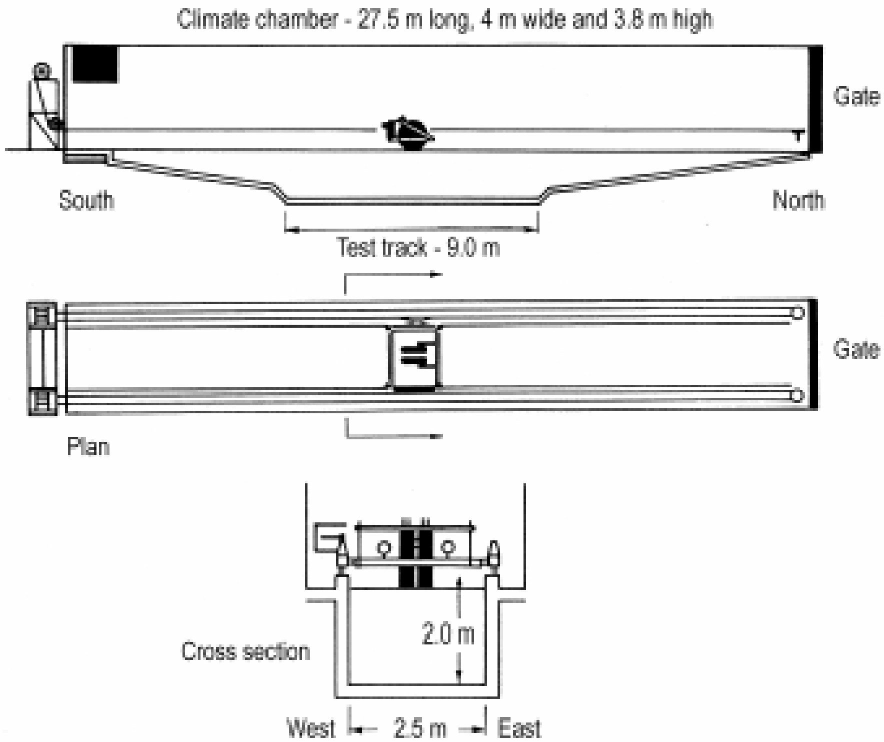

Figure A9
Schematics of the Danish RTM and the environmental chamber

A different type of facility that can provide faster rates of loading (speeds) is the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF). This facility (figure A10) is enclosed in a hexagon-shaped building that is 85.3 feet (26 m) wide and 20 feet (6 m) high. An annular 5-foot (1.5 m) deep and 13-foot (4 m) wide concrete tank confines the bottom and sides of the track, enhancing the control of moisture contents in the subsurface systems and drainage. The track is 191 feet (58.1 m) long, with a median diameter of 60.7 feet (18.5 m) (figure A11). Normal field construction and compaction equipment is used in the facility. The main feature of CAPTIF is the Simulated Loading and Vehicle Emulator (SLAVE). Each vehicle consists of the axle, which is driven by a hydraulic motor, a suspension, a frame, instrumentation, and standard wheel hubs and truck tires. The SLAVE vehicles can carry either single- or dual-tires; their loads can be adjusted to between 4.7 kips and 13.5 kips (21 and 60 kN, respectively), moving at a maximum speed of 30.8 mph (50 km/h), and can be varied while running. The vehicles can be moved slowly, and positioned at any location on the track using a remote control. The facility also allows for 3.3 feet (1.0 m) of traffic wander during testing.

a)

b)

Figure A10
CATPIF: a) Facility and load track, and b) Construction of section

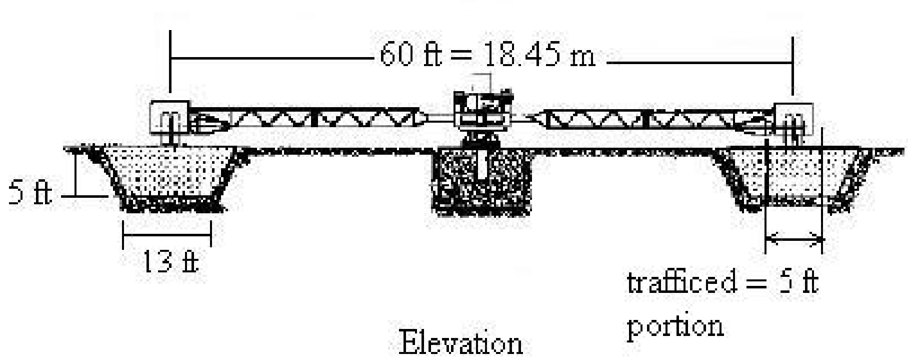

Figure A11
Schematics of the SLAVE track and load