Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| *CTR Research Report 997-3F* | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| *THE DEVELOPMENT OF AN ACCELERATED PAVEMENT TEST FACILITY FOR FLORIDA DEPARTMENT OF TRANSPORTATION* | *May 1994* |
| | 6. Performing Organization Code |
| 7. Author(s) | 8. Performing Organization Report No. |
| *Michael T. McNerney, Frederick Hugo, and B. Frank McCullough* | *Research Report 997-3F* |
| 9. Performing Organization Name and Address | 10. Work Unit No. (TRAIS) |
| *Center for Transportation Research<br>The University of Texas at Austin<br>3208 Red River, Suite 200<br>Austin, Texas 78705-2650* | 11. Contract or Grant No.<br>*Research Project 99700-3503-010* |
| 12. Sponsoring Agency Name and Address | 13. Type of Report and Period Covered |
| *Florida Department of Transportation<br>605 Suwannee Street<br>Tallahassee, Florida 32399-0450* | *Final* |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes

*Study conducted in cooperation with the State of Florida, Department of Transportation*
*Research Study Title: "Development of an Accelerated Pavement Load Simulation Device and Support Facility"*

16. Abstract


*This report is the Final Report in a three-phase research project to study the feasibility of establishing an accelerated pavement testing (APT) facility in Florida. The first Interim Report covered Phase I, which included a review of the state of the art in accelerated pavement testing devices and an APT needs analysis for the Florida DOT. The first report identified three potential locations for an APT facility in Florida and listed all the potential APT devices.*

*The second Interim Report concluded the Phase II research effort. The three devices selected by Florida DOT for further study in Phase II were the Texas Mobile Load Simulator (MLS), the Spanish CEDEX racetrack device, and the Purdue University small linear device. Each of the three devices was revisited and thoroughly studied for Florida application during Phase II.*

*The requirements of an accelerated pavement test facility are linked closely with the level and types of testing. In most cases, for a given level of testing, the type of device selected will have less effect on the support facilities required. Administration, laboratory, instrumentation, maintenance, repair, and storage requirements are a function of the level of testing and staffing. Layout of the facility can be accomplished depending upon the level of testing and support provided for each of the options. The layout of the Spanish facility, the new Turner-Fairbanks facility, and the conceptual MLS fixed facility are examples that should be considered in a final facility design.*

*In case the schedule has an impact on the device selected, the report provides estimated schedules to compare the relative time to design and construct both the device and facility for each option. The MLS options can be implemented in the shortest time.*


| 17. Key Words | 18. Distribution Statement |
|---|---|
| *accelerated pavement testing (APT), Texas Mobile Load Simulator (MLS), Spanish CEDEX racetrack device, Purdue University small linear device, application, testing, facilities, layout, schedule* | *No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.* |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| *Unclassified* | *Unclassified* | *268* | |

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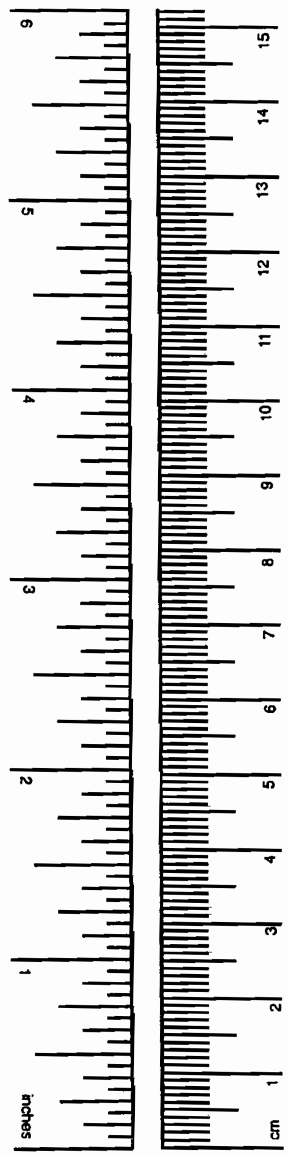
# METRIC (SI*) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 2.54 | centimeters | cm |
| ft | feet | 0.3048 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | millimeters squared | $mm^2$ |
| $ft^2$ | square feet | 0.0929 | meters squared | $m^2$ |
| $yd^2$ | square yards | 0.836 | meters squared | $m^2$ |
| $mi^2$ | square miles | 2.59 | kilometers squared | $km^2$ |
| ac | acres | 0.395 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2,000 lb) | 0.907 | megagrams | Mg |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.0328 | meters cubed | $m^3$ |
| $yd^3$ | cubic yards | 0.0765 | meters cubed | $m^3$ |

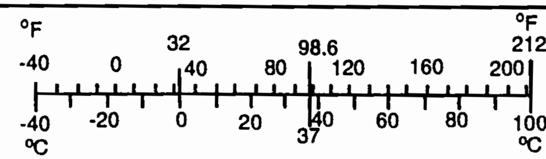
NOTE: Volumes greater than 1,000 L shall be shown in $m^3$.

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |




## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | millimeters squared | 0.0016 | square inches | $in^2$ |
| $m^2$ | meters squared | 10.764 | square feet | $ft^2$ |
| $m^2$ | meters squared | 1.20 | square yards | $yd^2$ |
| $km^2$ | kilometers squared | 0.39 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.53 | acres | ac |
| | | **MASS (weight)** | | |
| g | grams | 0.0353 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams (1,000 kg) | 1.103 | short tons | T |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | meters cubed | 35.315 | cubic feet | $ft^3$ |
| $m^3$ | meters cubed | 1.308 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |




These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

# EXECUTIVE SUMMARY

This report is the Final Report in a three phase research project to study the feasibility of establishing an accelerated pavement testing (APT) facility in Florida. The first Interim Report covered Phase I, which included a review of the state of the art in accelerated pavement testing devices and an APT needs analysis for the Florida DOT. The first report identified three potential locations for an APT facility in Florida and listed all the potential APT devices.

The second Interim Report concluded the Phase II research effort. The three devices selected by Florida DOT for further study in Phase II were the Texas Mobile Load Simulator (MLS), the Spanish CEDEX racetrack device, and the Purdue University small linear device. Each of the three devices was revisited and thoroughly studied for Florida application during Phase II.

Chapter 2 of Phase II of this report provides an analysis of the cost effectiveness of the Florida DOT APT needs identified in Phase I. The study concludes that most of the Florida DOT needs—including environmental control, full tandem axles, 44,000 pound loads, and the ability to test a wide variety of pavement variables and materials—can be met in a cost effective manner. The report also concludes that simulation of braking is not cost effective at this time. Based upon data measured at the Spanish facility, there is no need for speeds in excess of 20 mph. There is no need to exceed actual testing lengths greater than 33 feet, unless skid testing was planned.

Based upon the guidance of the advisory committee and the analysis of APT needs, the Center for Transportation Research presented seven possible options for constructing an APT facility. Three options were presented based upon the MLS design, and three additional options were presented based upon the recently improved Spanish CEDEX device. The seven options detailed in Phase II Chapter 3 include the following:

- Option 1 is a standard Texas MLS without modifications; it is capable of testing the higher 44-Kip tandem axles legal in Florida, but only at 20 mph and at a reduced fatigue life.
- Option 2 adds a 44,000-lb axle capability at full-speed range and normal service life; it also adds an environmental control system for temperature, humidity, and surface water.
- Option 3 doubles the test section length of the MLS to 70 feet, but the device can operate only at a fixed location.
- Option 4 is a single upgraded Spanish CEDEX gravity-loaded vehicle with tandem half axle, cantilevered from a concrete monorail (as operated in Madrid).

- Option 5 uses the cantilevered guide vehicle concept of the Spanish track, but would design two new devices to increase production with full tandem axles and towed trailers; it would also design a complex environmental control system on half of the track.
- Option 6 retains the racetrack layout and environmental control system of Option 5 but replaces the vehicle with a self-propelled, automatically guided truck simulator with four sets of tandem axles.
- Option 7 is the Purdue device with some environmental control upgrades.

Table 1 Lists the advantages and disadvantages of each option.

The cost of designing and building the devices and facilities is discussed in Phase II Chapter 4 of this report. The level of testing determines staffing, data acquisition, instrumentation, and laboratory requirements (with the costs insensitive to the device chosen). Cost of staffing is based upon the Spanish CEDEX organization and TxDOT MLS staffing plan. The potential for recovering initial facility costs over time and the potential for commercial use of the devices were studied. The costs of the devices, their production rates, annual support costs, and a cost per production axle were determined. The Table 2 is a short summary of the device costs, the estimated hourly production rate, the estimated annual cost, and the estimated cost per unit axle based upon typical costs.

Chapter 5 of Phase II of this report discusses the items to be considered in building an accelerated pavement testing facility, including the facility requirements, potential facility layouts, and the potential schedules. It also discusses benefit-cost ratios and the potential for commercialization.

The requirements of an accelerated pavement test facility are linked closely with the level and types of testing. In most cases, for a given level of testing, the type of device selected will have less effect on the support facilities required. Administration, laboratory, instrumentation, maintenance, repair, and storage requirements are a function of the level of testing and staffing. Layout of the facility can be accomplished depending upon the level of testing and support provided for each of the options. The layout of the Spanish facility, the new Turner-Fairbanks facility, and the conceptual MLS fixed facility are examples that should be considered in a final facility design.

In case the schedule has an impact on the device selected, the report provides estimated schedules to compare the relative time to design and construct both the device and facility for each option. The MLS options can be implemented in the shortest time.

## Table 1 Comparison of APT Options

| APT Facility Type | Advantages | Disadvantages |
|---|---|---|
| Option 1:<br>Texas Mobile Load Simulator | 1. High axle production rate.<br>2. Acceleration without overloading.<br>3. Excellent simulation of truck loads.<br>4. Uses standard truck tires, suspension, and axles.<br>5 Variable load, speed, and suspension.<br>6. Can be operated as mobile or fixed site.<br>7. Capable of full axles.<br>8. Experience shared with TxDOT in operations and testing.<br>9. No additional engineering costs.<br>10. Fastest delivery to Florida DOT.<br>11. Low cost per axle. | 1. No environmental control.<br>2. Cannot exceed 44,000-pound tandem axle loads.<br>3. Cannot exceed 20 mph at 44,000-pound loads.<br>4. Requires attended operation. |
| Option 2:<br>44-Kip Mobile Load Simulator with Environmental Control | 1. High axle production rate.<br>2. Acceleration without overloading.<br>3. Excellent simulation of truck loads.<br>4. Uses standard truck tires, suspension, and axles.<br>5. Variable load, speed, and suspension.<br>6. Can be operated as mobile or fixed site.<br>7. Capable of full axles.<br>8. Experience shared with TxDOT in operations and testing.<br>9. Low engineering costs.<br>10. Quick delivery to Florida DOT.<br>11. Capable of full environmental control reasonably priced.<br>12. Low cost per axle. | 1. The device would be heavier for transport in order to resist the 44-Kip loading.<br>2. Requires attended operation.<br>3. Maximum testing speed of 20 mph.<br>4. Ten rather than six bogies to maintain. |
| Option 3:<br>Extended Length Mobile Load Simulator for Fixed-Site Operation | 1. High axle production rate.<br>2. Acceleration without overloading.<br>3. Excellent simulation of truck loads.<br>4. Uses standard truck tires, suspension, and axles.<br>5 Variable load, speed, and suspension.<br>6. Capable of using long test sections.<br>7. Capable of full axles.<br>8. Experience shared with TxDOT in operations and testing.<br>9. Capable of full environmental control and is reasonably priced. | 1. Fixed site operations only.<br>2. Maximum operating speed of 20 mph.<br>3. Requires center support to span the longer test section length.<br>4. Ten bogies required for equal production.<br>5. Increased maintenance and increased total cost.<br>6. Maximum load of 44,000 tandem axles. |

## Table 1 (Cont.)

| APT Facility Option | Advantages | Disadvantages |
|---|---|---|
| Option 4:<br>Spanish CEDEX Facility | 1. Acceleration without overloading.<br>2. Unattended operations.<br>3. Capable of using long test sections.<br>4. Capable of testing six sections at once.<br>5. Experience shared with CEDEX in operations and testing. | 1. Fixed site operations only.<br>2. Slow production rate.<br>3. Must stop testing for construction and maintenance of any test section.<br>4. Uses only half axles.<br>5. No environmental control except water. |
| Option 5:<br>Modified Spanish CEDEX Facility | 1. Acceleration without overloading.<br>2. Potentially unattended operations.<br>3. Capable of using long test sections.<br>4. Capable of testing six sections at once.<br>5. Improved production rate.<br>6. Capable of full axles.<br>7. Capable of full environmental control.<br>8. Excellent simulation of truck loads.<br>9. Uses standard truck tires, suspension, and axles.<br>10. Variable load, speed, and suspension. | 1. Fixed site operations only.<br>2. Must stop testing for construction and maintenance of any test section.<br>3. Environmental control system is complex and expensive.<br>4. Requires two devices.<br>5. High initial costs. |
| Option 6:<br>Automatically Guided Vehicle Facility | 1. Acceleration without overloading.<br>2. Capable of using long test sections.<br>3. Capable of testing six sections at once.<br>4. Improved production rate.<br>5. Capable of full axles.<br>6. Capable of full environmental control.<br>7. Excellent simulation of truck loads.<br>8. Uses standard truck tires, suspension, and axles.<br>9. Variable load, speed, and suspension. | 1. Fixed site operations only.<br>2. Must stop testing for construction and maintenance of any test section.<br>3. Safety concerns of 188,000 pound automatically guided vehicle.<br>4. Environmental control system is complex and expensive. |
| Option 7:<br>Small Linear Facility | 1. Inexpensive.<br>2. Can be built indoors.<br>3. Simple to operate.<br>4. Can potentially be used for unattended operations. | 1. Can not test all pavement structures needed by Florida DOT.<br>2. Very low production rate.<br>3. Requires acceleration by environment or overloading.<br>4. Cannot test multiple axles.<br>5. Cannot simulate truck dynamics.<br>6. Limited speed capability. |

*TABLE 2 SUMMARY OF ECONOMIC ANALYSIS*

| Option | Device Cost (Each) | Production Rate (Axles/Hr) | Annual Cost | Cost Per Axle (Cents) |
|---|---|---|---|---|
| 1. TxMLS | $2,100,000 | 8,800 | $ 1,079,600 | 1.89 |
| 2. 44-Kip MLS | $2,310,000 | 8,800 | $ 1,150,600 | 2.02 |
| 3. Long MLS | $4,550,000 | 10,500 | $ 1,634,500 | 2.40 |
| 4. CEDEX | $2,147,000 | 250 | $ 884,400 | 11.37 |
| 5. CEDEX mod | $2,397,000 | 850 * | $ 1,838,200 | 5.32 |
| 6. AGV | $2,200,000 | 850 | $ 1,250,000 | 3.84 |
| 7. Purdue Facility | $ 400,000 | 250 | $ 300,800 | 19.00 |

* Assumes two devices to reach this productivity

For a benefit-cost comparison, along with the potential for commercialization, several factors are readily apparent. The options with the highest axle productivity provide the best benefit-cost ratios. For commercialization, the options that provide the lowest operating costs, highest productivity rates, and the best simulation of loads will be in the most demand. Several options provide a cost per axle that is commercially cheaper than the testing conducted commercially in France. If there is a demand for a mix of testing durations (0.5, 1, 2, and 10 million axles), then the racetrack options are at a severe disadvantage because of the problem of scheduling simultaneous testing and because of the slow individual test section production rates.

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## CHAPTER 5. ALTERNATIVE SOLUTIONS



## CHAPTER 6. POSSIBLE SITE LOCATIONS FOR THE ACCELERATED PAVEMENT TEST FACILITY



## CHAPTER 7. SYSTEM COSTS

# PHASE I

# CHAPTER 1. INTRODUCTION

The benefits obtained through accelerated pavement testing devices have led authorities to conclude that such devices are necessary pavement engineering tools. All over the world, provision for accelerated testing is made in one form or another, from plate loading devices to full-scale test tracks. This new commitment is easily understood when one considers the investment in pavement structures and the need for testing them in a cost effective way.

Recognizing the need to consider the application of accelerated testing in their state, the Florida DOT contracted with the Center for Transportation Research (CTR), of The University of Texas at Austin, to study the possibility of such an application. This report documents the first phase of this study.

To provide a mutual understanding between the reader and the authors with respect to nomenclature and concepts, this chapter first presents relevant background information. Following this are sections describing the objectives and scope for both the project and this report.

## BACKGROUND

Fifty years ago, most pavement problems were solved by engineering judgment based on trial-and-error experience and on sundry laboratory experimentation. But by the 1960s, industrial and transportation developments, together with the advent of more powerful computer technology, led to several new techniques to improve pavement performance and construction. Computer analysis of pavement structures and extensive material sampling in laboratories, for example, resulted in dramatic advancements in engineering knowledge. And the renewed focus on road tests, particularly the AASHO Road Test, aided in the development of such valuable pavement engineering concepts as the present serviceability index and load equivalency. Numerous structural improvements, such as including the use of a cement-treated base to reduce pumping and thick ACP wearing courses, also grew out of these road tests.

With the extensive data, results, and implications flowing from the AASHO Road Test, the highway industry recognized the need to effectively transfer the knowledge gained from one set of climate conditions (Ottawa, Illinois) to other regions. Thus, the concept of "satellite road test" was initiated by AASHTO through NCHRP. The program was implemented through the construction of special in-service test pavements. Three test sections were designed and/or selected in accordance with an experimental design. Unfortunately, the full benefits of this program were never realized on a national or statewide basis. In contrast to the short term (2 years) required to obtain results from a road test, longer periods are required to obtain results from in-service test sections—a result of design life (20-plus years) or the hesitancy to build in "future" on an in-service roadway.

This in turn led to the need for further improvements in accelerated pavement testing. By the early 1970s, advancements in heavy machinery manufacturing prompted the development of mobile accelerated test machines that utilized simulated traffic loading. Examples of such devices include the Heavy Vehicle Simulator (HVS) in South Africa and (later) the Accelerated Loading Facility (ALF) in Australia. Both the U.S. Air Force and Army Corps of Engineers were also using load simulators to simulate the loading of both fighter-type and transport-type aircraft on pavements (1).

In the 1980s, researchers evaluating actual loading and environmental conditions adopted the approach of the Strategic Highway Research Program's (SHRP) Long-Term Pavement Performance (LTPP) Program, which involves gathering long-term performance data from sites throughout the United States, Canada, and Puerto Rico. Basically, this is a return to the previous satellite concept of observing in-service pavement behavior and performance, which is generally considered the ultimate evaluation method for obtaining time real-loading and conditions (traffic and environment). Today, while this approach has the potential for increasing our pavement knowledge, it remains, severely limited because of all the variables and traffic information collected. The SHRP studies remain in essence very large statistical analyses of large numbers of variables over which there is little or no control.

Unquestionably, the SHRP program has made real advances in the recording of current truck loading on many of our highways; but at the same time it will not really prove beneficial until those study sites have concluded their data collection, which will take many more years. Therefore, other forms of pavement testing must be employed for supplying data, criteria, and models to the engineer currently facing decisions about pavement design, construction, and maintenance.

### *Concepts of Pavement Research*

Since it is not possible to test all of the infinite combinations of real-world conditions and variables, the role of pavement research is to supply reliable and effective performance prediction models that may be used in the design process. The advent of the rapid computations possible with computers permits complex mathematical models to be solved rapidly and calibrated to real-world conditions. Thus, the union to theory and empirical observations leads to mechanistic-empirical pavement design.

With mechanistic-empirical methods, theoretical models are used to analyze stress, strain, and deformation (response or behavior) for given loadings in a pavement structure. Whereas the development of roughness, rutting, and cracking (performance) are empirically related, or calibrated, to the response. The models are subjected to uncertainty stemming from the stochastic nature of the inputs such as traffic, environment, subgrade properties and material characteristics. Researchers recognize that pavement performance prediction is also influenced by factors that are not accurately modeled by mechanistic methods: thus the necessity of calibration to field pavement testing.

There are many test methods available for model calibration; there is also a wide range in the reliability and the costs of these methods. Depending on the availability of funding, the testing may range from engineering parameters being estimated by testing batches of individual material samples to testing the total pavement structure by using one of the following available methods:

- Computer simulation
- Direct sampling methods and laboratory testing
- Nondestructive evaluation or field testing
- Test roads
- Accelerated pavement testing
- Condition monitoring of in-service pavements

The relationship between knowledge and order of complexity for these test methods are conceptually illustrated in Figure 1.1, where pavement performance is increased as the complexity of the testing proceeds from simple engineering judgment, to mathematical models, to laboratory testing, to accelerated pavement testing. Additionally, going beyond accelerated pavement testing to in-situ road tests or accelerated road tests leads to a further incremental increase in knowledge. Unfortunately, costs must at some point be considered in the pursuit of such knowledge. For example, the increase in cost from laboratory testing to accelerated pavement testing is significant, though most engineers would agree that the knowledge gained is worth the increased cost. However, the costs involved in going beyond accelerated pavement testing to in-situ road tests or accelerated road tests can be prohibitively expensive.

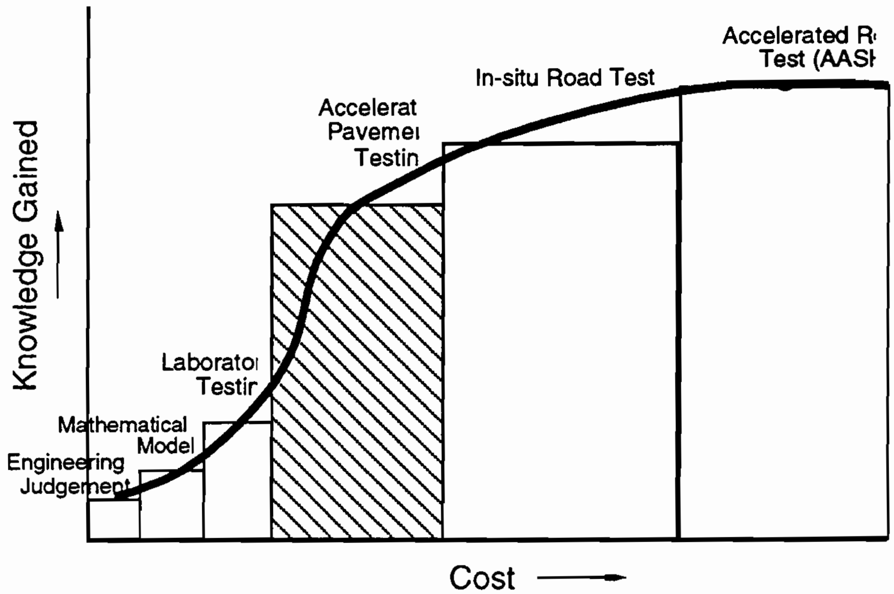



*Figure 1-1. Role of accelerated pavement testing*

The AASHO Road Test is an example of accelerated pavement testing using real traffic. Depending on the quality of the device selected and on the care in which experiments are carried out, the knowledge gained by accelerated pavement testing may nearly rival that of a road test—but at a small fraction of the cost.

## *Role of Pavement Testing*

The previous section discussed the concepts of pavement research in terms of the tools or approaches that might be used. These tools may then be used to study the factors that affect pavement performance. If the results are to be truly quantitative and possess a high degree of reliability, then pavement testing in some form must be performed. Thus, the most effective approach is to consider the range of factors desired in a study and the capabilities of the equipment to be used.

Although many factors affect the behavior of pavement structures under load, including environmental conditions, Table 1.1 gives the most important. Most problems experienced in pavement engineering today are related to these factors. Any pavement design or test method should be evaluated on its ability to account for these factors in a cost-effective, yet reliable way. Although they are well known in 1990, their extent has only gradually become known during the last 30 years. The role of pavement testing as stated earlier is to quantify these factors in terms of modeling pavement performance for eventual use in the pavement design method.

Thus, as was the case for the pavement design method, the most cost-effective pavement testing methods are those that can account for the larger number and range of factors. In the past 10 to 20 years, pavement engineers have accepted accelerated pavement testing as a way to quickly and reliably evaluate a wide range of factors in terms of actual pavement performance.

For this reason, any state's decision to pursue the development of an accelerated pavement testing device must be considered a prudent one. Thus, given the need for such testing, the problem becomes not only a tactical and logistical one, but a practical one as well: How does one match the testing specifications to the particular requirements of a particular state? Clearly, Florida has its own research needs and its own requirements for accelerated pavement testing. The answers to these questions lead to the objectives and scope of this study and of this report.

## OBJECTIVES OF THE STUDY

Decision makers at all levels of the FDOT, recognizing that accelerated pavement testing would be beneficial to the group, initiated a study focusing on the application of such a program in Florida. The objectives of the study (as defined by the Request for Proposals and as clarified in the Center for Transportation Research Proposal) included the following:

1. Perform a review of the accelerated pavement testing (APT) needs of Florida DOT.
2. Review and compare current state-of-the-art technology and designs for accelerated loading devices.
3. Compare the advantages and disadvantages of candidate accelerated loading devices so that the committee can recommend a preliminary design to the department. Prepare preliminary cost estimates of the applicable loading devices that the committee might recommend.
4. Develop preliminary alternate plans for the test facility and the operations of the facility.
5. Compare the alternatives for location, operation, and maintenance of the facility. This is to include the concept of operation and the staffing levels.
6. Prepare interim reports and presentations to the committee and a final report at the conclusion of the study.

*TABLE 1-1. TESTING FACTORS FORMING THE BASIS OF ENGINEERING KNOWLEDGE*

| I INPUT VARIABLES | |
|---|---|
| A. Wheel Loading<br>Axle configuration<br>Tire type<br>Tire pressure<br>Suspension type<br>Load dynamics<br>Load range<br>Speed of load application<br>Rate of application of ESALS<br>Transverse wander of wheel<br>Wheel configuration<br>Extent of gradient<br>Breaking force<br>Traction force | B. Configuration & Preparation of Test Site<br>Nature of test site<br>- Permanent research location<br>- In-service roads<br>Test section length<br>Construction equipment and methods used<br>C. Environmental Variables<br>Temperature<br>Surface water<br>Sub-surface water<br>Wind<br>Humidity<br>Geographically varying field environments |
| **II PAVEMENT ENGINEERING TEST VARIABLES** | |
| A. Asphalt Pavement Variables<br>Alternative surface seal coats<br>Rejuvenation application<br>Aggregate-AC interaction<br>Extent of aging of AC<br>Mix composition<br>Friction between layers<br><br>B. Portland Cement Concrete Pavement Variables<br>Aggregate-PCC interaction<br>Extent of aging (curing) of PCC<br>Variation in reinforcing steel in CRCP<br>Concrete mix composition | C. Pavement Compositional & Structural Variation<br>Variation in pavement type<br>Layer thicknesses<br>Structural compositions<br>Continuity between layers<br>Effect of shoulders<br>Variation in construction quality<br>D. Other Material/Pavement Characteristics<br>Subgrade compaction<br>Subgrade stiffness<br>Subgrade plasticity<br>Degree of isotropy<br>Composites of new and used materials<br>Statistical material variability<br>Maintenance strategies<br>Rehabilitation strategies<br>Axle load equivalency<br>Joint seals |

*TABLE 1-1. CONTINUED*

| III OUTPUT VARIABLES | |
|---|---|
| A. Response<br>Deflection<br>Stress<br>Strain | B. Performance<br>Load associated cracking<br>Non-load associated cracking (i.e. D-cracking)<br>Cracking due to load and non-load interactive causes<br>Rutting<br>Surface roughness<br>Riding quality<br>Structural condition (integrity)<br>Surface condition<br>Residual life<br>Surface friction/Skid resistance<br>AC-stripping<br>Edge drain efficiency<br>Joint seal behavior<br>Load transfer at PCC joints<br>Delamination of layers<br>Steel concrete bond<br>Wear of aggregate |

## OBJECTIVE OF REPORT

In addition to providing a general progress report on project objectives, this preliminary report provides observations and recommendations relative to Study Objectives #1 and #2.

## SCOPE

The CTR proposal for this project provided for six detailed tasks—divided into Phases I, II, and III—that coincided with the study objectives. Phase I, the largest portion of the work, includes all of Tasks 1 and 2. Interim reports will be given on the preliminary findings of Tasks 3, 4, and 5. If, at the end of Phase I, Florida DOT decides not to pursue an accelerated pavement test facility based upon the preliminary findings, it has the option of not continuing with Phase II of the study; in this case CTR would then prepare a final report. If the recommendation is to proceed, then CTR will continue with Phase II based upon further guidance of the Advisory Committee. Thus the scope of this report is to provide the findings relative to Phase I.

For a more detailed description of the tasks and the subtasks, including a project schedule, the reader is referred to Phase I—Appendix A.

Chapter 2 reports the findings of an assessment of the FDOT needs in pavement testing (this assessment was based on meetings, interviews, and questionnaires as outlined in Task 1). Chapter 3 presents a review of existing accelerated pavement testing facilities and applications obtained from the literature, experience, and site visits, as per the objectives of Tasks 2. Chapter 4 supplements the information in Chapter 3 by providing a more technical analysis of the vehicle dynamics for the ALF and the MLS, two possible candidate devices for FDOT. Chapter 5 presents a range of solutions by evaluating eight different options. Chapter 6 reports the observations of our initial visits of potential sites. Chapters 7, 8, and 9 are preliminary progress reports on our studies in connection with Tasks 3-5.

# CHAPTER 2. FLORIDA DOT NEEDS

In order to better assess the needs of Florida DOT, CTR proposed, and carried out, a limited needs assessment. Preliminary information obtained through discussion, and through a first questionnaire introduced at the project kick-off meeting, gave some insight into what Florida DOT would need for accelerated pavement testing, with the selected methodology also derived from this first meeting. While William Lofroos provided to CTR the Pavement Management Implementation Plan, additional information was obtained by the site visit to the Materials Office in Gainesville.

This information, along with CTR experience in evaluating accelerated pavement testing needs for TxDOT, led to the development of the second questionnaire, which was used to better quantify those characteristics and concepts relating to the use of accelerated pavement testing (such quantification could then be used to support Florida DOT needs). The questionnaire was distributed to the members of the advisory committee by William Lofroos; responses were sent directly to the Center for Transportation Research.

## SURVEY RESULTS

The following pages report the results of our second survey of the Accelerated Pavement Testing Advisory Committee. The results were tabulated by adding the weighted values given to individual items on the survey. The survey asked that the most important items be rated a 5, and that the lowest-priority, or not-needed items, be rated a 1 (a 3 rating was considered neutral). There were 7 respondents; the highest possible rating was 35, the lowest possible was 7. Items not rated by a respondent were given a 3 or the mode value as appropriate, to correspond with the value from the other raters. This permitted a relative comparison of items the committee deemed most important, and those which they deemed least important or not needed. This preliminary analysis was subsequently used to develop a first draft of the specific operational requirements (SOR) of an APT facility (see Phase I—Appendix C).

To provide trend information from the data, the responses were grouped into four categories based on the value of the responses. The items are not sorted but merely listed in order of ranking.

> Category I items had a combined point value of 28-34 and strongly indicate those items which are most desirable for an APT device, facility, and or its operation.

Category II items, rated at 24-27 points, indicate those items which the majority of respondents indicated were necessary or favorable for an APT device, facility, and or its operation.

Category III items were rated a point value of 20-23. They indicate the group's indifference as to whether those items would be necessary or of a priority for an APT device, facility, and or its operation.

Category IV items had point values of 15-19 and generally indicate that the respondents on the average believed these items to be of lowest priority for an APT device, facility, and or its operation.

## ANALYSIS OF THE QUESTIONNAIRE

Broadly speaking, the questionnaire, even with only seven respondents, can be considered accurate in its assessment of the high or low priority of a given item. The closer to the middle the individual items were rated, the least statistical significance can be placed on the ranking of those items. With a larger sample size it would be possible to perform a more aggressive statistical analysis; but given the results shown, the statistical analysis should be proportional to the amount of care used in the preparation and completion of the questionnaire. After all, this questionnaire was prepared to elicit a general feel for the needs of Florida DOT, and to try to get some sort of quantitative indication of the committee's perceptions. The results of the questionnaire seem to do that very well.

Looking at the listing of items in Category I, the questionnaire shows that the two items voted most necessary (34 out of a possible 35 points), for an accelerated pavement testing facility in Florida, were the use of normal construction equipment and the testing of concrete mix composition. This corresponds well with the committee comments that the current test pits at Gainesville were inadequate for concrete testing. Several committee members remarked that quality control of construction was a top priority, especially since test roads tended to outlast normal construction under identical environments. The advisory committee remarked that a possible concept of operations for the facility would require contractors to validate their construction practice by performing the actual paving with their own equipment and site-specific materials.

Looking again at the Category I listing, the next highest rated group (33 out of a possible 35) again contains some important items. This group states that the rutting of asphalt and the study of asphalt mix composition are extremely important. The structural integrity of the pavement was also considered to be important. Accordingly, the respondents indicated that the device must have dual tires, an adjustable load, and be capable of loads 25 percent higher than legal.

In general, those items in Category I considered a high priority for testing included:

- pavements which test construction practices;
- concrete or asphalt mix properties;
- pavements which test structural condition (integrity);
- pavements which test structural composition and different layer thicknesses;
- pavements with new materials or recycled asphalt;
- asphaltic and flexible bases;
- subgrade compaction; and
- subgrade stiffness.

In general, Category I items indicated a high priority for the need to measure the following:

- stress
- strain
- deflection
- surface condition
- skid resistance
- rutting
- load associated cracking
- cracking due to load and non-load interactive causes
- tire pressure

In general, keeping in mind that cost was not a factor in the questionnaire, the strong response in Category I indicated that the accelerated pavement testing device, if feasible, should have some of the following characteristics:

- have full axles, tandem axles; and dual tires;
- have a variable suspension;
- have a selectable load to include normal load, 25% overload, or greater;
- have a load application of greater than 30 mph;
- have an ESAL application of greater than 2000 per hour;
- test axle load equivalency;
- simulate braking; and
- have the capability for environment control of temperature and subsurface water.

This entire process can be repeated for Category II items either by rank order or as a group. For example, if one looks at the items that were at the top of the Category II list, it can be seen that the following items were also rated very high and could arguably be considered Category I items:

- the capability to test aggregate-AC interaction and variation in construction quality;
- the ability to measure surface roughness;
- a device with multiple axles, and capable of wander and super single tires; and
- a test section of greater than 82 feet (25 meters).

The questionnaire did not have a large enough sample to reflect that items rated 28 points are of a higher priority than those rated 27 points. A one-point rating difference only indicates that, of the seven raters, only one thought there was a significant difference. Differences of less than 3-points are; therefore, not of significance in this rating scale.

Conversely, the validity of the questionnaire is also confirmed by the fact that the lowest item rated (15 out of a possible 35 points) was an application rate of less than 500 ESAL per hour. If concrete pavements, and interstate-quality asphalt pavements, are going to be tested, then a high application rate is essential. One of the biggest problems with the AASHO Road Test was that the PCC pavements were over-designed; very few of the thicker rigid pavements ever reached failure or even showed distress.

Other items that were rated very low in the questionnaire, for testing by an accelerated pavement testing device, were CRCP and JRCP pavements, variations in steel reinforcement and bond, and seal coats. Also rated a very low priority was whether or not the facility allowed environmental control of wind, an item currently being investigated in concrete pavements. Finally, the survey rated all of the following very low: if the facility had a speed of load application of less than 10 mph (16 kph), had a limited capability to change wheel configuration, and had test section of 16-33 ft (5-10 m).

A complete **rank order** listing of the items is provided with their individual point ratings on the following pages by **Category**. In addition, Phase I—Appendix B contains a copy of the questionnaire, where a block darkened for each item rated corresponds to the point value of the category it most closely represents.

## *CATEGORY I: Items Deemed Highest Priority for APT*

34. use of normal construction equipment

34. concrete mix composition

33. load: 25% overload

33. selectable load

33. asphalt mix composition
33. dual tires
33. rutting
33. structural condition (integrity)

32. tandem axles
32. asphaltic bases
32. flexible bases
32. recycled asphalt
32. load associated cracking

31. load: > 25% overload
31. normal legal truck load
31. stress measurement
31. strain measurement

30. deflection measurement
30. tire pressure
30. braking simulation
30. environmental control of temperature
30. environmental control of subsurface water
30. pavements with different structural composition
30. pavements with different material layer thicknesses
30. new materials/mixtures
30. axle load equivalency
30. skid resistance

29. subgrade compaction
29. variable suspension
29. surface condition

28. full axle

28. load application >30 mph (48 kph)

28. ESAL application >2000 ESAL/hr

28. subgrade stiffness

28. cracking due to load & non-load interactive causes

### *CATEGORY II: Items Deemed Necessary for APT*

27. aggregate-AC interaction

27. multiple axles

27. test length >82 feet (25 meters)

27. variation in construction quality

27. surface roughness

27. super single tires

27. wander

26. geographically varying field environments

26. artificial aging of AC

26. lime-treated bases

26. plain concrete pavement

26. statistical material variability

26. maintenance strategies

26. rehabilitation strategies

26. delamination of layers

26. load applications of 20-30 mph (32-48 kph)

26. ESAL application rate of 500-2000 ESAL/hr.

25. portable testing machine to test in-service roads

25. environmental control of surface water

25. artificial accelerated aging of PCC
25. cement-treated bases
25. subgrade plastic behavior
25. voids beneath concrete
25. effect of shoulders
25. change in surface friction
25. wear of aggregate

24. Limited device-induced dynamics
24. test section length of 49-82 feet (15-25 meters)
24. friction between layers
24. edge drain efficiency
24. extensive wheel configuration

## *CATEGORY III: Items Deemed Indifferent for APT*

23. single tire
23. gradient simulation
23. permanent research location
23. environmental control of humidity
23. non-load associated cracking (D-cracking)
23. residual life
23. AC-stripping
23. joint seal behavior
23. load transfer at PCC joints
23. behavior of anisotropic material

22. load application from 10-20 mph (16-32 kph)
22. aggregate PCC interaction

21. natural aging of PCC
21. natural aging of AC

20. half axle
20. test section length 33-49 feet (10-15 meters)
20. rejuvenation application
20. oyster shell
20. joint seals

### *CATEGORY IV: Items Deemed Unnecessary for APT*

19. load application speed <10 mph (16 kph)
19. limited wheel configuration
19. environmental control of wind
19. variation in reinforcing steel in CRCP
19. jointed reinforced concrete pavement (JRCP)

18. alternative surface seal coats
18. continuously reinforced concrete pavement (CRCP)
17. steel concrete bond
16. test section length 16-33 feet (5-10 meters)
15. application rate of ESAL <500 ESAL/hr.

# CHAPTER 3. REVIEW OF EXISTING ACCELERATED PAVEMENT TESTING FACILITIES AND APPLICATIONS

## INTRODUCTION

This chapter discusses the types of full-scale accelerated testing methods that are currently operational worldwide, with important applications and utilizations of accelerated pavement testing also highlighted. Many of these applications have been documented in detail elsewhere. (At the recent international conference on asphalt pavements in Nottingham, six papers reported on the use of APT devices.)

The testing facilities presented here are those designed for studying problems associated with pavement design, i.e., those facilities having wheel loads in the typical range of trucks and operating on complete pavement structures. The Center for Transportation Research, which has been studying the state of the art in accelerated pavement testing devices for the last five years, is currently involved in the design and construction of the TxMLS device for the Texas Department of Transportation. The comprehensive report on the project (2) served as a valuable source document for the present review; other sources included a literature review, prior knowledge, new discussions, and visits to specific sites and manufacturers.

The devices selected for inclusion in this report are those which were considered of interest to Florida Department of Transportation. The Request for Proposal submitted by Florida DOT specifically required that the following devices be reviewed:

1. The Linear Device built by Purdue University
2. The TxMLS under construction by TxDOT
3. The ALF operated by FHWA
4. The HVS from South Africa
5. Circular devices (including one operated by the University of Central Florida)

## EXISTING APT TESTING FACILITIES AND DEVICES

Attributes and shortcomings of APT testing devices have been comprehensively discussed by Hugo et al. (3). However, to acknowledge recent developments, the following overview was compiled. Particular attention was given to facilities having features that would assist FDOT in its investigation.

Test facilities can be presented in three different categories, according to their design and method of load acceleration:

(1) full-scale test tracks

a) CEDEX race track)

(2) circular testing devices

a) New Zealand CAPTIF-I

b) UCF CATT

(3) linear testing devices

a) UK TRRL and LINTRACK in the Netherlands

b) Purdue ATS

c) South Africa HVS

d) FHWA ALF

e) TxDOT TxMLS

A common feature of the three categories is the transmission of a load to the pavement through a rolling wheel, to simulate real vehicle loads as close as possible.

The following pages describe the features of the above devices. More details can be found in the references.

## FULL SCALE TEST TRACKS

This type of accelerated testing was used in the AASHO Road Test (1958-1961) and, before that, the Bates Experimental Road in Illinois (1920), the Maryland Test Road (1941), the WASHO Road Test in Idaho, and many other prototype pavements constructed by the FHWA and the US Army Corps of Engineers.

The OECD report on full-scale pavement testing (4) also lists test roads with controlled real-vehicle loading, including the mile loop at Pennsylvania State University, the Public Works Research Institute in Japan (having automatically guided tracks), the Nardo Test Track in Italy (which utilizes a vehicle test track), the approximately 2-mile-long Virtaa Test Field in Finland, and the eight instrumented test sections of the Alberta Research Council of Canada.

### *CEDEX Test Track, Madrid Spain*

A unique facility that has recently become operational in Spain uses a race track layout and a monorail device that traverses a concrete rail. Dr. Hugo visited this facility at the beginning of this study and reported his findings at the 1992 TRB annual meeting (5). The facility has two sections of linear track and two semicircular sections at each end, as shown in Figure 3.1. It applies the force hydraulically and has a test speed of 25-28 mph

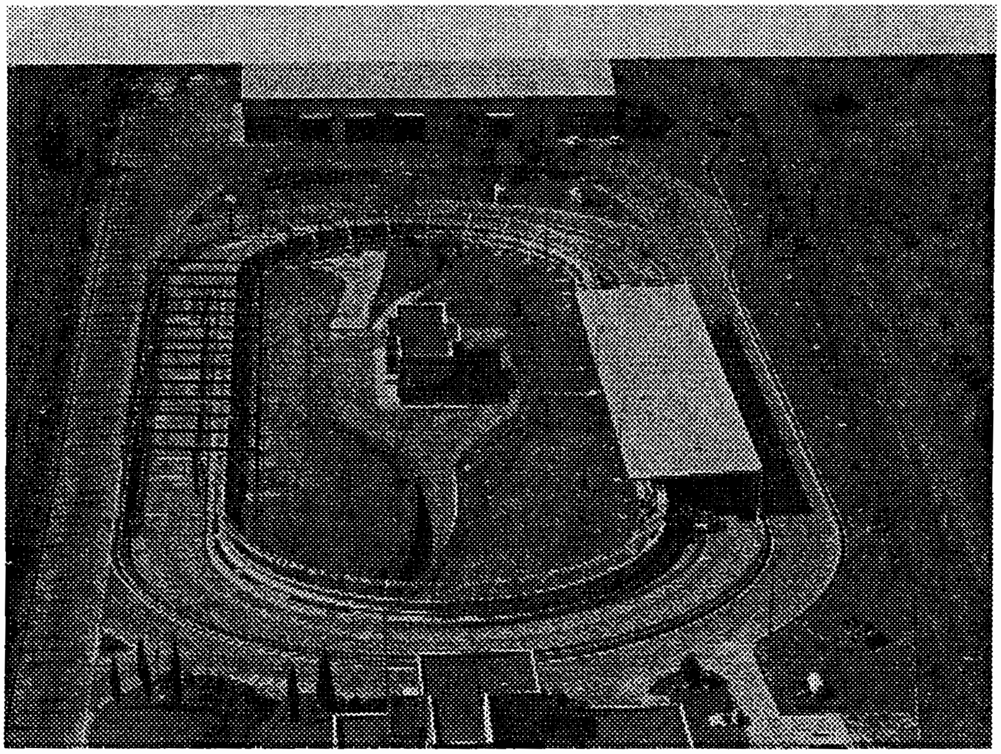


*Figure 3-1 Racetrack*

| | |
|---|---|
| Name: | CEDEX Test Track |
| Fixed or Mobile: | Fixed |
| Date of Manufacture: | 1987 |
| Location: | Madrid, Spain |
| Length of Test Section: | 2 linear sections 210 feet (67 m) each |
| Number of Test Sections: | 6 at 66 feet (20 m) each |
| Wheel Speed: Normal: | 19-28 mph (309-45 km/h) |
| Maximum: | 32 mph (50 km/h) |
| Axles: | 1 half axle |
| Number of Testing Tires: | 1 or 2 |
| Suspension: | Leaf spring |
| Test Axle Load: | 14,300 lbs (6.5 ton) |
| Axle Load Transfer: | Dead weight (drive axle) |
| Lateral Load Distribution: | ± 16 inches (± 0.4 m) |
| Test Direction: | Unidirectional |
| Days to achiueve 1,000,000 axles: | 334 days (24 hr/day) (3000 rev/day - max speed) |
| Housing: | Outdoor - sheltered test section |
| Environmental Control: | Ambient |

(40- 45 kph) and a maximum speed of 31 mph (50 kph). The facility has six test sections in the two 70-foot covered linear sections. The track loop is approximately 1000 feet long and the maximum number of load applications is only 150 per hour per test section.

The monorail racetrack recently completed the first series of tests in which 1 million applications over a 3-year period were applied. This device is designed for fixed site operations. However, it can conceivably be dismantled and re-assembled at another test site.

The structure of the device is such that it can probably be enhanced by linking, and hauling along, trailer bogies to increase the axle load applications (which is probably its main limitation). Plans have been discussed to add one or two more driven bogies to reduce the testing time. Currently, there are highway segments in the U.S. which have higher load application rates than does the CEDEX facility.

## CIRCULAR TEST TRACKS

Owing to the simplicity of operation and to the high rate of load application achievable through the use of these facilities, circular test tracks are popular. Most of these test facilities make use of a loaded wheel assembly, resembling a half axle that tests a circular track, with an expandable and foldable arm serving as the guide which rotates at the center of the circle, while the loaded wheel assembly is rotating around the circular track. Most of the smaller (less than 40-foot-diameter) facilities are housed in special buildings, while the larger facilities are operated outdoors. The two methods for propulsion are: providing rotation power at the circle center or at the wheel in contact with the pavement. The speed range is up to 75 mph (121 kph), and a production rate in excess of 5,000 loadings per hour is achievable.

Although most test machines follow a half-axle concept for the loading, and have single- or dual-tired wheels in single or tandem axle arrangement, some installations offer alternative options. The test track of the University of Karlsruhe simulates one-half of a two-axle truck, with one front wheel (representing the steering wheel) and a dual wheel behind it (the driving axle). Certain test facilities in eastern Europe also have arrangements with complete axles. These give rise to the concern about the unnatural shear that develops between dual tires if both are driven. To compensate for this effect, only inside or outside wheels are powered. Innovative transmissions that provide the correct wheel speed at different radii can be provided by manufacturers, although most circular facilities operate without this option. Loads may reach 22.5 kips on dual tires or 34 kips on complete axles, where the loading is achieved using either gravity (ballast) or a hydraulic force on the smaller tracks. Some facilities use gradient or longitudinal shoving simulating methods. This is achieved by applying braking at the center point of rotation, thus requiring the driven wheel to work against the additional force. Many of the facilities provide a variable wheel slip angle, which is of value when cornering or tire wear effects are being studied.

Many of these machines incorporate a system allowing transverse distribution of loading. This is achieved either through a central pivot on a planetary gear or through extendable arms. The University of Central Florida device is a notable exception that can not accommodate wander.

Different test sections can be built into the circular test track by dividing it into thirds or quarters, and these are loaded at the same rate, thus permitting a direct comparison of the behavior of these structures under the same environmental conditions. The type of equipment used for construction of the test pavements depends largely on the size of the facility. While manual construction is usual for smaller facilities, different construction machines of up to normal size may be used with increased radii of the track. The manufacturer of a circular type facility, the RTT CAPTIF of New Zealand, claims that the radial effect of the circular track becomes negligible at a radius above 46 feet (14 m).

Circular type facilities are excluded from application on as-built and in-service pavements to predict performance of a specific pavement section. Construction methods for these test tracks varies somewhat from real conditions especially on smaller tracks. On the other hand these facilities benefit from the fact that an accurately controlled environment, which also serves as noise pollution control, is provided by the enclosed housing on the smaller facilities. Questions arise as to the accuracy or ability to induce various environmental effects into the structure even under these controlled conditions. Instrumentation of the tracks is well developed and can be left in place due to the secure housing.

### *University of Canterbury, New Zealand Circular Test Track*

The University of Canterbury Department of Civil Engineering owns and operates the prototype RTT CAPTIF simulated loading and vehicle evaluator. The design of the Road Test Technology (RTT) Circular Accelerated Pavement Indoor Facility (CAPIT) was conceived and executed by Ian Wood Associates in Christchurch, New Zealand. Funding for the prototype was provided primarily by the New Zealand National Roads Board. The device is patented in the U.S. (several other international patents are pending).

The device has been in University service since 1986, when it replaced an older circular device that had been in operation since 1968. The size of the prototype was kept at a 60-foot diameter to fit within the original building. A larger version with a 98-foot diameter has been designed and is available for export. Ian Wood Associates is actively marketing this device and will ship it to the United States.

The special capabilities of this circular device are described in the literature and videotape provided by Ian Wood Associates to CTR and Florida DOT. The device has the capability to test two half axles with a gravity load suspended over the wheels. The device is highly automated and is capable of unattended operation. The software is such that the speed can be varied over quarters of the track. The computer can be accessed by modem and the control of the device changed remotely.

The design of the device is such that tire track wander is programmable by the movement of the central arms. Considerable attention in the design was given to the problems of shear forces. Only the inner wheel is driven and the outer wheel is free to rotate. Special adjustments to the bogie are possible for camber to compensate for deflection with different loads and for slip angle to minimize cornering effects of the circular track. Figure 3.2 summarizes the characteristics of the New Zealand circular test track.

### *University of Central Florida Circular Test Track*

Dr. Kuo has an operational circular test track at the University of Central Florida campus which he designed and built himself. The facility has three driven half axles with dual wheels in a 51 foot diameter. The facility design, construction, and testing were conducted on a very limited budget and a tight time constraint. The project was begun in May 1987 and the design took approximately one year. This unique design includes three hydraulically driven, planetary-gear, axles with a central 7500-gallon water tank that permits axle loadings from 10,000 to 30,000 pounds per half axle. The device is powered by a 220 horsepower diesel engine that drives the 60-horsepower hydraulic motors attached to each of the three axles. Figure 3.3 summarizes the characteristics of the circular test device.

The primary purpose of the device is to deliver a high application rate of legal and overloaded truck axles on bridge expansion joints. The device has been in operation for one and half years. A severe budget limitation of approximately $250,000 for design, construction, and testing has resulted in many compromises in the design to save money. The current design has no significant operational problems for the bridge joint test program.

The application of axle loads is controlled from inside a building occupied by the university department of physical plant where the operator watches through the window to a fenced enclosure. The device was designed for operation up to 30 mph but operation is usually kept at 10-15 mph (16-24 kph) for safety reasons. The typical axle rate is one-half axle every 1.2 seconds.

Due to budget limitations, the drive axles were obtained as used parts, the data acquisition system is limited to 12 channels, and the load cells to monitor the exact loading is now inoperative. Severe start-up problems were experienced due to severe loading on the central swivel. A new custom designed swivel has been installed and the device is currently working properly.

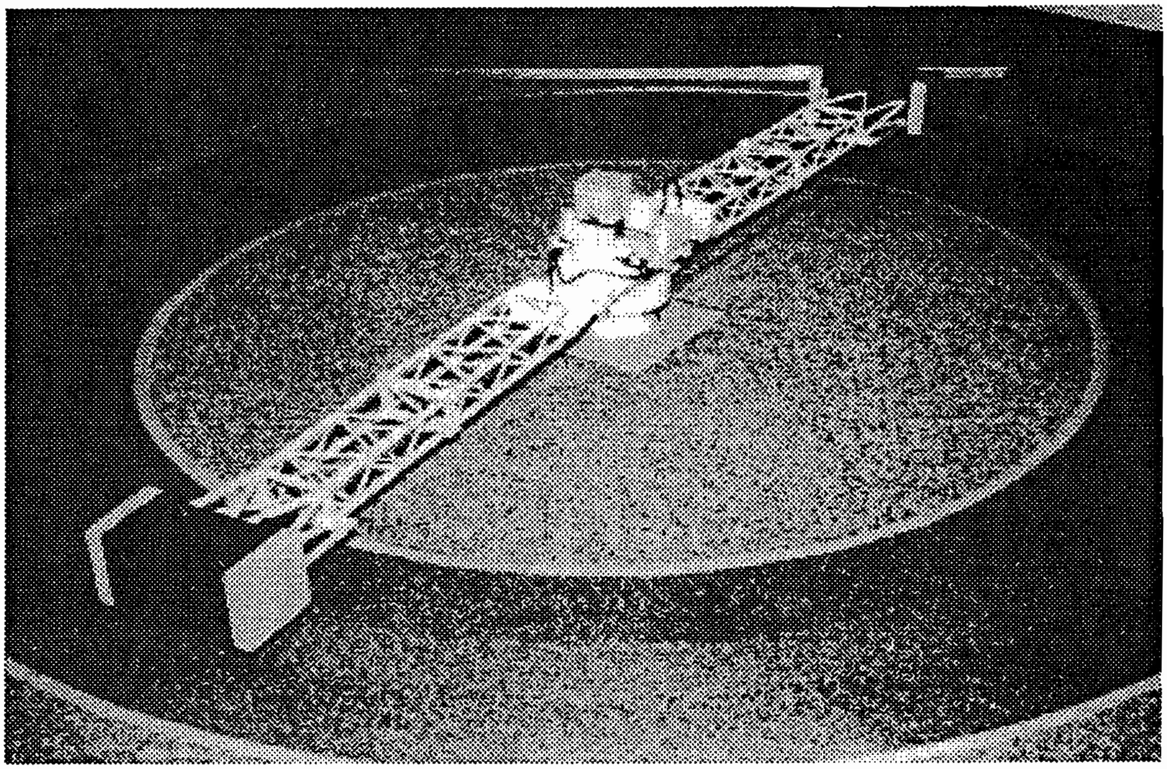


*Figure 3-2 Circular - New Zealand*

| | |
|---|---|
| Name: | Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF-I) |
| Fixed or Mobile: | Fixed |
| Date of Manufacture: | 1986 |
| Location: | Christchurch, New Zealand |
| Length of Test Section: | 190 feet (58 m) circumference |
| Number of Test Sections: | Subdivided up to 9 |
| Wheel Speed: Normal: | |
| Maximum: | 31 mph (50 km/h) |
| Axles: | 2 half axle |
| Number of Testing Tires: | 2 or 4 |
| Suspension: | Leaf spring |
| Test Axle Load: | 4,725-11,250 lbs (21-50 kN) |
| Axle Load Transfer: | Dead weight (drive axle) |
| Lateral Load Distribution: | ± 20 inches (± 0.5 m) |
| Test Direction: | Either direction |
| Days to achiueve 1,000,000 axles: | 25 days (24 hr/day) (860 rev/hr) |
| Housing: | Indoor |
| Environmental Control: | Ambient (subgrade moisture) |

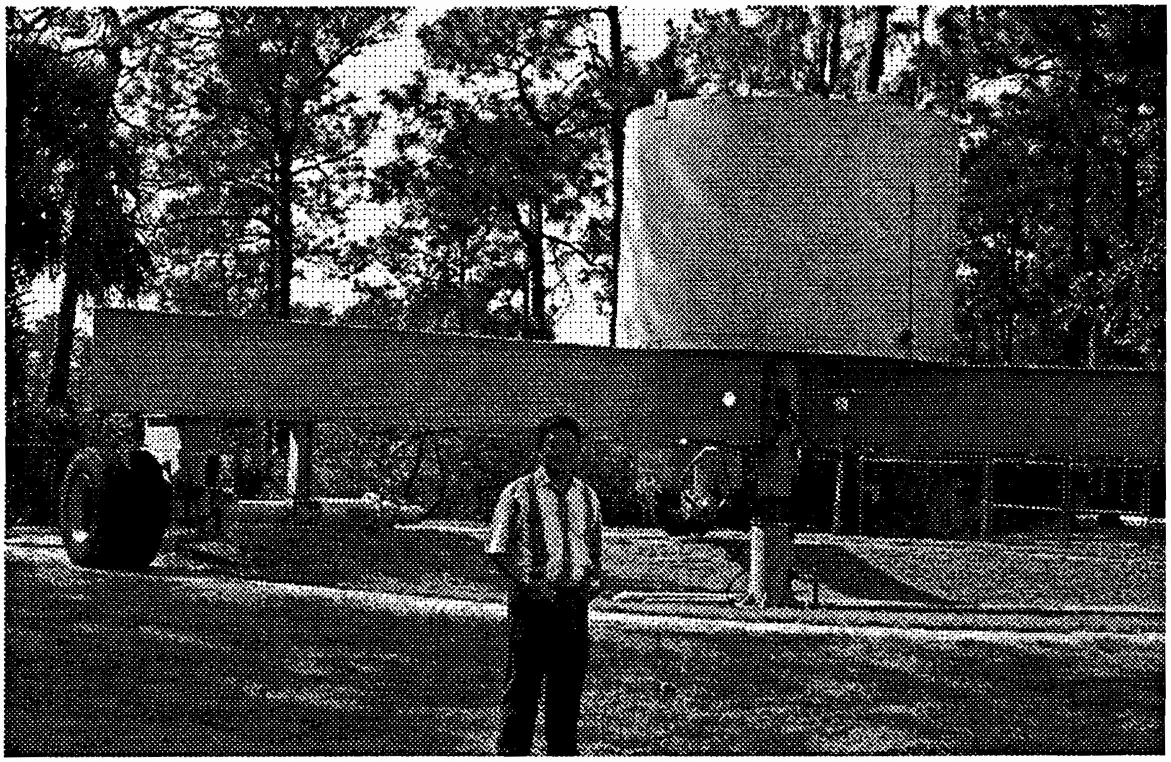


*Figure 3.3 - Circular - Florida*

| | |
|---|---|
| Name: | UCF - Circular Accelerated Test Track (UCF-CATT) |
| Fixed or Mobile: | Fixed |
| Date of Manufacture: | 1990 |
| Location: | Orlando, Florida |
| Length of Test Section: | 160 feet (49 m) circumference |
| Number of Test Sections: | Two 12-foot bridges |
| Wheel Speed: Normal: | 15 mph (24 km/h) |
| Maximum: | 30 mph (58 km/h) |
| Axles: | 3 half axle |
| Number of Testing Tires: | 6 |
| Suspension: | Leaf spring |
| Test Axle Load: | 10,000-30,000 lbs (44-133 kN) |
| Axle Load Transfer: | Dead weight (central water tank) |
| Lateral Load Distribution: | None |
| Test Direction: | Either direction |
| Days to achiueve 1,000,000 axles: | 28 days (24 hr/day) (500 rev/hr) |
| Housing: | Outdoor (indoor controls) |
| Environmental Control: | Surface water (used to cool tires) |

The shearing forces on the tires due to centrifugal accelerations is quite evident. Due to budget limitations no special devices were installed to reduce these forces (other than sand application) as it was cheaper to replace tires than to reduce these forces. Tire wear is not excessive with over a six month lifetime based upon the current operation which is less than eight hours per weekday. No full-time technician is funded and the device is always attended by a graduate student/operator during testing. To increase tire life, water is sprayed on the tires at two locations to reduce heat build up. Dispensing sand was found effective in reducing friction and tire wear but is not currently used. An attempt to have a free-wheeling outer wheel hub was also abandoned due to budget limitations.

The operation of the device is relatively simple and smooth. The device is infinitely adjustable in speed and can be operated in either direction. The major source of noise is the 220 hp diesel engine. The data acquisition system is run by a 386 PC to record cycles and speed. The instrumentation originally included two load cells and several strain gauges. However, much of the original instrumentation is no longer fully functional due to budget limitations and long term exposure to the environment.

The results of testing have been very successful in comparing the performance of bridge joints. Some joints have failed in one or two days while others have lasted for months. Much of the testing has included severe loading in excess of current legal loads. Some tests have also included the addition of foreign objects such as broken glass and bolts in the wheel path on the joints.

The facility is definitely a one-of-a-kind facility with a special niche in bridge component testing. Other possible uses include fiber reinforced bridge panels and concrete repair materials. One bridge panel was cracked and repaired with a special low viscosity epoxy applied by a vendor that has held for over six months with no additional cracking in that area even though unrelated new cracking is forming due to fatigue of the concrete panel.

This device can test concrete panels and concrete bridge joints faster and cheaper than any other device of which we are aware. This device would have severe limitations on trying to test pavements on grade. The device is just above the current water table and existing pavement is only suitable for testing concrete patching or thin overlays. The two short span test bridge joints use a small portion of the test track. The remaining test track surface is thick concrete which has shown only a little wear in the wheel path. The device has no provision to account for wander in wheel path.

## LINEAR TEST FACILITIES

Linear type test facilities come in a variety of shapes and sizes, depending on their intended application. This will determine if the facility will be used at a fixed location, such as a laboratory, or if its intent is to evaluate in-service pavements, therefore requiring mobility of the facility. These types of machines achieve loading of pavements through rolling wheels which are loaded down and translated in a straight line across a section of pavement. Test lengths vary from 16.4 ft (5 m) to 39 ft (12 m) with some having extended lengths to enable conventional construction of the pavements. Loading is generally applied by force. However, the ALF uses a gravity ballast. The size of the test load ranges from 1000 pounds to 27 kips (67 kips for airports). The speeds range from 5 mph (8 kph) to 18 mph (29 kph).

### *Fixed Location Linear Test Facilities*

Many testing centers, such as the Transport and Road Research Laboratory, have elected to build and construct linear testing facilities of practical dimensions. These facilities do not need as much room as circular test tracks and, therefore, benefit greatly from the ease of logistics and environmental simulation. Providing the size and the accessibility of the housing are adequate, full-size construction equipment can be employed, which provides closer simulation of real conditions. Pavements are constructed either on specially selected fills or inside trapezoidal or rectangular channels.

N. W. Lister of TRRL (6) states that this method allows researchers to take moderate steps away from observed performance, that is, for extending designs in conventional materials for heavier traffic, in varying relative thicknesses of the pavement layers, and for introducing modest changes in materials. However, major innovations continue to require the observation of actual pavement behavior, both as a basis for applying design theory and to give confidence to designers in introducing innovation.

### *Accelerated Pavement Testing in the UK*

The construction of full-scale road experiments was preferred in the UK (6), primarily because of the ability to control and measure in detail during construction and to obtain a more complete record of pavement performance. The consideration of traffic disruption also weighed heavy in the decision. The original aim was to vary the design parameters of material type, characteristics, and/or thickness as systematically as possible at any one site.

The UK has a mild maritime climate that varies relatively little across the lowland of the country. It can, therefore, be considered as one temperature region, and temperature variables, such as frost susceptibility, need not be considered in the design of experiments.

The development of the full-scale testing program revealed limitations that had to be taken into account. It was decided that reductions in thicknesses to produce early failures would give misleading information due to the seasonal deterioration seen in the deformation of bituminous pavements. It proved to be impossible to obtain a subgrade of sufficiently uniform strength to enable direct comparisons between sections in a single experiment to be made.

It was found that full-scale experiments based on testing of in-service roads, although highly attractive in principle because of the apparent simplicity did, in practice, present problems in obtaining practical results in reasonable time.

Models based on fatigue cracking obtained in laboratory testing resulted in an underestimate of the onset of cracking in the road by a factor of 1000, which has been confirmed by limited testing in a circular pavement testing facility at TRRL. A partial explanation of the discrepancy lies in the use of laboratory testing, which is a simplification of stress conditions in the road. Similarly a subgrade strain criterion cannot be a totally satisfactory surrogate for the development of deformation in all layers of the road, due to the neglecting of the internal deformability of the pavement layers.

Back analysis of the results of full-scale road experiments, in which the effects of mixed wheel loads and temperature variation cannot be directly disentangled, must remain a relatively crude approach to the derivation of these performance criteria but must be used in the absence of experimentation that quantifies the effects systematically.

Therefore, authorities decided to develop a more efficient mechanical testing system that would provide detailed information of pavement behavior under controlled temperature and loading conditions. This would serve as a solution to the problem of waiting for evidence of long-term pavement performance. Detailed accelerated testing of in-service roads was not envisaged as being practical on densely trafficked roads in the UK and a static facility was preferred.

The choice between a linear and a circular facilities fell on a linear facility, due to the fact that both loading and temperature variations could be evaluated. This facility reaches a maximum speed of 12.5 mph (20 kph) over a 22-foot (6.7 m) section. Both uni- and bi-directional loadings are possible, with the latter producing 900 load applications per hour. Loads of up to 22.5 kips are applied to single or dual wheels.

Pavements are laid with conventional machinery in a 10 ft (3 m) deep pit which allows for 10 strips to be accommodated side by side. Pavement temperatures are simulated by oblique infra-red heating of the pavement from banks of heaters on either side of the pavement. Supplemented testing includes dynamic stiffness, creep deformation, fatigue plate bearing, and Falling Weight Deflectometer measurements.

Increasing emphasis is placed on the evaluation of structural performance and the performance of various maintenance treatments. The Special Pavement Studies program covers a wide range of topics. Long-term experiments are still considered necessary for the assessment of surface characteristics and of materials and designs for which there is no acceptable analytical design method. These include improved, dense, and open-textured bituminous surfacing materials and reinforced surfacings over lean concrete. The program also includes sections of improved and new roadbase materials, which were laid primarily to establish that their properties, determined in laboratory and pilot scale research, can be obtained under contractual conditions on the road.

### *Netherlands Linear Device -LINTRACK*

The Road and Railroad Research Laboratory, at Delft University of Technology in the Netherlands, has a linear device very similar to the TRRL device. The device is named LINTRACK which is short for linear tracking apparatus and is shown in Figure 3.4. It is important to note that linear devices have the problem of accelerating to speed and stopping, therefore, in the LINTRACK device only the middle third of the test section has a constant velocity and can be used for testing.

The LINTRACK device was built over a four year period in the University's shops. The software was also written by the university. The steel gantry is 66 ft (20 m) long and a loading carriage moves back and forth over an 37.4 ft (11.4 m) distance. The loading carriage is power by an 80kW electric motor which pulls the free rolling wheel with a steel cable. The maximum speed of the device is 12 mph (19.3 kph) and can be moved for bi-directional or uni-directional loading. Because of the distance necessary to accelerate to 12 mph (19.3 kph) only a 11.1 ft (3.4 m) section of the middle of the 37.4 ft (11.4 m) may be used for testing purposes.

The device is mounted on 180 ft (55 m) long rails at both ends which are used to move the entire device laterally to accommodate wander up to one meter either side of centerline. The device also uses these rails to move from one test section to another, each are approximately 13 ft (4 m) in width.

The load is applied by a pneumatic airspring which can vary the load from 3,000 to 22,500 pounds on the half axle. There is no other suspension system other than the loading mechanism. The load can be lifted for the return trip during uni-directional loading by means of a hydraulic cylinder. The load wheel can be either a dual wheel or super single wheel.

### *Purdue University Linear Device ATS*

Professor Thomas White, at Purdue University, has recently completed fabrication and has started testing with a small linear device designed and built by Purdue University for Indiana DOT. The device, called ATS (Accelerated Testing System), is smaller than the TRRL or LINTRACK device, as the speed was purposely designed to be only five mph. Operated at this slow speed the acceleration and deceleration distance could be minimized and the device could be fit within the building space and budget required.

Also, this device was specifically designed for a series of tests for rutting of thin asphalt overlays over concrete pavements. Accelerated rutting is achieved by the slow speed of travel and elevating the temperature of the asphalt. The asphalt is heated by a controlled system of hot water piped through the underlying concrete slabs. At the time of our visit the device was still in shakedown testing and was soon to begin the first test series.

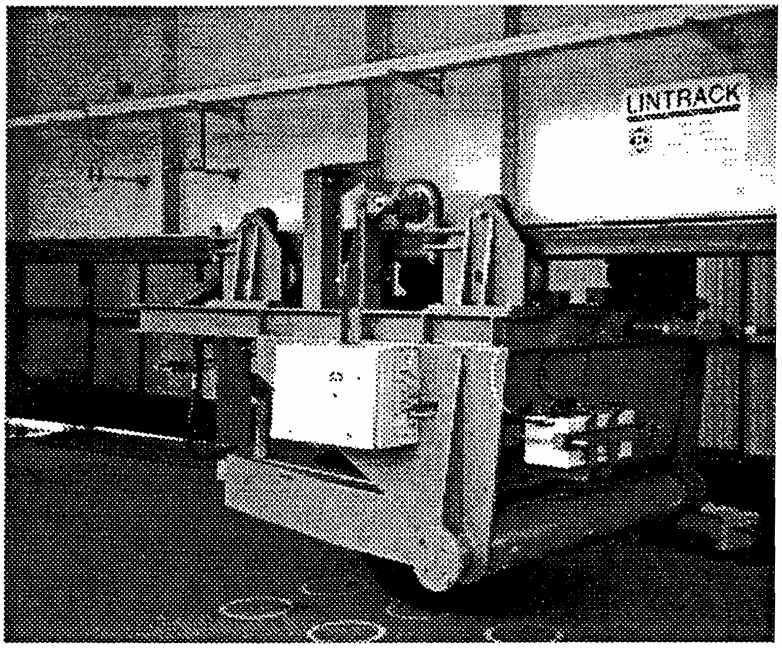



*Figure 3-4 Linear - LINTRACK*

| | |
|---|---|
| Name: | LINTRACK |
| Fixed or Mobile: | Fixed only |
| Date of Manufacture: | 1991 |
| Location: | Road & Railroad Research Lab, Delft University, Netherlands |
| Length of Test Section: | 37 feet (only 11 ft useable)<br>11.4 m (only 3.4 m useable) |
| Number of Test Sections: | 1 |
| Wheel Speed: Normal: | 12 mph (20 km/h) |
| Maximum: | 12 mph (10 km/h) |
| Axles: | 1 half axle |
| Number of Testing Tires: | 1 or 2 |
| Suspension: | None |
| Test Axle Load: | 15-100 kN (3-22.5 kip) (1.5-10 tonnes) |
| Axle Load Transfer: | Pneumatic air spring (free wheel) |
| Lateral Load Distribution: | ±3 feet (± 1 m) |
| Test Direction: | Bi-directional or unidirectional |
| Days to achiueve 1,000,000 axles: | 39 days (540 cycles/hr bidirectional) |
| Housing: | Movable shed |
| Environmental Control: | Ambient |

Another unique feature of the device is the spring activated load system which is designed to keep a constant force on the tire along the test section. This is done with a scissor jack type system of springs which provides forces in balance in both tension and compression. Because of the slow speed the device is not designed to simulate the dynamic forces of truck traffic. The load on the single or dual tires is determined by the size of the springs. Springs have been purchased for a 9,000 pound load, which is currently in use. The device was also designed for a 20,000 pound load but those springs have not yet been purchased.

The device can be operated either bi-directionally or uni-directionally. This capability was programmed in the special control system software. The device can also simulate wander in the uni-directional operation mode by a computer programmable adjustment of up to eight inches during the return trip of the wheel.

The test area is 20 by 20-feet (6 m x 6 m) which is subdivided into four individual traffic lanes, each with its own individual heating system. The device must be unbolted and manually moved along rails to the other lane. Rutting measurements are taken manually after a predetermined number of load applications. Unattended operation is not planned, but could be accomodated if required. Figure 3.5 summarizes the characteristics of the Purdue linear device.

### *Mobile Test Facilities*

Apart from the proposed Texas Mobile Load Simulator (TxMLS), which is in the design and construction stage, only two types of linear, mobile devices have been constructed that apply an accelerated number of wheel loads to pavement sections at various locations. One of the two mobile linear devices is the Heavy Vehicle Simulator (HVS), developed at the end of the 1960's in South Africa. Three improved HVS's are still operational. The other device is the Accelerated Loading Facility (ALF), in use in Australia since 1984 and operational in the U.S. since October 1986.

### *Heavy Vehicle Simulator HVS*

The HVS has the dimensions of an oversized heavy vehicle. Over long distances it can be pulled as a trailer by hooking the goose neck to a three-axle truck tractor and transporting it on two axles with twelve wheels total. Steerable wheels and a drive train allow movement of the machine over short distances without a tractor. The test wheel applies bi- or uni-directional loading over a length of 32.8 feet (10 m), and is pulled back and forth by a hydraulic system. Successive passes are being distributed over a track width of up to 5 feet (1.5 m) at a top speed of 9 mph (14.5 kph). Although the wheel is normally variable up to 22.5 kips, loadings of 45 kips have been achieved for the testing of airport pavements. The mechanical working and features of the HVS are described in the proceedings of the 1984 and 1985 Annual Transportation Convention of the South

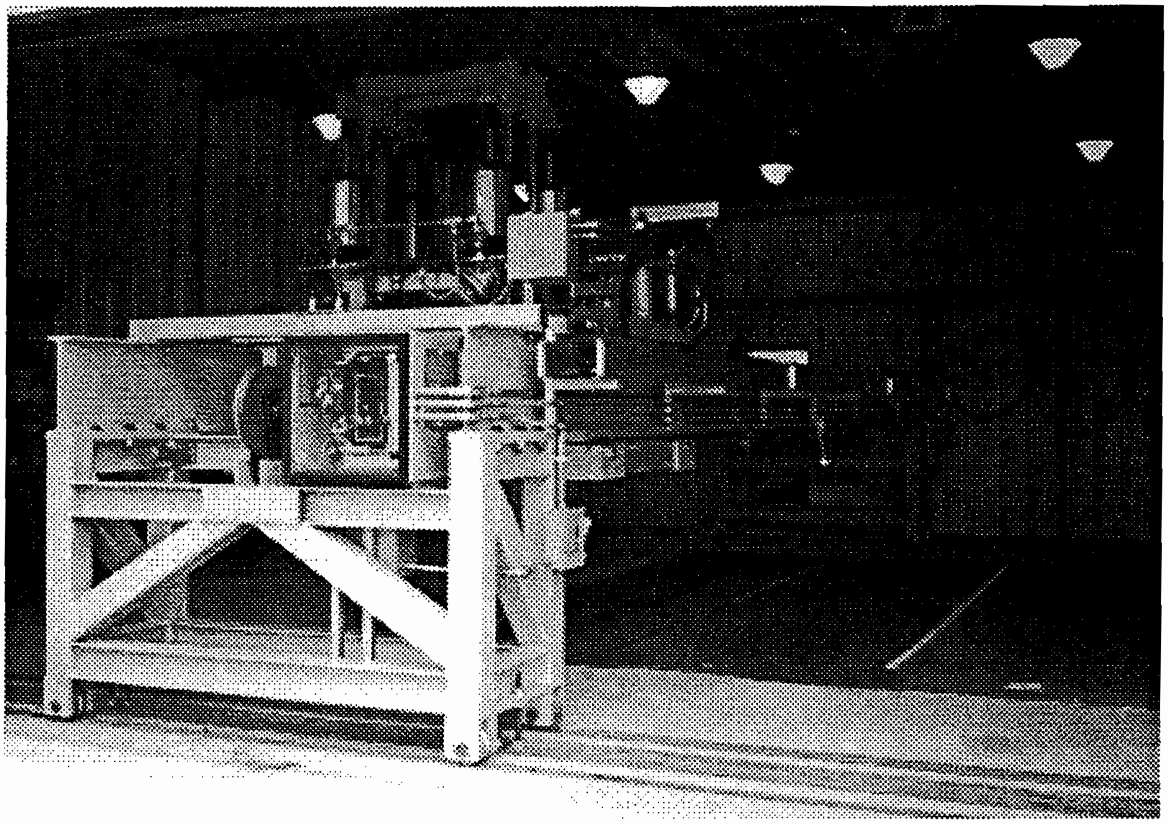


*Figure 3-5 Linear - ATS*

| | |
|---|---|
| Name: | Accelerated Testing System (ATS) |
| Fixed or Mobile: | Fixed only |
| Date of Manufacture: | 1991 |
| Location: | West Lafayette, Indiana |
| Length of Test Section: | 20 feet (6 m) |
| Number of Test Sections: | 1 at a time, 4 on site |
| Wheel Speed: Normal: | 5 mph (8 km/h) |
| Maximum: | |
| Axles: | 1 half axle |
| Number of Testing Tires: | 1 or 2 |
| Suspension: | None |
| Test Axle Load: | Up to 20,000 lbs (9,072 kg) |
| Axle Load Transfer: | Constant force by spring (free wheel) |
| Lateral Load Distribution: | ±8 inches (± 20 cm) |
| Test Direction: | Bi-directional or unidirectional |
| Days to achiueve 1,000,000 axles: | 58 days (bi-directional) (363 cycles/hr) |
| Housing: | Indoors |
| Environmental Control: | Partial (heated from below) |

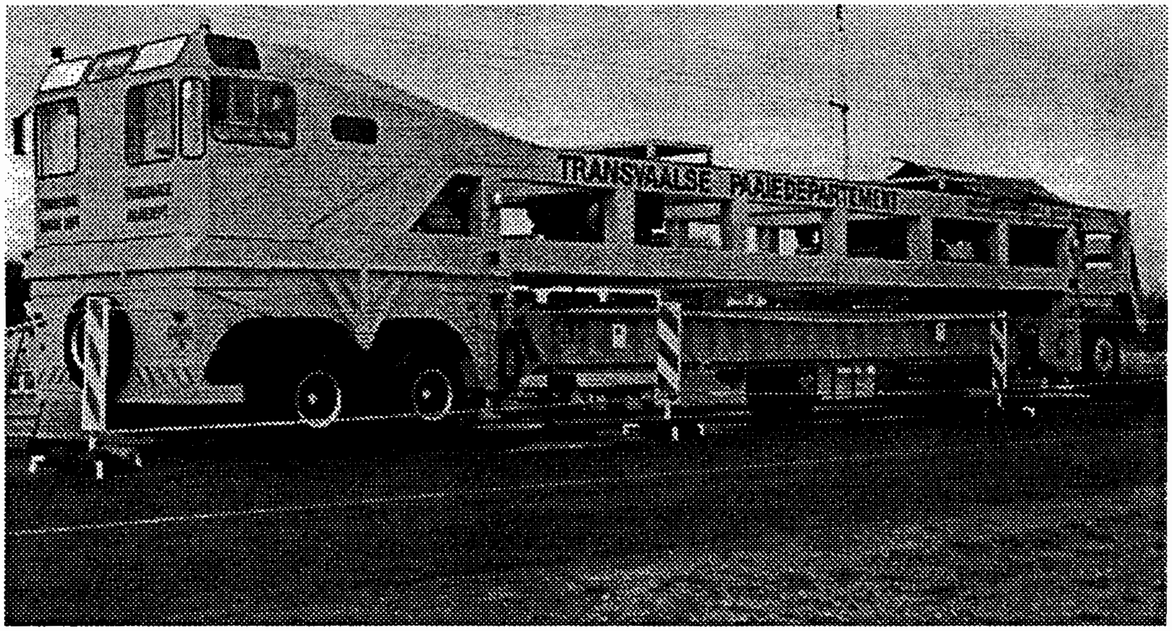



***Figure 3-6 Heavy Vehicle Simulator (HVS)***

| | |
|---|---|
| Name: | Heavy Vehicle Simulator (HVS) |
| Fixed or Mobile: | Fixed and/or transportable |
| Date of Manufacture: | 1972 |
| Location: | South Africa |
| Length of Test Section: | 33 feet (10 m) |
| Number of Test Sections: | 1 at a time |
| Wheel Speed: Normal: | |
| Maximum: | 9 mph (14 km/h) |
| Axles: | half axle |
| Number of Testing Tires: | 1 or 2 |
| Suspension: | None |
| Test Axle Load: | 4,500-22,500 lbs (20-100 kN) |
| Axle Load Transfer: | Hydraulic force against frame (free wheel) |
| Lateral Load Distribution: | ±5 feet (± 1.5 m) total |
| Test Direction: | Bi-directional or unidirectional |
| Days to achiueve 1,000,000 axles: | 33 days (630 cycles/hr) |
| Housing: | Outdoor |
| Environmental Control: | Partial (high and low temperature chamber) |

African Department of Transport. Figure 3.6 shows the HVS and gives a brief summary of its capability.

It is well known that the load equivalency factor relates the number of a given axle loads to the equivalent number of standard axles to introduce a specific level of a certain distress type. Through the use of a Heavy Vehicle Simulator (7), measurements are taken of the pavement under trafficking and are used in the calculation of the load equivalency factor. Moduli determined in methods set out in the previous section of this chapter were used as input values to calculate the mechanistic life of the pavement under various wheel loads. From these lives, the equivalency coefficient (n) would be calculated:

$$F = (L / ESAL)^n$$

where

F = load equivalency factor,

L = wheel load applied by HVS,

ESAL = Equivalent Single Axle Load (40 kN), and

n = equivalency coefficient.

It was shown that there is no common equivalent coefficient for the different pavement layers. Through analysis of the data, it was calculated that the coefficient for the thin surface layer is, surprisingly, a negative value at the start of the test. The implication is that lighter wheel loads cause more fatigue of the surface layers than heavier loads. However, these calculated values were much less than the observed lives and shift factors of up to 5, to predict field behavior from laboratory measurements, were required. This implies that the negative value may not necessarily be correct. Equivalence factors for other layers varied according to the pavement category. Equivalency coefficients for crushed-stone bases decreased from 4.8 to 2.4 and down to 0.7 at higher loads. After the application of water, the equivalency dropped to zero. This implies that, under saturated conditions, the load is no longer of importance. Measurements of the radius of curvature at various wheel loads confirmed the belief that radii of curvature was higher at heavy loads. Generally, the calculated lives of surface layers were much less than observed lives.

A method for determining the field effective moduli and stress dependence of pavement materials is described in, amongst others, Transportation Research Record (8). The effective moduli were determined from resilient deflections measured with a multi-depth deflectometer at different depths within pavement structures. Measurements are reported on four structures, which include light, unbound pavements to stronger inverted structures. The South African HVS was used to produce deflections at different wheel loads at various stages of trafficking. Subsequently, a linear elastic-layered program, ELSYM5, was used in an iterative technique to produce the measured deflections. In this way, a very realistic record of the change in structural response of the pavement was obtained.

The stress stiffening behavior of granular materials and the stress softening behavior of subgrade materials were demonstrated. Stress-dependent models for granular and cohesive materials were applied to the effective moduli, especially to the moduli of the unbound crushed-stone bases. The regression constants were determined for different moisture conditions and at various stages of trafficking. This study also verified the sensitivity of the regression constants in the analysis of various moisture levels. The stress dependence of the subgrade moduli was generally less than that of the base, but the effect on the total deflection was probably just as pronounced. It was shown that not all subgrades exhibit stress softening behavior.

A shift factor of 0.3 to 0.5 had to be applied to moduli determined through the use of constant confining pressure triaxial tests but trends similar to those observed suggests that the actual wheel load could influence the shift factor.

The whole South African mechanistic design method, derived from use of Heavy Vehicle Simulation, includes input for moduli for typical pavement materials corresponding to legal axle loads as equivalent axles (E80's). For different loading conditions, such as overloading, or for airport pavements, adjustments to moduli are necessary. This stress dependence of unbound materials confirms the importance of a non-linear approach to analysis of pavement structures.

### *Accelerated Loading Facility (ALF)*

The Australian Accelerated Loading Facility (ALF) is owned by the Australian Road Research Board and has been operational since February 1984. FHWA interest in the machine stemmed from the March 1984 International Pavement Conference in McLean, Virginia (9). In mid-1984, the plans and authority to build the U.S. ALF were acquired and the machine was delivered in August 1986. The ALF is patented in twenty countries and Engineering Incorporated in Virginia holds the patent rights in the US. Figures 3.7a and b show the ALF and give a brief summary of its capability.

Using dual truck tires with loads ranging from 9,000 to 22,500 pounds, the ALF applies accelerated loading to the pavement at a rate of 9,200 applications per day at a speed of 12 miles per hour (19 kph) on a test section 30 feet (9 m) long. The load is carried with the load wheel and is energy efficient, due to the utilization of gravity in the start-up procedure and to allow gravity to provide the acceleration and deceleration of the load. Electric motors are used for replacing energy lost due to friction. Lateral load distribution is provided, with various loading patterns to select from. The manufacturing of the U.S. ALF is fully documented in a 1987 FHWA Technical Report (10).

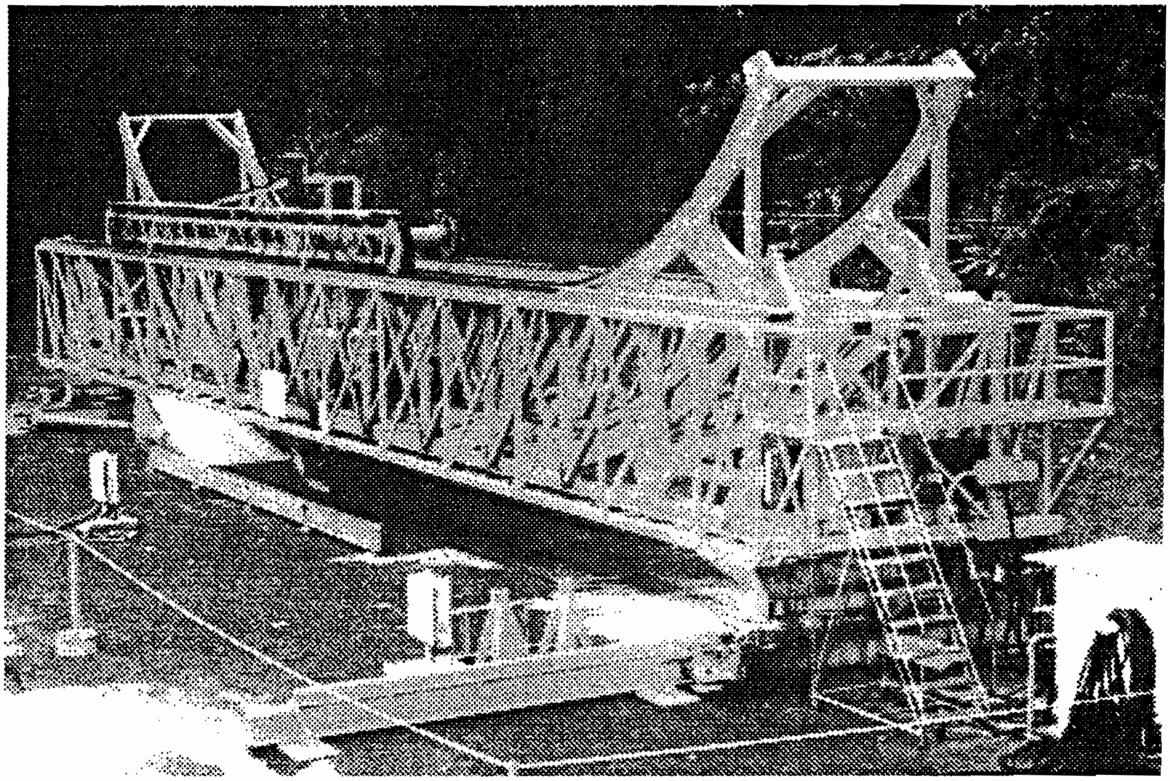


*Figure 3-7a Accelerated Loading Facility (ALF)*

| | |
|---|---|
| Name: | Accelerated Loading Facility (ALF) |
| Fixed or Mobile: | Fixed or transportable (2 days for moving) |
| Date of Manufacture: | 1987 |
| Location: | FHWA Turner-Fairbanks Research Center |
| Length of Test Section: | 40 feet (12 m)<br>30 feet (9 m) useable with cam system |
| Number of Test Sections: | 1 at a time (currently 12 on site) |
| Wheel Speed: Normal: | 12 mph (20 km/h) |
| Maximum: | |
| Axles: | half axle |
| Number of Testing Tires: | 1 or 2 |
| Suspension: | Air bag with shock absorbers |
| Test Axle Load: | 8,800-22,000 lbns (4-11 tonnes) |
| Axle Load Transfer: | Dead weight (drive axle) |
| Lateral Load Distribution: | ±14.75 inches (± 0.375 m) |
| Test Direction: | Unidirectional (could be modified for bi-directional) |
| Days to achiueve 1,000,000 axles: | 108 days (376 cycles/hr bidirectional) |
| Housing: | Outdoor |
| Environmental Control: | Ambient (possible) |

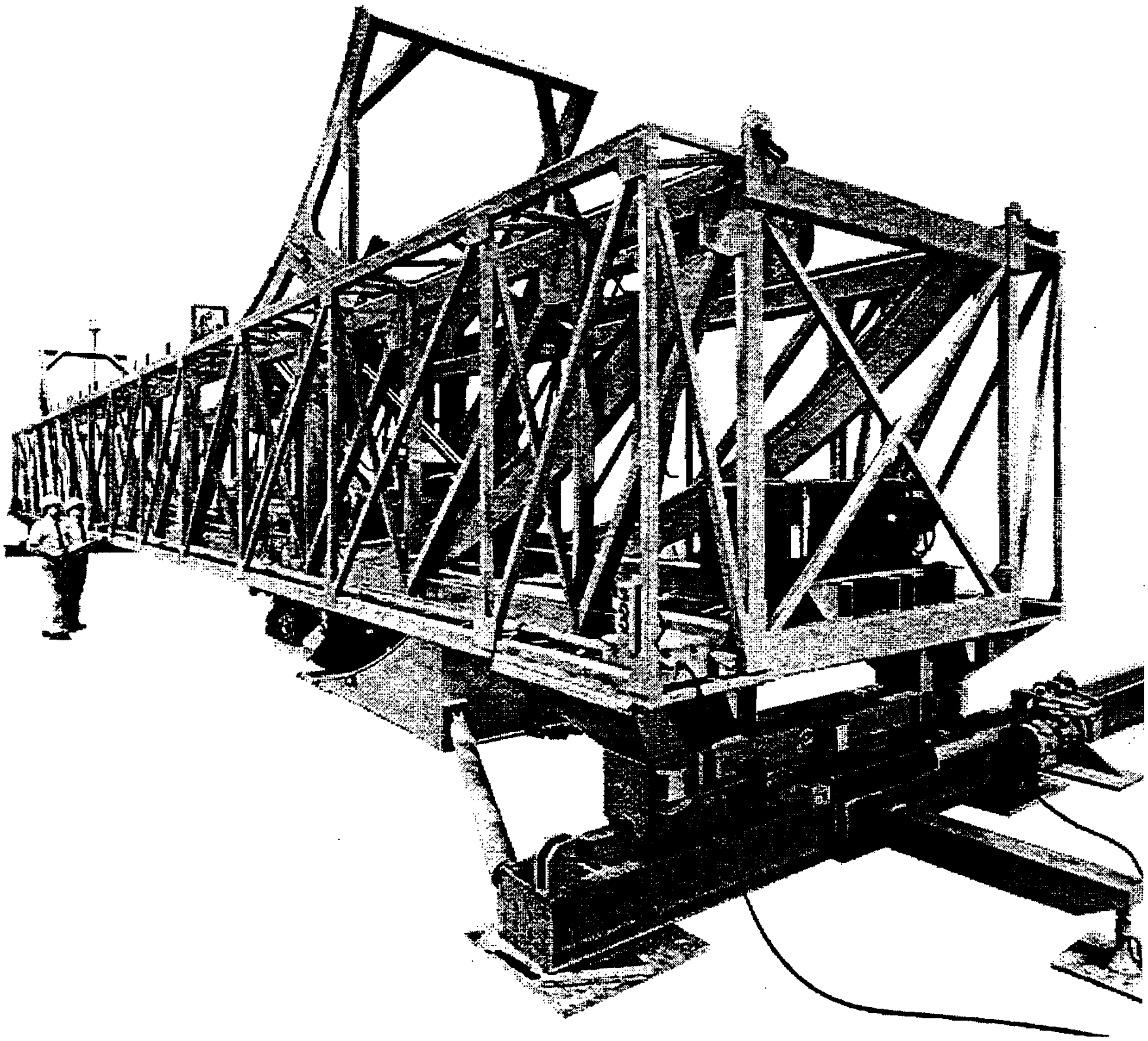


*Figure 3-7b*

Test pavements were constructed in 1986 at the Turner-Fairbank Highway Research Center in McLean, Virginia (11), and during the first phase of testing, a range of loads and tire pressures were used to evaluate a range of loads and tire pressures on each of the eight test sections. The objectives of the first phase of research were to:

- establish load equivalencies for 11,600, 14,100, and 19,000 pounds,
- compare calculated versus measured pavement response (strains, deflections, cracking, rutting, and roughness), and
- evaluate the accuracy of the AASHTO design procedure, which was used to design the test pavements.

The ALF was used in the evaluation of the rutting potential of the asphalt concrete layer of each test pavement. The initial conclusions indicated that rutting was not a problem and that the designed pavement structure performed satisfactorily. Rutting, cracking, longitudinal roughness, PSI (Present Serviceability Index), structural response to non-destructive testing, and the ALF wheel loadings were used to study the pavement performance. After this, a post mortem evaluation of the two pavements was conducted.

FHWA has recently completed five years of testing with the ALF and has returned the device to the manufacturer for major overhaul. A recent modification of the device was the incorporation of a mechanical cam that raises and lowers the wheel to the pavement rather than depending on the force of gravity and a ramp system. This cam system has been installed to reduce the unsuitable bouncing and dynamic effects that the device induces on the test section. It was reported that the system has improved the dynamics problem but not eliminated it.

Louisiana Transportation Research Center at Louisiana State University at Baton Rouge has recently purchased an ALF device and expects to take delivery in 1994. The device was completed in 1992 but the facility for testing is not yet complete.

### *Texas Mobile Load Simulator TxMLS*

Recently the Texas Department of Transportation (TxDOT) embarked on the development of a mobile linear tracking device, the Texas Mobile Load Simulator (MLS), which is expected to be operational by the summer of 1994. The TxMLS has some unique features and is described as the next generation of testing devices. Some of the features characteristic of the TxMLS are:

- mobility for use on fixed sites and on in-service roads
- use of regular truck suspensions
- dynamic load variation similar to that of trucks
- high rate of load applications at 8,800 per hour
- fully enclosed chamber with future ability to apply environmental control

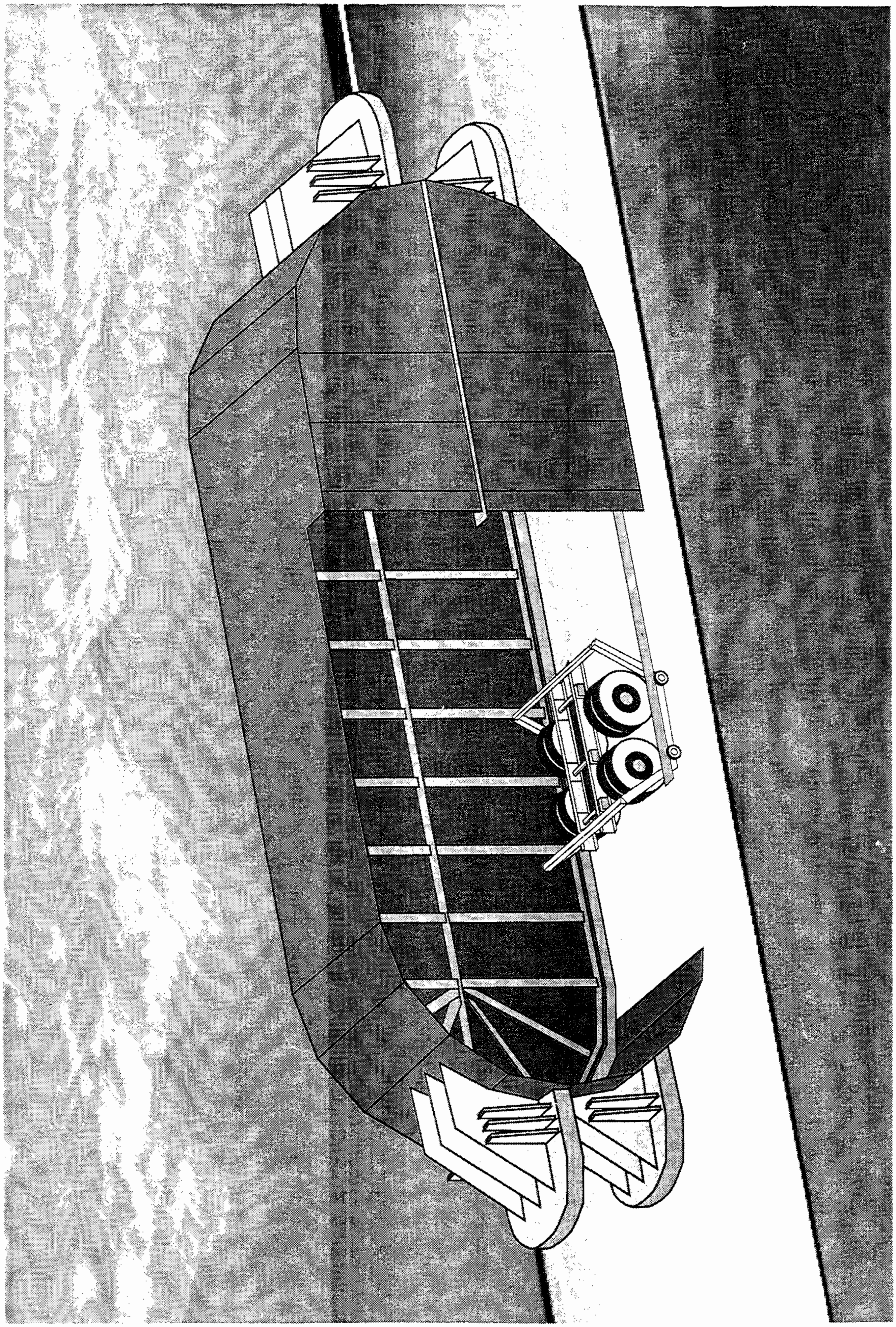


*Figure 3-8*

As shown in an artist's drawing Figure 3.8, the TxMLS continuous loop design is notable for exceeding the high application rates of circular tracks while providing mobility only found in linear devices. Also, the TxMLS does not have the usual start, accelerate, stop and reverse course of all other linear devices because of its unique vertical looping system. The addition of real truck suspensions, full axles, and close simulation of pavement vehicle interaction makes the device truly ideal for simulating truck loading on pavement.

The loading system of the TxMLS is based upon a fixed-geometry load rail. By applying a fixed distance between the pavement and the load rail, the suspension of the single or tandem bogies are compressed to the desired loading. By keeping the same load throughout the cycle, even while upside down, the fatigue loading is minimized on the device and artificial dynamic loads imparted to the pavement are minimized.

The TxMLS has the capability of using an adjustable number of single or tandem axle bogies. The first device will be built using six tandem axle bogies each with a Rayco four-spring suspension and Rockwell axles. Two bogies will be powered using 200 hp DC electric motors with a belt drive to the single drive axle. Either drive bogie has sufficient power to drive the complete system and DC drive controllers keep constant control of the motors. As shown in Figure 3.9, the bogies are connected with a chain which is attached to both sides of the bogie carriage. The bogie carriage is used to align the bogies and transfer the load from the load rail to the bogie suspension. Figure 3.10 provides a detail of the load rail and bogie carriage interface.

The device is designed with extensive monitoring of the loads on the axles and will automatically shutdown if parameters are out of tolerance for acoustical, temperature or acceleration sensors. The highly automated control system is ruggedized and completely programmable. The speed of the device will be infinitely adjustable and programmable from creep speeds to 25 mph (40 kph) with a design speed of 20 mph (32 kph). TxDOT is purchasing a complete data collection system and control trailer for deployment with the device.

The device has primarily been designed as a mobile device capable of setting up within one day on any road within the state of Texas and performing simulated truck traffic at rates of 8,800 axles per hour or one million axle applications per week. As shown in Figure 3.11, the device has been designed with the capability to move short distances without dismantling to perform data collection on the test section. The device could also be used in a permanent facility for specially constructed research sections. TxDOT has plans for constructing such a facility with one of the additional TxMLS devices they plan to acquire.

Figure 3.12 provides a summary of the TxMLS technical information.

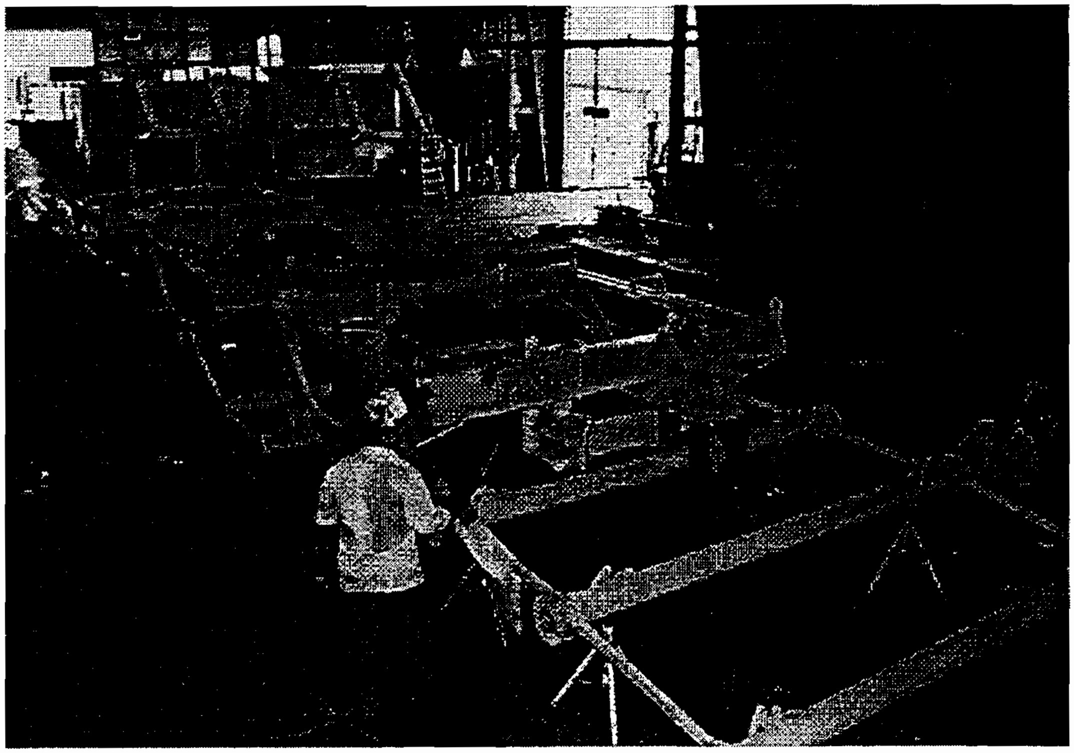


*Figure 3-9*

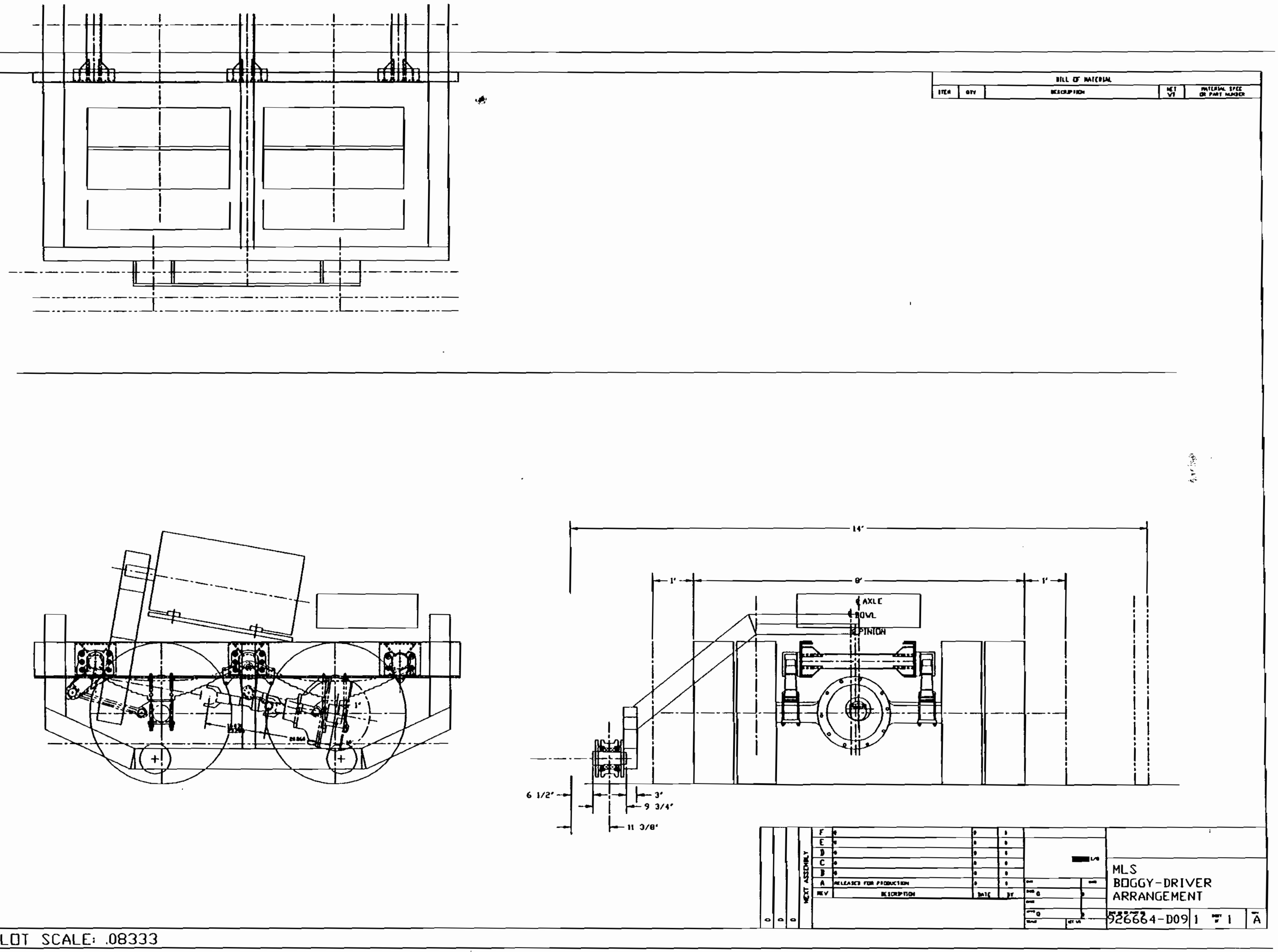

BILL OF MATERIAL
14'
1'
8'
1'
AXLE
BOWL
PINION
6 1/2"
3"
9 3/4"
11 3/8"
RELEASED FOR PRODUCTION
NEXT ASSEMBLY
MLS
BOGGY-DRIVER
ARRANGEMENT
926664-D09
PLOT SCALE: .08333

*Figure 3-10*

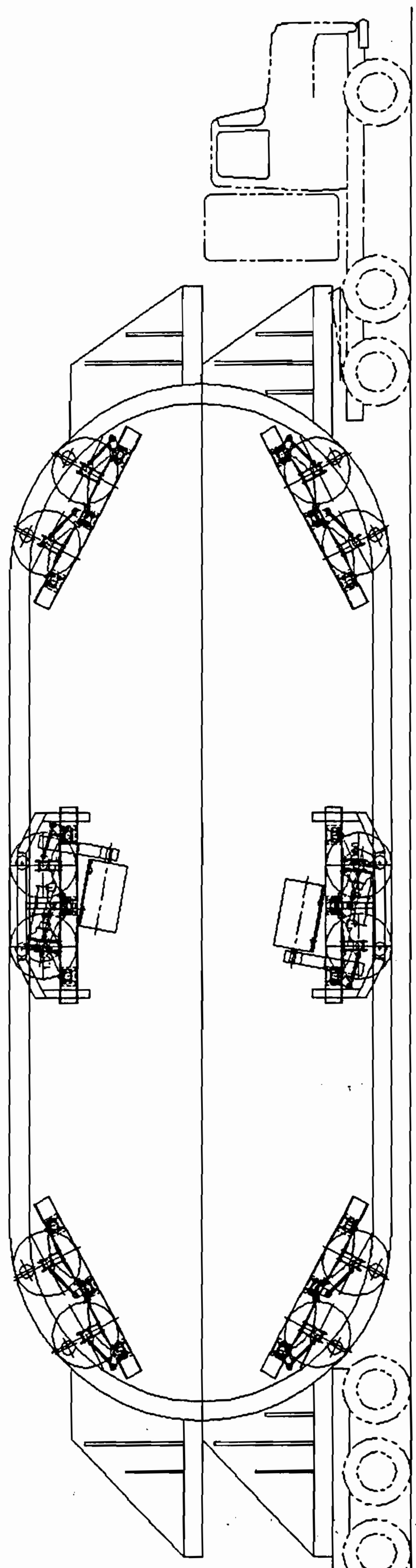


*Figure 3-11*

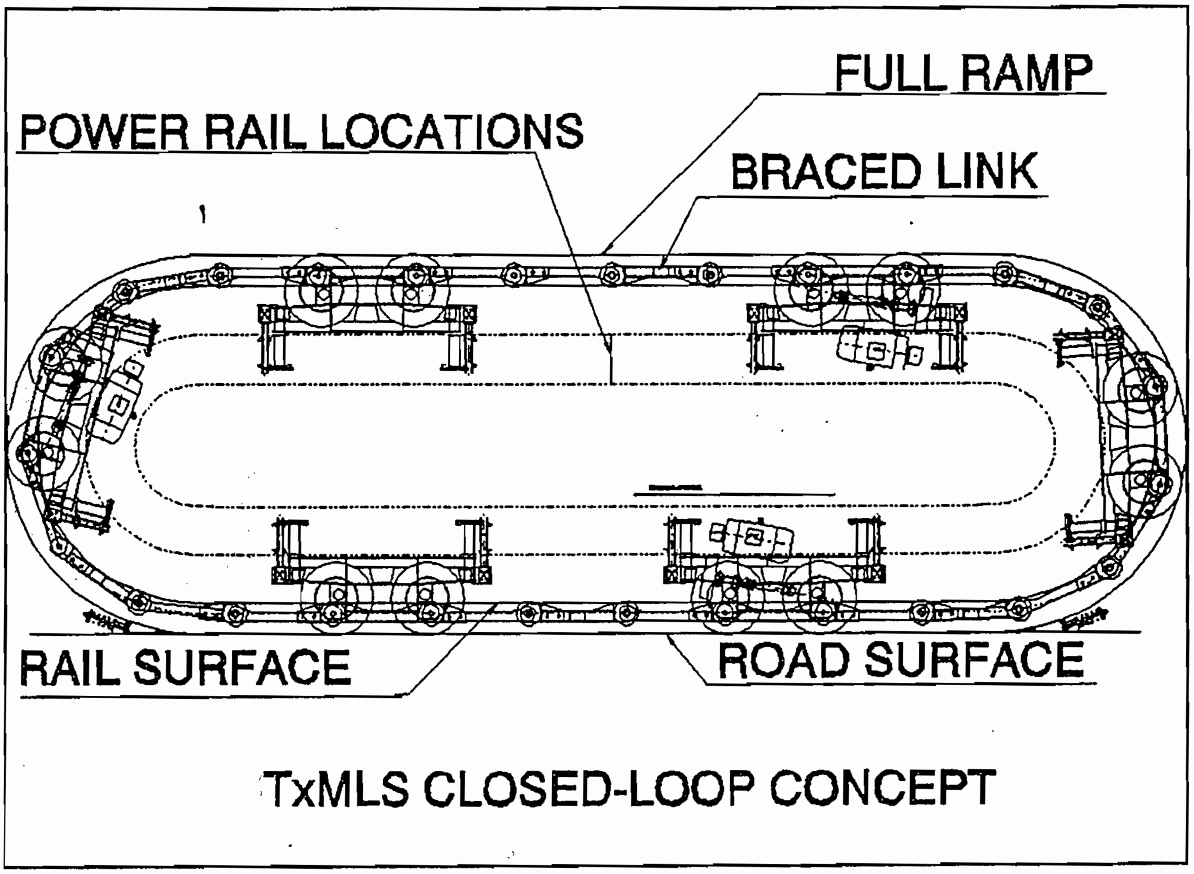



*Figure 3-12 Texas Mobile Load Simulator (TxMLS)*

| | |
|---|---|
| Name: | Texas Mobile Load Simulator (TxMLS) |
| Fixed or Mobile: | Fixed or mobile |
| Date of Manufacture: | 1994 |
| Location: | Austin, TX |
| Length of Test Section: | 36.5 feet (11.1 m) |
| Number of Test Sections: | 1 at a time or 2 wheel paths |
| Wheel Speed: Normal: | 20 mph (32 km/h) |
| Maximum: | 25 mph (40 km/h) |
| Axles: | 12 full axles / 6 tandem axles |
| Number of Testing Tires: | 48 or 24 |
| Suspension: | Standard truck suspensions |
| Test Axle Load: | 20,000 lbs/axle + 25% overload |
| Axle Load Transfer: | Load rail against suspension (drive axle) |
| Lateral Load Distribution: | ±12 inches (± 39 cm) |
| Test Direction: | Unidirectional |
| Days to achiueve 1,000,000 axles: | 4 days (900 cycles/hr) |
| Housing: | Outdoor |
| Environmental Control: | Partial (closed chamber) |

## CONCLUSION

In this chapter, all types of accelerated pavement testing facilities were listed along with their benefits for both the local agency and the international pavement community. Most researchers appreciate that there are vast areas in pavement engineering that can be successfully addressed with the aid of accelerated pavement testing. Knowledge generated will feature a high reliability/cost ratio in comparison with other available methods.

Table 3.1 summarizes the information given on the existing devices and the relative capabilities of each device. Using the table and the previous descriptions one can have a very good understanding of the capabilities and limitations of the devices. A technical discussion of the pavement-vehicle interaction and of the vehicle dynamics, with specific comparisons between the ALF, TxMLS, and actual truck measurements, is provided in Chapter 4. A further comparison of the devices and how they relate to the Florida DOT needs assessment is discussed in Chapter 5.

Table 3-1 : VEHICLE-PAVEMENT INTERACTION OF ACCELERATED PAVEMENT TESTING DEVICES RELATIVE TO REAL TRAFFIC

| Notes on Highway-vehicle interaction | | Ability of APT - devices to simulate or test | | | | |
|---|---|---|---|---|---|---|
| **Vehicle Input variables** | **Frequency/ Importance of Event** | **Circular-LPPC, etc.** | **Race Track-Spanish** | **Linear HVS/Lintrack** | **Linear ALF** | **Linear MLS** |
| Uni-directional travel | Normal | Yes | Yes | Yes | Yes | Yes |
| Bi-directional | Not normal | Yes | Yes | Yes | No - could be adapted | Yes |
| Surface Torsional shear | Occurs only at specific points | Yes | Only in curved sections | No | No | No |
| Longitudinal Shear due to acceleration/ deceleration | Important on gradients | Can be generated by resistance to rotation | Limited only by track geometry | No - except for deceleration | Yes but limited to overcoming rolling resistance | Yes-Limited to gradient of 3% |
| Very slow rolling wheel loads | Only on specific sections | Yes | Yes | Yes | Lowest speed limited by system geometry | Yes |
| Medium speed wheel loads | Limited to sections | Yes | Yes | No | No | Yes - 22 mph (36 kph) max. |
| High speed wheel loads | Normal | Yes - 62 mph (100 kph) max. | Yes - 31 mph (50 kph) max. | No | No | No |
| Dynamic response of suspension, axle and vehicle body | Long and short wave lengths manifested due to body suspension, tire and pavement dynamics. Resonant frequencies range between 3 and 12 Hz. | Controlled by system geometry which differs from trucks. Normally a constant load is used | Controlled by section geometry which differs from trucks, and the use of a constant load | Suspension such as airbag can be installed. Load equalizer absent. Normally constant load is used | Influenced by system geometry and differing body dynamics due to gravity loading | Controlled by system geometry, but simulates short wavelength dynamics |

# CHAPTER 4. PAVEMENT-VEHICLE INTERACTION

## INTRODUCTION

The upsurge in accelerated pavement testing (APT) during the last decade is understandable in view of the advancement in pavement design technology. There is a quest for continued improvement of methods in an attempt to utilize the extraordinary advancement of microcomputers. In 1967 few engineers believed it possible to model pavements with sufficient accuracy to be able to execute designs. Today there are many systems in operation which purport to do exactly that. However, a problem has been the inability to validate such theoretical designs to the satisfaction of the critical reviewer. APT is one of the tools that is able to contribute in this regard. A perceived limitation of APT devices is their inability to address the dynamic aspect of pavement-vehicle interaction. This section considers this topic with specific reference to the available devices. Before discussing the dynamic aspect, it is necessary to say something about acceleration of pavement response.

## MEANS OF ACCELERATION OF THE NUMBERS OF EQUIVALENT SINGLE AXLE LOAD APPLICATIONS (ESAL)

Many ingenious methods have been attempted to achieve accelerated pavement testing. One of the first ambitious attempts was the AASHO road test of the early 60's. Criticism of the test was mostly focused on the climatic conditions and the fact that the base for extrapolation was so limited.

Accelerated pavement testing devices, therefore, began to flourish in an attempt to address some of the shortcomings of the AASHO-road test. APT devices have also been criticized but most of the concerns have been addressed and in the last decade APT has grown rapidly in extent. A major event was the commitment from the Organisation for Economic Co-operation and Development to an organized effort to have national full-scale pavement test facilities participate in a joint coordinated program (4) that has lead to fruitful execution of tests.

As mentioned earlier, one of the criticisms of APT is its inability to account for pavement-vehicle dynamics. In order to evaluate this criticism and to address it, it is important to briefly review the method of acceleration and the manner in which the environment is given consideration.

### *Acceleration by Using Controlled Physical Environment*

It is well known that the environment influences the rate of deterioration of a pavement. In addition, this process is interactive with the effect of loading. There are many instances where this has been found to be the case. Recently Van der Merwe et al.

(12) reported on the effect of transfer functions used for the design of a rehabilitation project with asphaltic material when accelerated aging is applied and the asphalt is tested at 104 °F (40 °C). They demonstrated that accelerated testing had to account for the effect of aging in order to produce meaningful results. Croney (13) has also reported the same findings in the long-term pavement performance studies by the TRRL in the UK.

Hugo et al. considered the effect on APT in their TRR 1293 paper (3). Bell also discusses the topic in a recent paper to the ISAP conference in Nottingham (14).

In view of these findings, another method of acceleration is to control the physical environment to cause distress to occur more rapidly. This process is naturally complex and will require correlation with LTPP-studies for validation. Methods include testing at high (40C) and low (0C) temperatures as well as the accelerated artificial aging of the pavement materials by temperature, UV-radiation and variable exposure. While this process will not be discussed further, it will have to be borne in mind when the effect of dynamics, due to wheel loading, is considered.

Suffice to say that it can be expected that this topic will feature strongly in future accelerated paving testing programs.

### *Acceleration by Overloading*

Acceleration by overloading is achieved by sustained application of a selected load that is often twice the amount as the mass of an ESAL. The increased loading of the test wheels is done on the premise that the equivalency of damage is some exponential power function. Thus the number of ESALs per load application is related to an factor relating to the exponent. This, of course, requires that such an exponent be used to determine the extent of acceleration. There are concerns about this procedure since it raises many questions about the stress conditions within the pavement and the rate of degradation of pavement materials.

Naturally the question as to whether the test devices actually simulate the dynamic response between trucks and pavement has to be addressed when considering size and range of the wheel load. Many devices simply use a constant force with little or no dynamic action. Clearly the difference experienced under a rolling wheel load, in contrast to a static load, is the change in speed and its affect on the material behavior. The difference in the pavement's response to the entry edge of the rolling wheel and the exit edge is also a matter of importance.

It is therefore understandable why a rolling wheel, with dynamically changing forces has to be considered when studying the actual relationship between wheel and pavement. As will be shown, if this is not considered it could cause incorrect deductions to be made with respect to the performance of the pavement.

## METHODS OF LOADING WHEELS

APT-devices have different modes whereby the load is applied to the wheel and the pavement.

- Gravity Method: By gravity through a dead weight resting on a single (or dual) axle with or without a suspension between tire and mass. Clearly this method simulates a portion of a truck but it has its own unique body dynamics!

- Force Method: By traversing the wheel (with or without a suspension system) between a suspended mass and the pavement surface. The mass serves as reaction for the force on the tire(s). Suspensions and multiple axles can be used.

As will be shown later, the ALF, the Spanish device and many circular devices use the Gravity Method. In contrast, the MLS, the HVS and LINTRACK use the Force Method. However, the HVS-force is fixed whereas the MLS-force varies depending upon suspension type, road surface, and the quality and grade of the pavement. The LINTRACK-device and many others have a mechanism for maintaining a constant force. This is clearly in contrast to the dynamic nature of real vehicle-pavement interaction. There are, of course, occasions where such a device may be of use, e.g. when the variation in load is unwanted in an investigation.

In order to do a comparative evaluation of the different devices it was necessary to gain a better understanding of their respective dynamic responses.

## NATURE OF DYNAMIC LOADS OF APT-DEVICES

The ALF, which has been in operation in Australia and at Turner Fairbanks, applies a dynamic load by having a dead weight supported on a half axle with an air suspension.

Unfortunately it would appear that the natural dynamic frequency of the ALF loading device gives rise to excessive rutting, in the areas of high stress (see discussion later). This in turn generates further device dynamics which, unfortunately, could lead to unrealistic deterioration of the quality of the road. The same applies to some of the circular devices.

In an attempt to address these problems the MLS is being developed. Its design is such that the travel of the undercarriage simulates a snap-shot of a vehicle traveling along a pavement surface. The importance of this will be briefly considered.

As a vehicle travels along any given highway it is subjected to a continuously varying pavement surface. As a result it experiences varying forces on the wheels, axles and suspensions. This is due to the complex body dynamics of the vehicles. Very comprehensive studies have been done to identify and understand these forces and only a few need be referenced (15, 16, 17, 18).

If one studies the profile of typical measured wheel forces it is apparent that the dynamic forces vary in a somewhat random fashion. However upon analyzing the measurements by means of a frequency distribution it is clear that they mostly have a normal distribution. This is dependent upon, among other things, the speed and the nature of the vehicle.

For the purpose of this discussion it is important to focus on another feature, namely the fact a variance in loads occurs when a short time interval is studied. It should be remembered the vehicle is moving over a pavement length which varies in gradient as well as cross section. On the basis of the body dynamics it could be argued that a window or time slot relative to a fixed point along the road, exhibiting a less than average value of forces would tend to do so regardless of the vehicle type passing by. At most, it may vary relative to the fixed position. The same could be said if the forces are higher than the normal average values. This would of course explain the reason why roads experience distress in localized areas.

For APT this is of particular importance since the test section is of limited length. Depending upon the section it could be argued that the position of the test load should equate to or simulate the nature of the actual loads experienced. This of course doesn't mean that one can simply select the most adverse or beneficial conditions. Rather it means that to understand and utilize the test results one has to take account of the phenomenon.

This also explains why pavements have to be tested for varying test loads. In fact, to reach a proper conclusion the test load should simulate the actual traffic load as closely as possible. To do this, it would be necessary to actually predetermine what the load frequency distribution at a particular point is in order to set the APT to achieve this as closely as possible.

It is apparent that not all APT devices are able to simulate actual traffic loading to the same degree. This does not mean that such tests are valueless. It simply means that the test device has to be used for the situation which it best simulates.

Furthermore, since acceleration can be done by several means it is necessary to decide whether the mode of acceleration is compatible with the pavement system that is being studied. Then, the method of load application must also be studied in order to determine whether it simulates the actual distress modes most likely to occur in the field.

### *Measured Dynamic Response*

Figure 4.1 shows the wheel force transducer output of two suspension types measured on trucks by Sweatman (16) on a section of a road. If the results are all pooled the frequency distribution under different axles and suspensions are as is shown in Figure 4.2. Figure 4.3 shows similar results at a different speed measured by Gillespie (18). However,

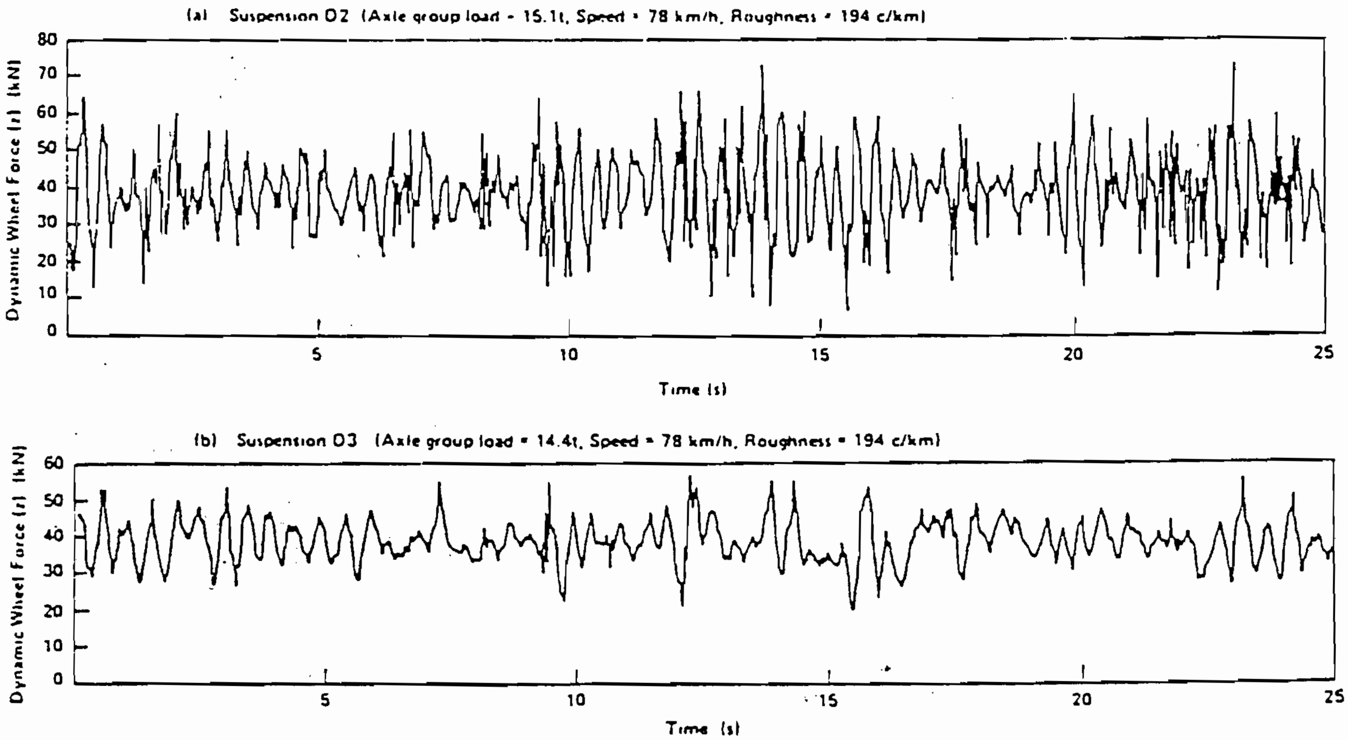



***Figure 4-1 Examples of wheel force tranducer output (after Sweatman).***

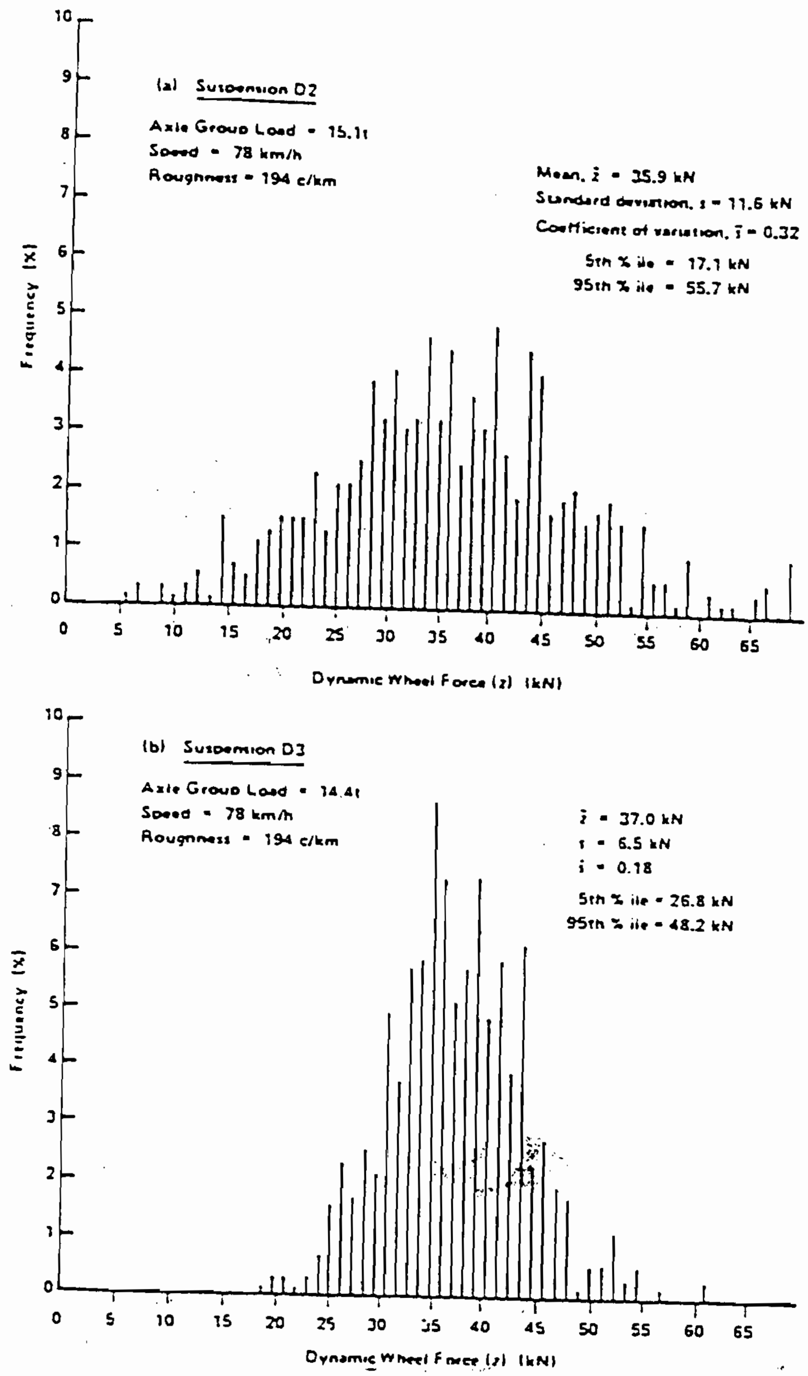



*Figure 4-2 Examples of dynamic wheel force amplitude distributions (after Sweatman).*

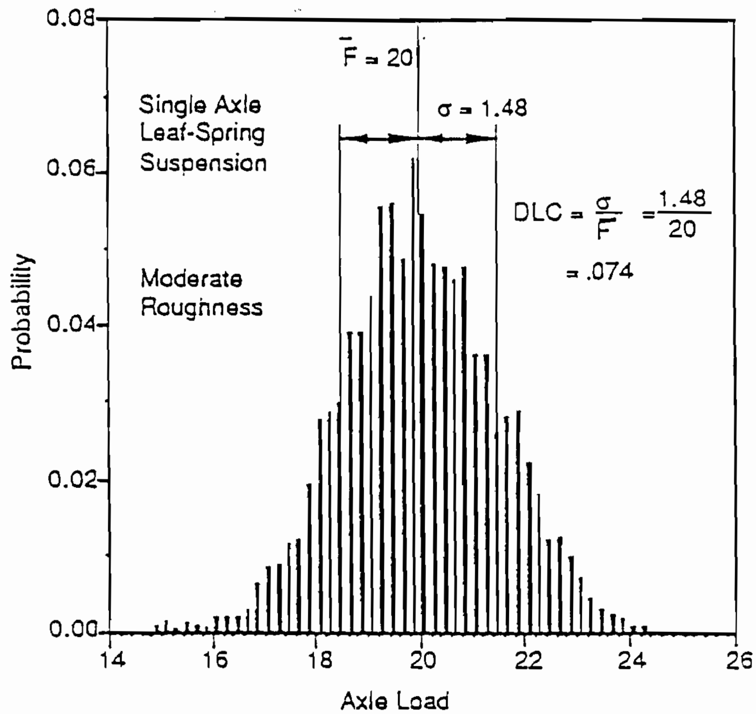



***Figure 4-3 Frequency distribution for actual dynamic axle loads at 88 kph in kips. (10 kip ≈ 45 kN) (after Gillespie).***

by taking a small sector of the results from Figure 4.1, equal to the nominal size of a truck or the APT devices, it will be seen that the average load is different. See Figure 4.4.

Sweatman and Gillespie have reported extensively on the nature of this interaction. Their main findings may be summarized as follows:

- Dynamic loading on pavements due to vehicles may be treated as a normal distribution characterized by a normalized coefficient of variation termed the dynamic load response (DLC)
- DLC is strongly affected by speed and road roughness
- Suspension type affects the DLC
- Tire pressure affects DLC and this is compounded by the structure of the tire
- Axle load is a prime factor regardless of whether DLC is taken into account or not.

In the next section computer simulated dynamic behavior of APT-devices is discussed.

## COMPUTER SIMULATION OF THE MLS AND ALF

During the development of the Texas MLS prototype it was decided to develop a computer program to simulate the transient dynamics of the device. The program was written in Microsoft Basic 7 by Heping Zhang of Stress Engineering Services as part of Phase 1 of the MLS development program (19). It modeled a single bogie with front and rear axle assemblies. The tires were simulated by springs and viscous dampers while the suspension spring was modeled as a Coulomb dampened leaf spring according to the numerical procedure of Fanch et al. as referenced by Hu (17).

Due cognizance was given to the mechanical and physical aspects of the system such as acceleration, structure, and pavement geometry and constraints, e.g. due to the equalizer, masses, and degrees of freedom. The data is used to generate graphical output in time versus force format.

By using the program, it was possible to study the effects of speed and pavement deterioration due to changes in the structural design. It has subsequently been adapted to simulate the dynamic behavior of the ALF. Because of a lack of data, some information regarding this system had to be estimated. Accordingly, the output presently does not precisely watch the measured data. However, for purposes of this discussion it was considered acceptable.

The two devices were subjected to similar conditions in order to see to what extent they matched real data. Furthermore, the information would be useful to determine the limitations of the devices and possible precautionary methods that were found to be necessary to improve best procedures and operations.

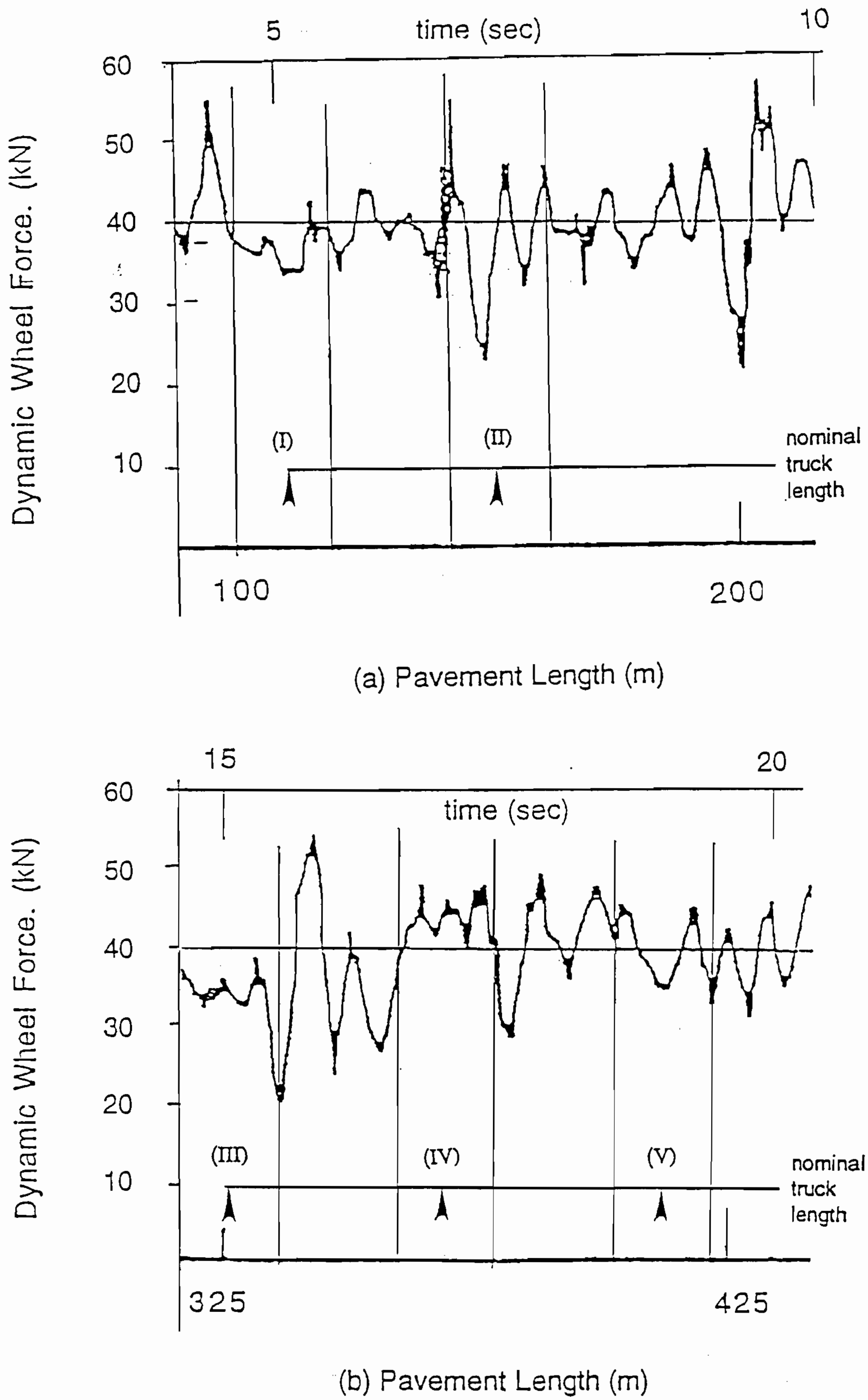



*Figure 4-4 Dynamic wheel force variations.*

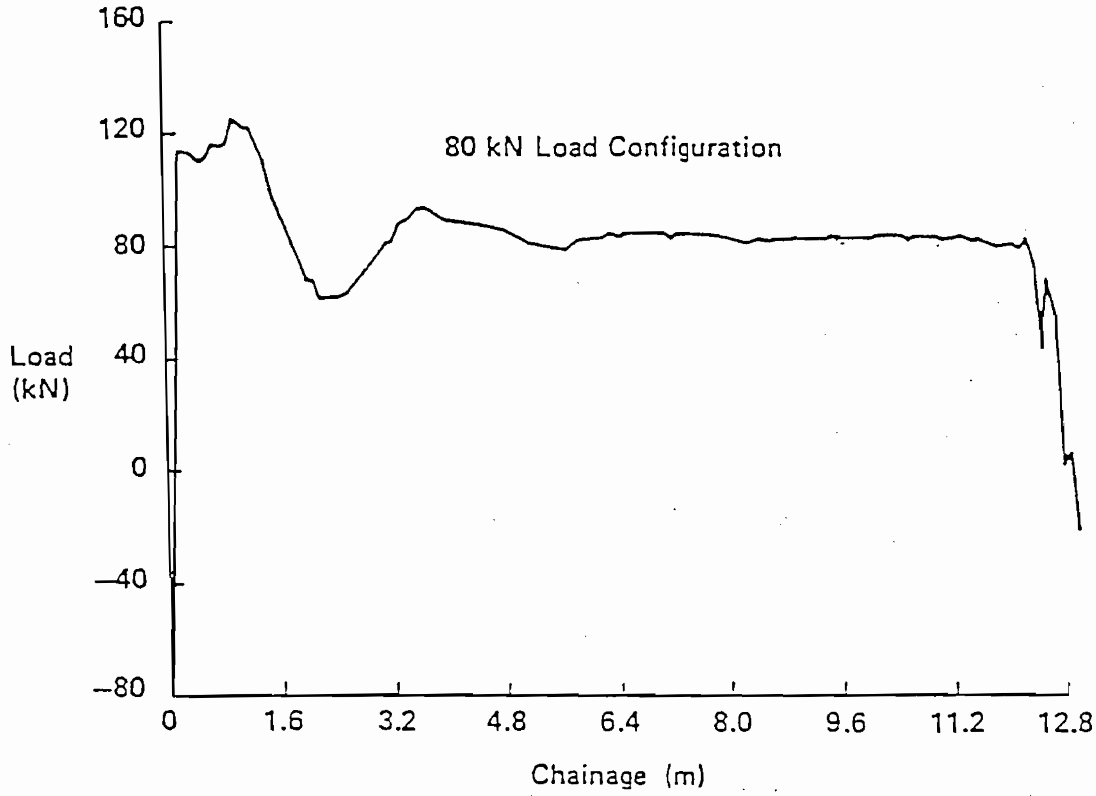



*Figure 4-5 Measured dynamic ALF load profile.*

A series of analyses were done and the results are presented in Figures 4.6 through 4.18. The devices were "run" on surfaces with zero defect and SI values of 4.5 and 2.0. Furthermore, the effect of excessive dynamic response at the point of entry (should it be present) was studied by hypothetically generating a rut mirroring the dynamic force.

### *Discussion of results of computer simulation*

From the results of the computer simulation the following could be deduced:

1. There is an increase in dynamic response as speed and surface roughness is increased. Compare Figures 4.14 and 15 as well as Figures 4.8 and 4.10, and 4.9 and 4.12.
2. The dynamic responses resemble actual measured data. Refer to Figures 4.19 and 4.20 where the frequency distributions of the tire forces were determined.
3. The effect of the gravity load of ALF is apparent in the nature of the dynamic response. See Figure 4.5. From a comparison of Figure 4.7, and the actual dynamic response measured on the ALF, it is clear that the simulation might still be under estimating the actual response.

In Figure 4.11 the effect of a load well below full load on a tire was shown to produce excessive dynamic response.

4. The artificial rut affected the dynamics as could be expected. It was also interesting to note the apparent detrimental effect of the perfect surface. This phenomenon has been reported by researchers when vehicles were subjected to a resonating load on a very smooth road surface due to slight imbalance in the tires. See Figures 4.14, 4.15, and 4.16.

The ALF's enlarged dynamic response resulting from the gravity load is apparent (see Figures 4.16). This behavior can be expected to occur with all devices using gravity only for providing the load. The possibility of accentuated rutting at discrete points along the path of the ALF wheel due to the cyclical nature of some dynamics is apparent.

5. The influence of the randomly spaced road surface unevenness was apparent in the beneficial effect it had on the generated dynamics. Compare Figures 4.17 and 4.18.

## CONCLUSIONS

The systems of the analytical study made it possible to draw certain conclusions with respect to the vehicle-pavement interaction of the MLS and the ALF. The results are, however, also more generally indicative of the response of APT devices using force and gravity, respectively, for generating the load.

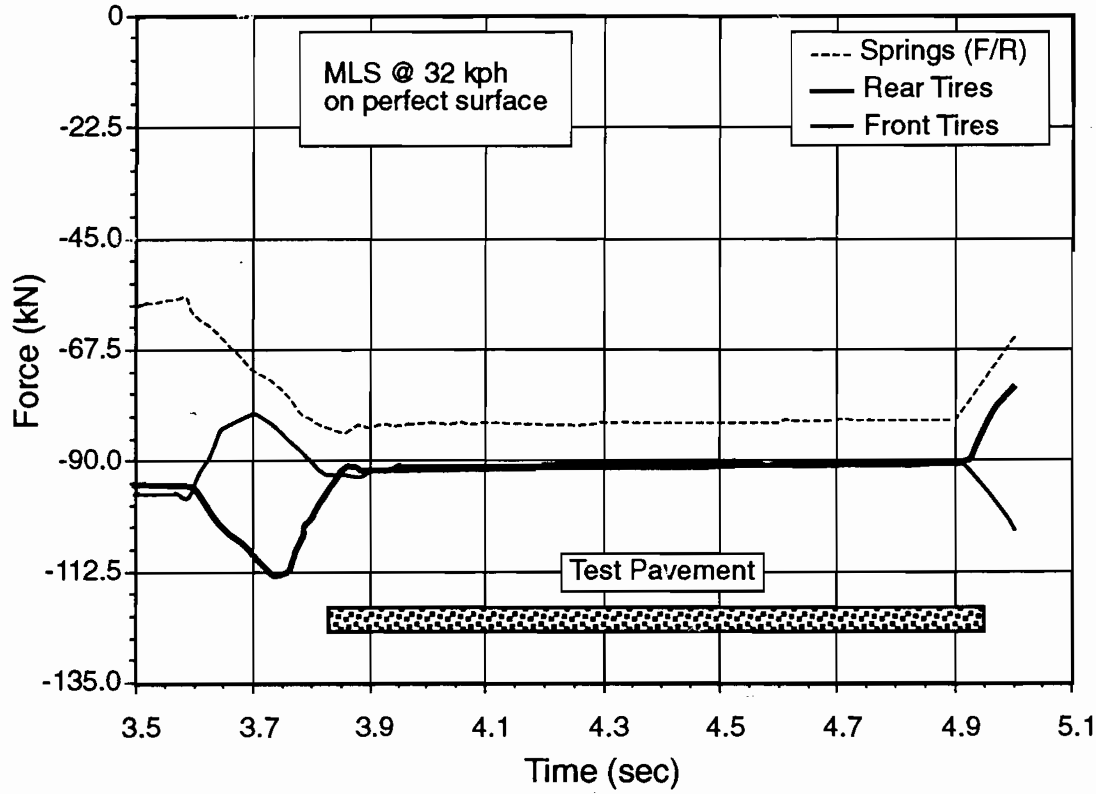



***Figure 4-6 MLS pavement interaction.***

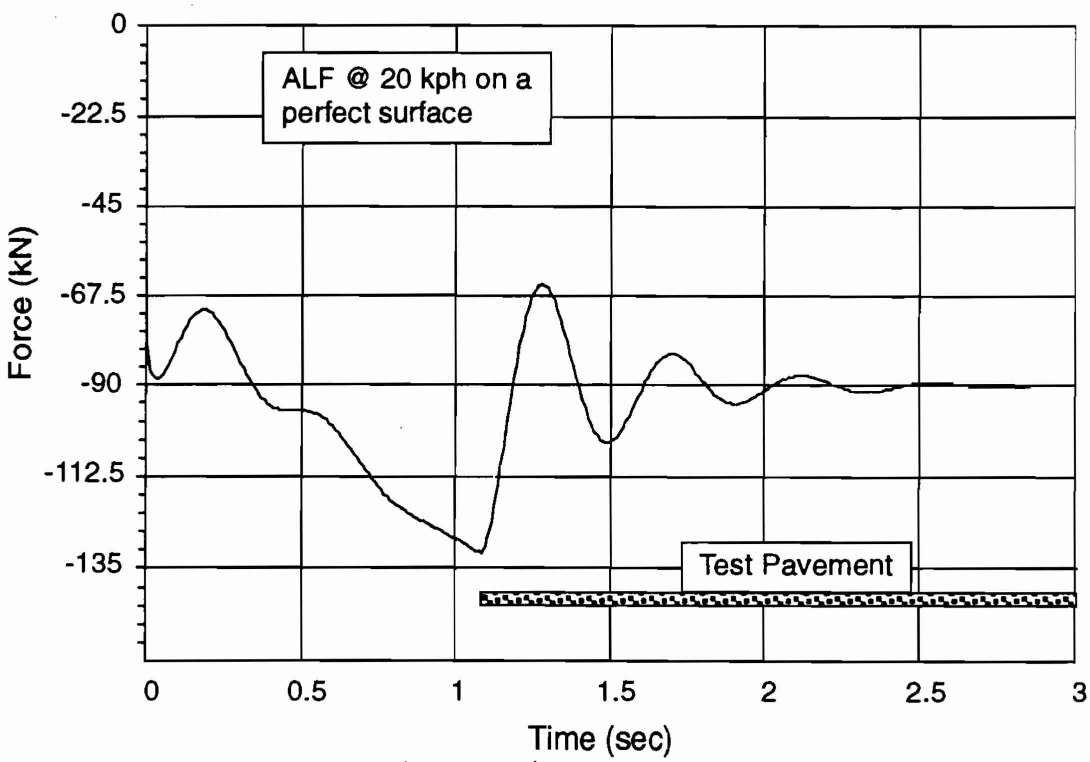



***Figure 4-7 ALF pavement interaction.***

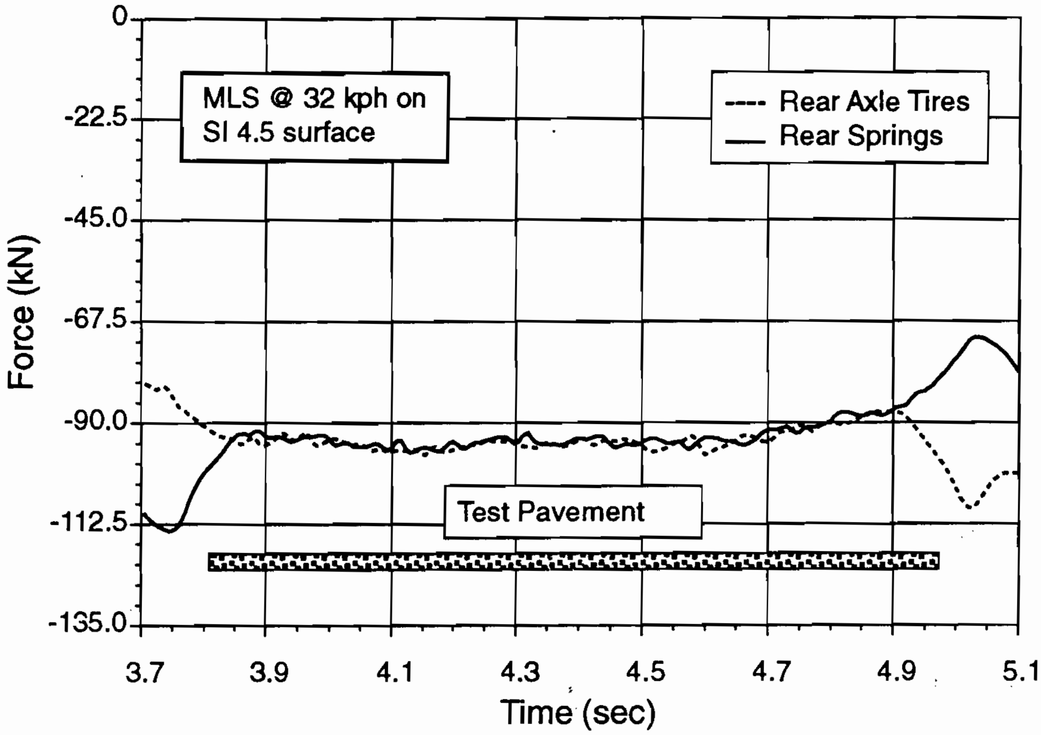



*Figure 4-8 MLS pavement interaction.*

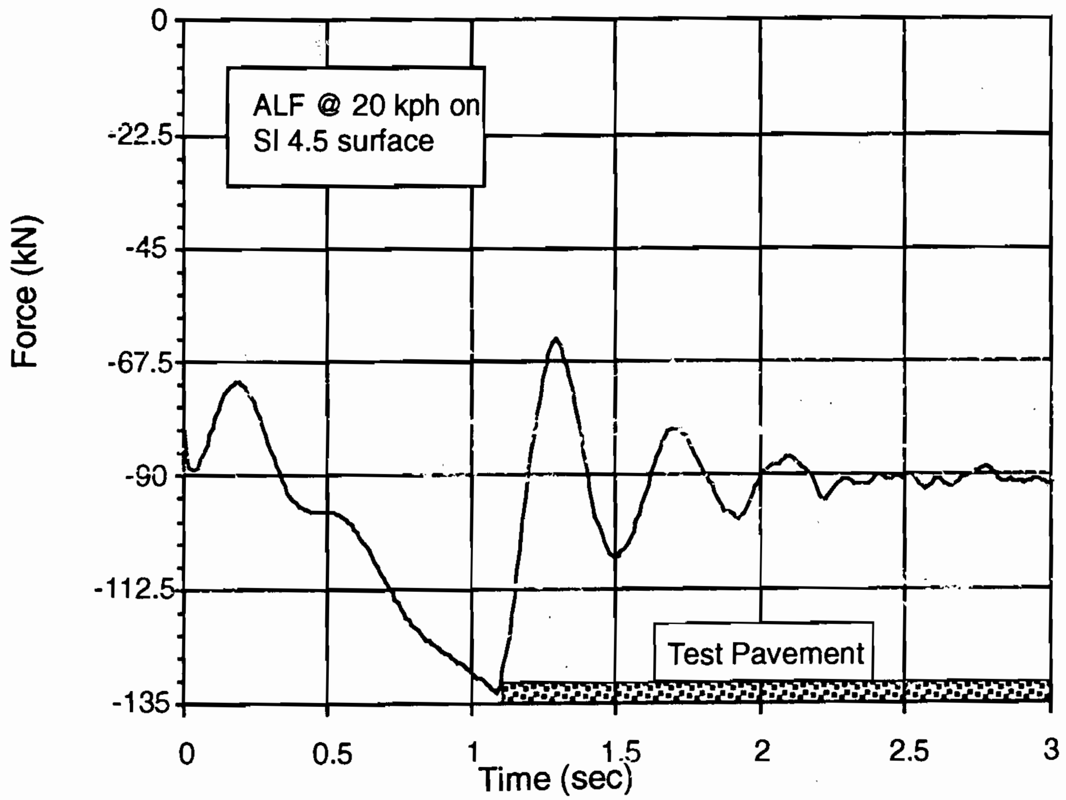



*Figure 4-9 ALF pavement interaction.*

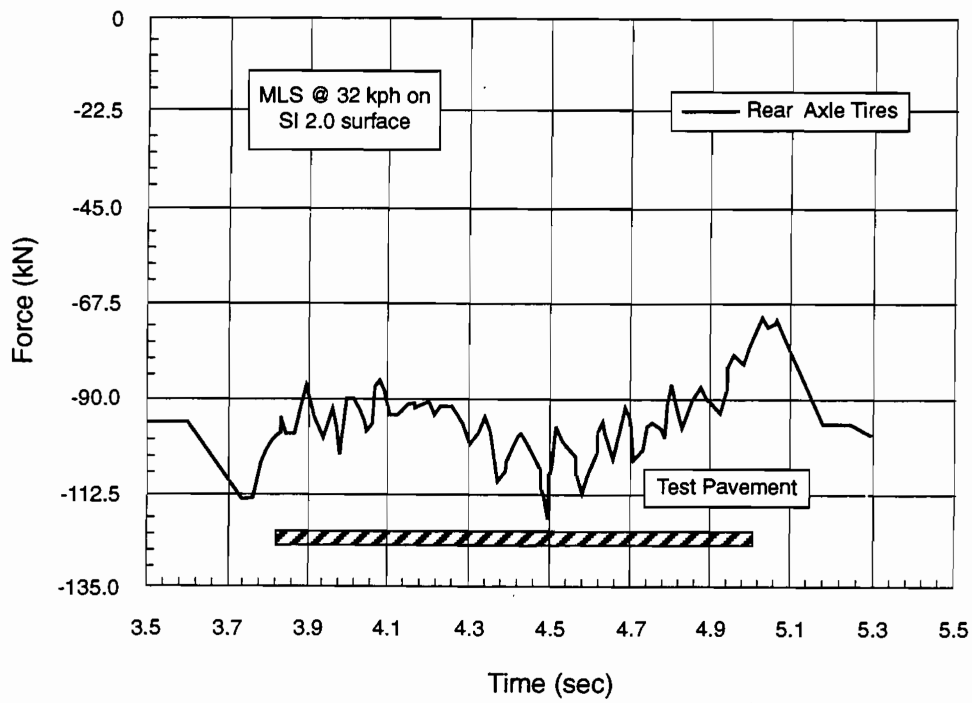



*Figure 4-10 MLS pavement interaction.*

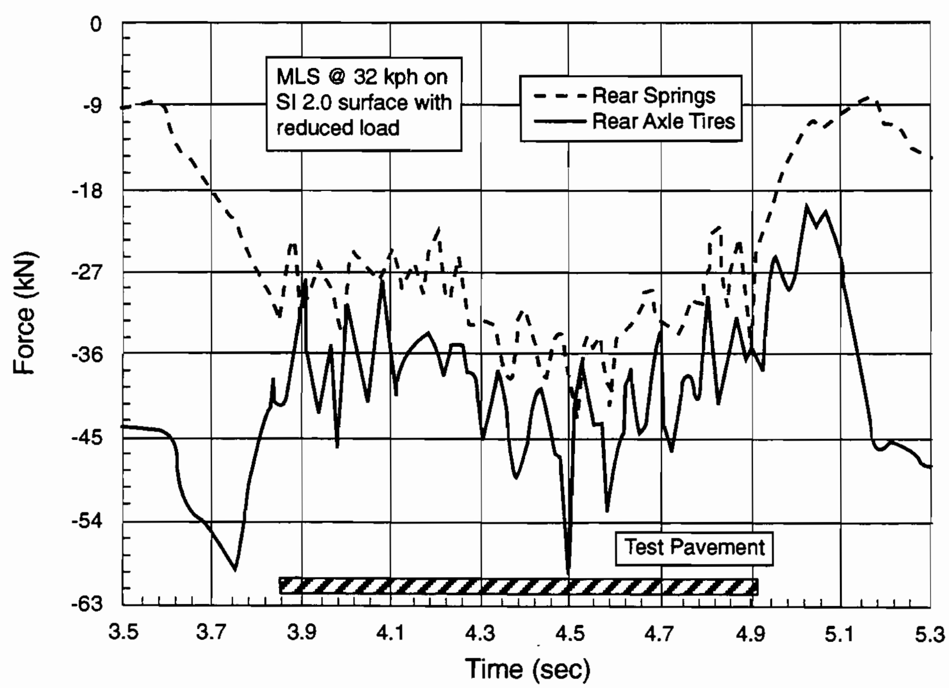



*Figure 4-11 MLS pavement interaction.*

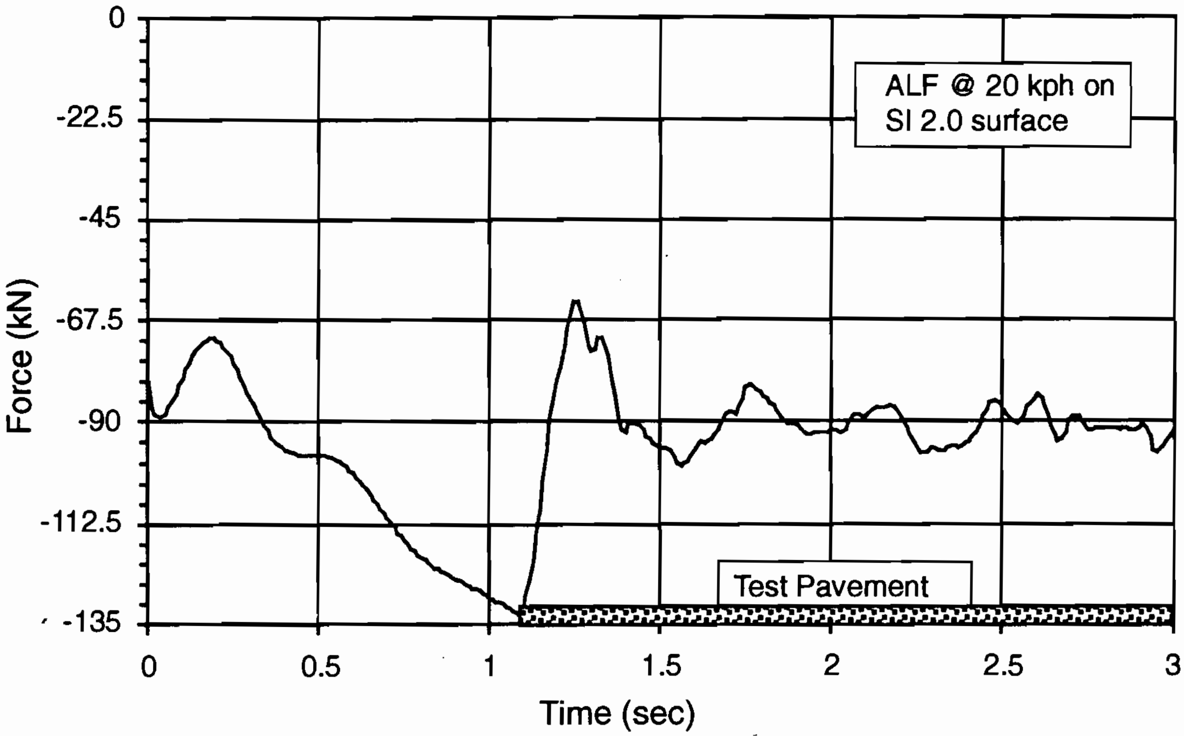



*Figure 4-12 ALF pavement interaction.*

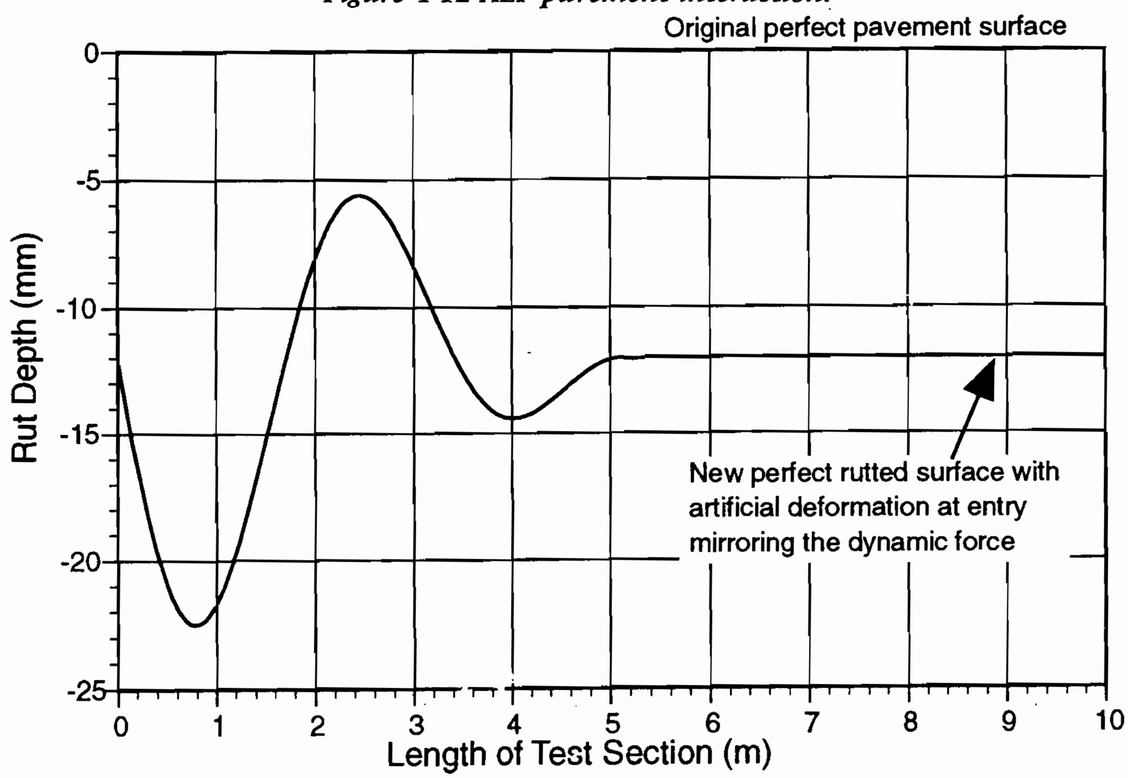



*Figure 4-13 Surface profiles used for theoretical analyses.*

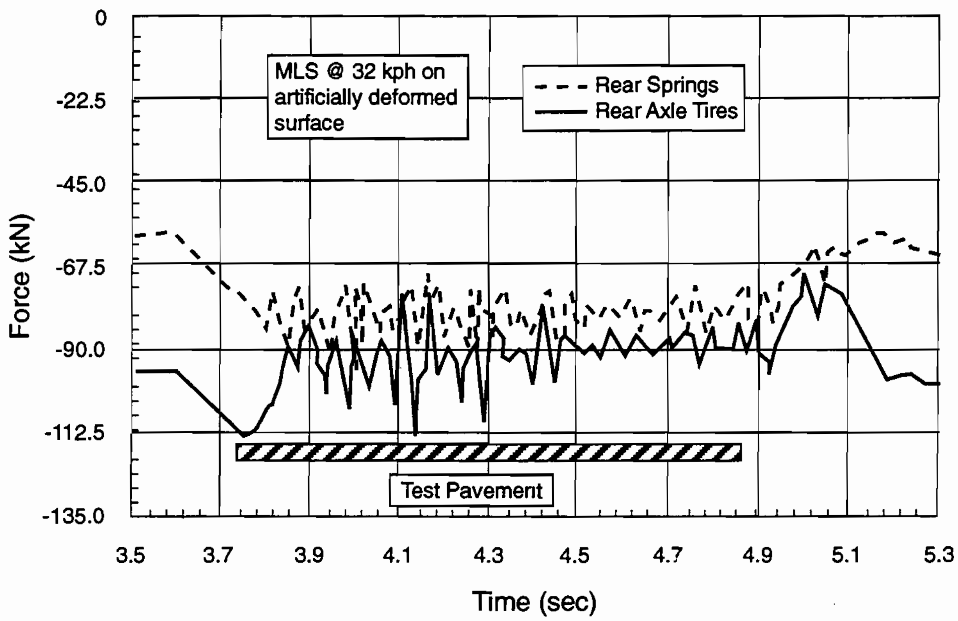



*Figure 4-14 MLS pavement interaction.*

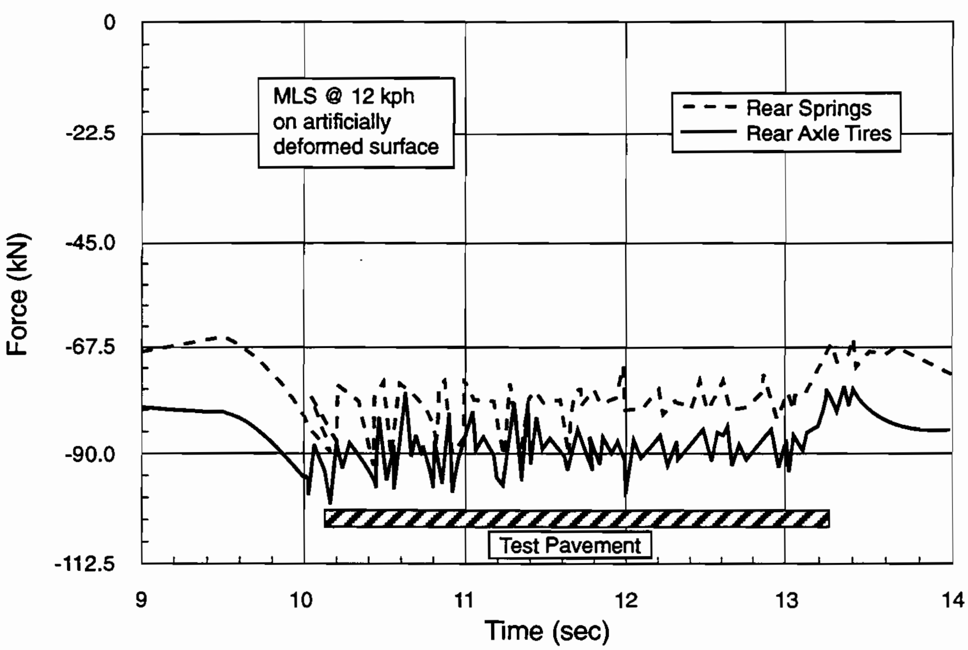



*Figure 4-15 MLS pavement interaction.*

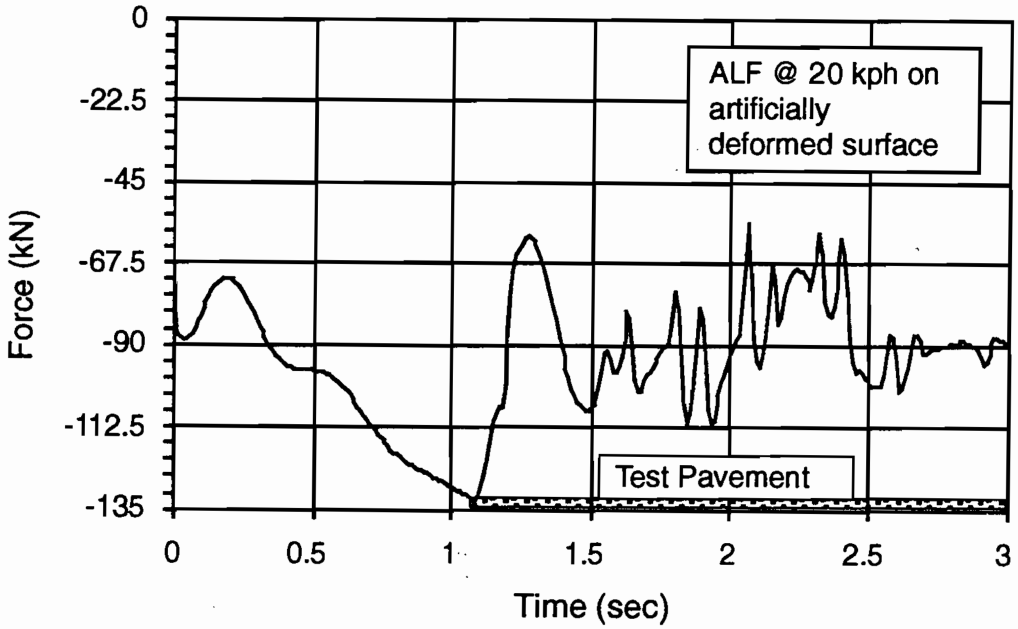



*Figure 4-16 ALF pavement interaction.*

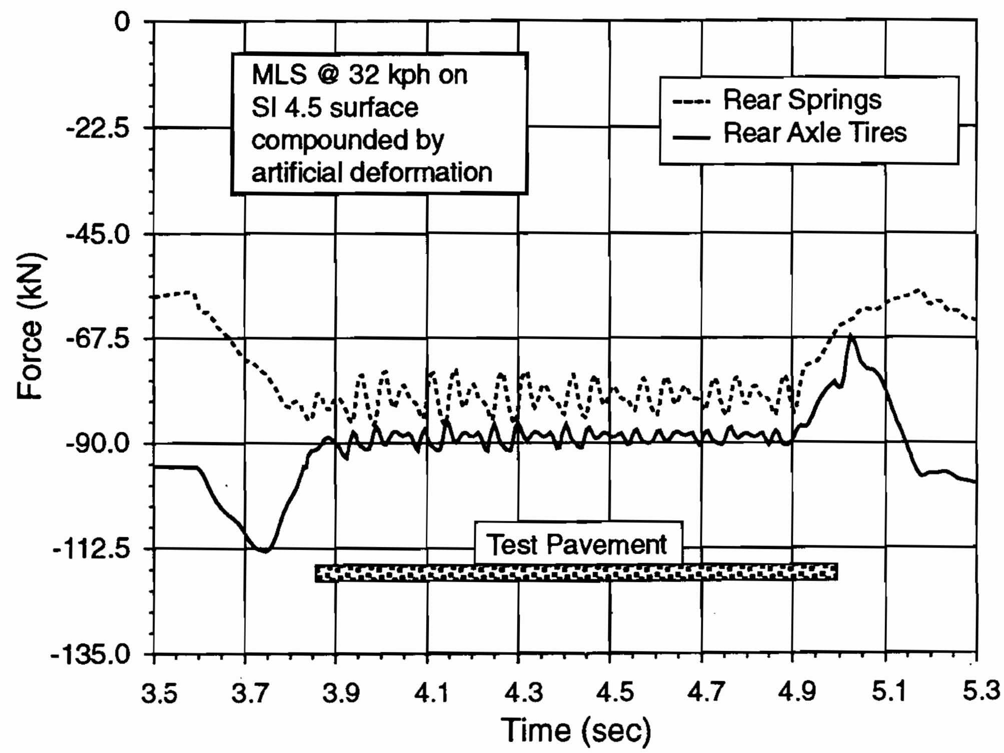



*Figure 4-17 MLS pavement interaction.*

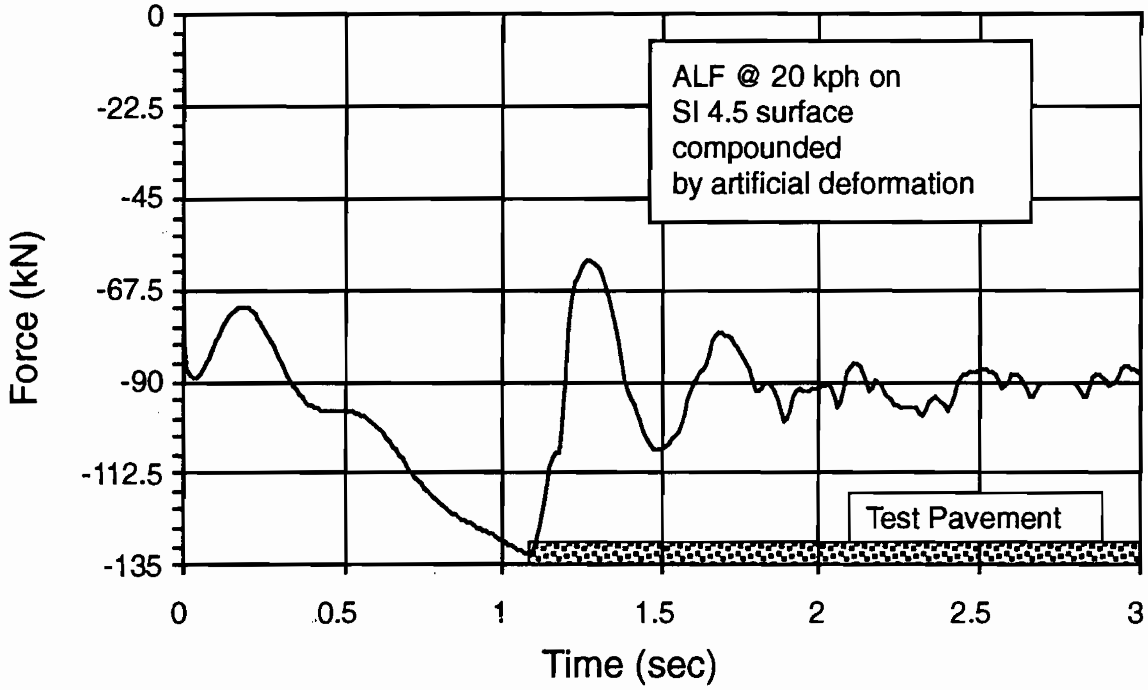



*Figure 4-18 ALF pavement interaction.*

1. In general, both the MLS and the ALF generate dynamics resembling measured vehicle dynamics. From Figures 4.8 and 4.9 it would appear as if the MLS has a smaller, and more even dynamic impact than the ALF. This is borne out by the results shown in Figures 4.19 and 4.20. It should also be remembered that the results of the MLS relate to a speed of 20 mph (32 kph) while the ALF is at 12.4 mph (20 kph) Under some specific conditions deviations could occur that would render the performance results difficult to interpret. Compare Figures 4.14 and 4.16.
2. The MLS-device is a tool that can be systematically applied to simulate the changing dynamic load profile on a section of road, as the vehicle moves along the road, by progressively changing the machine setting from a low load to a high one on adjacent sections of pavement. By consolidating results, an improved understanding of performance prediction should become feasible.
3. It should be remembered that there are many factors regarding pavement behavior still requiring study, and that not all require the sophisticated dynamic input of a device such as the MLS. Likewise, there are times when the ability of such a tool and its capability of acceleration, using standard axles, is indispensable.
4. The need to closely monitor the test pavement to take precautionary measures to prevent unwanted dynamics is clear. This could easily be done by using some form of deformation resistant slurry.
5. The dynamic forces are of course not necessarily always high enough to cause fracture. However, we consider these the root cause of the deterioration of a pavement surface. This then in turn leads to further deformation and the cycle continues.
6. The well-known phenomenon of increased dynamics with a lighter load was demonstrated. The only comfort is that the resulting loads are still not as large as that experienced under normal full load. On the other hand, this probably gives rise to differential deformation. In addition it must be pointed out that the extent of the dynamic factor would be to increase the load equivalency factor!
7. From a comparison of Figures 4.2, 4.3, 4.19 and 4.20 it is apparent that the speed of both the ALF and the MLS are still relatively slow in comparison to normal traffic. This would explain the smaller dynamic impact of the APT devices relative to normal traffic.
8. The skew nature of the dynamic response depicted in Figures 4.19 and 4.20 was probably due to the nature of the pavement surface profile from which data was taken.

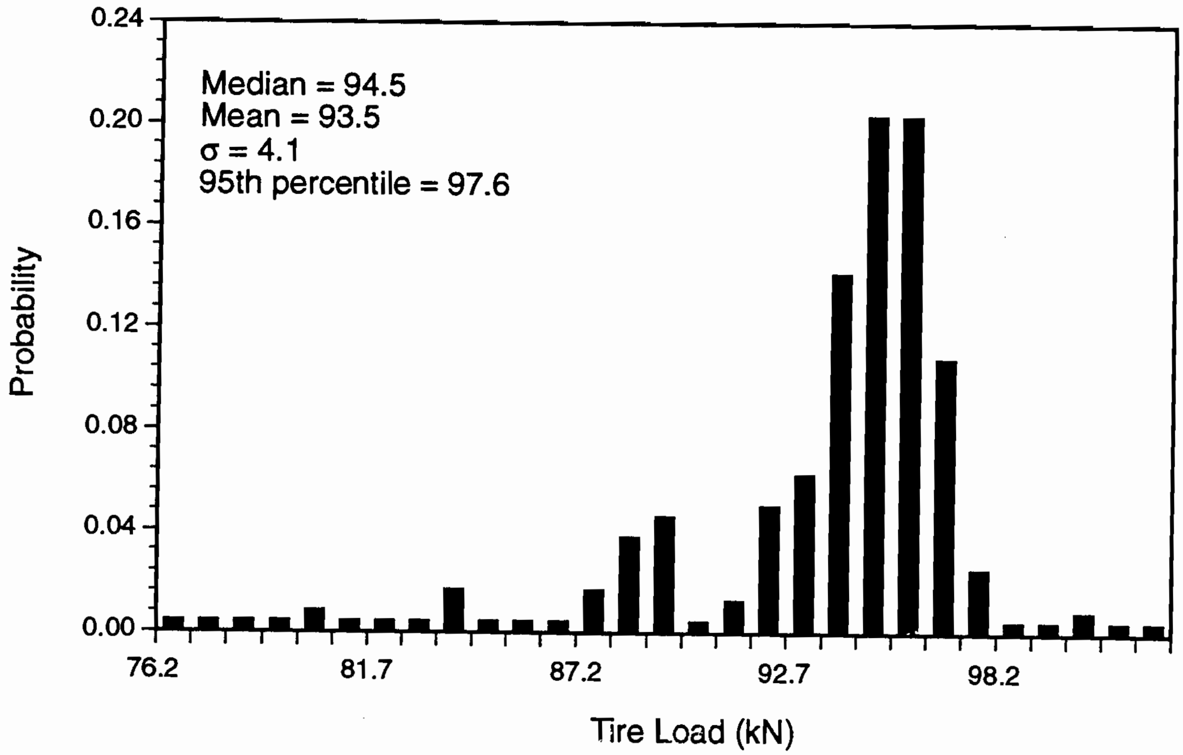



*Figure 4-19 Frequency distribution for MLS tire loads on SI 20 surface.*

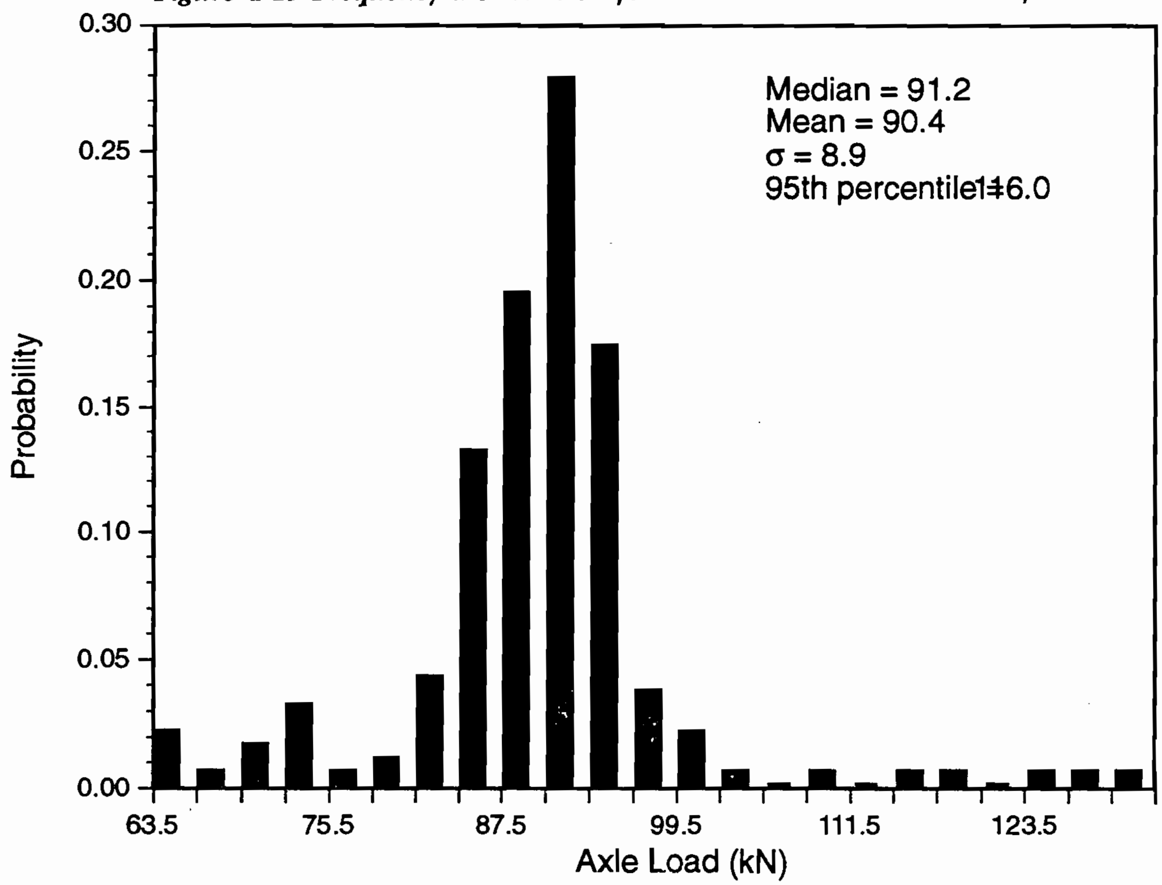



*Figure 4-20 Frequency distribution for ALF tire loads on SI 20 surface.*

## IMPLICATIONS OF PAVEMENT-VEHICLE INTERACTION

If the nature of vehicle-pavement interaction is considered, it is apparent that any APT-device that is used has to take these factors into account. In fact, it can and should be selected to cater to the specific aspect of the problem that is being investigated.

For example, it has been shown that some behavioral characteristics are less dependent on dynamics than others. In such instances, the use of a simple rolling wheel will suffice. In contrast it has been found that the environmental impact on pavement performance is so strong that it can not be neglected and always has to be considered concurrently, whatever the device.

In order to assist with the selection of appropriate devices a comprehensive list of influence factors has been compiled. These were then each considered against the respective modes of APT and critiqued with respect to their ability to be used to study the respective factors. This has been summarized in Table 5.1. It will be discussed in greater detail in the following chapter, where the various feasible options will be explored.

# CHAPTER 5. ALTERNATIVE SOLUTIONS

There are several options that Florida DOT can consider in relation to its accelerated pavement testing facility. This chapter will present those options and explain some of the advantages and disadvantages of each. Chapter 6 will describe the possible site locations and the advantages and disadvantages of each location. Chapter 7 will give a preliminary estimate of the range of costs involved with each of the devices that are considered for Florida DOT. Chapter 8 will focus on the operational cost and staffing of an accelerated pavement testing facility. This chapter is mostly preliminary and will require more attention in Phase II.

The options that Florida DOT should consider for the accelerated pavement test facility, ranked in relative order of the size and scope of commitment to accelerated pavement testing, are the following:

1. Do Nothing
2. Acquire an HVS on loan/hire as an intermediate step
3. Upgrade the Circular Test Device at UCF
4. Build a Small Linear Device.
5. Purchase an HVS Device
6. Purchase a Circular Test Device
7. Purchase an ALF Device
8. Purchase a TxMLS
9. Design and Build a Loop Test Track (Spanish Facility)

The above options cover the full range from option 1 which is to do nothing and not have an accelerated pavement testing program at all to options 8 and 9 which would probably fulfill most of the needs of Florida DOT for accelerated pavement testing. Table 5.1 gives a comparison of the relative abilities of several of the devices to cater for Florida APT needs.

In the Table items are rated with a Y (Yes) to show that the device has that capability, an N (No) that it does not have that capability, or a Q is shown and an explanatory note is provided. Using Table 5.1 and the discussion of Florida DOT needs in Chapter 2, the following options are each evaluated with respect to Florida DOT.

## OPTION 1. DO NOTHING

This option is the easiest to implement in which case there would not be a need to continue with Phase II of this study. However, the analysis of the Florida DOT Questionnaires indicated that there is a strong need to do some accelerated pavement

*TABLE 5.1 LIMITATIONS OF APT DEVICES FOR INVESTIGATING VEHICLE — PAVEMENT INTERACTION.*

**I INPUT VARIABLES**

A WHEEL LOADING

| | HVS | ALF | MLS | LTR | CIR | SP |
|---|---|---|---|---|---|---|
| Ability of devices to utilize/test: | | | | | | |
| Half axle<br>1. Not in present form | Y | Y | Q1 | Y | Y | Y |
| Full axle<br>1. Could be adapted<br>2. Not in present form - could be adapted<br>3. Limited by mechanical ability | Q1 | Q2 | Y | Q1 | Q3 | Y |
| Tandem axles<br>1. Could be adapted - test length would be limited | Q1 | Q1 | Y | Q2 | Y | Y |
| Multiple axles<br>1. Yes but questionable due to mechanical limitations | N | N | Y | N | Q1 | Y |
| Super single tires<br>1. Depends on radius of machine | Y | Y | Y | Y | Q1 | Y |
| Dual Tires | Y | Y | Y | Y | Y | Y |
| Tire pressure | Y | Y | Y | Y | Y | Y |
| Truck type suspension<br>1. Could be adapted to use<br>2. Air suspension used - other feasible | Q1 | Q2 | Y | Q2 | Y | Y |
| Variable suspension<br>1. Not in present form - could be adapted | Q1 | Q1 | Y | Q1 | Y | Y |
| Simulation of measured load dynamics on pavements<br>1. Has different body dynamics<br>2. Limited to short wave high frequency input<br>3. Could be adapted for Q2 | N | Q1 | Q2 | Q3 | Q1 | Q1 |
| Scope of load | | | | | | |
| • Normal legal truck axle loads<br>1. Not when accelerating by axle overloading | Q1 | Q1 | Y | Q1 | Y | Y |
| • 25% overload | Y | Y | Y | Y | Y | Y |
| • > 25% overload<br>1. Feasible | Y | Y | N | Y | Y | Q1 |
| • Selectable load | Y | Y | Y | Y | Y | Y |

| | HVS | ALF | MLS | LTR | CIR | SP |
|---|---|---|---|---|---|---|
| Speed of load application | | | | | | |
| • < 10 mph<br>1. Limited by geometry | Y | Q[1] | Y | Y | Y | Y |
| • 10 - 20 mph<br>1. Limit 12.5 mph | N | Q[1] | Y | Y | Y | Y |
| • 20 - 30 mph<br>1. Limited by geometry | N | N | Q[1] | N | Y | Y |
| • > 30 mph | N | N | N | N | Y | Y |
| Rate of application of ESALS | | | | | | |
| • < 500 ESALS/hr<br>1. Limited by operational system | Y | Y | Q[1] | Y | Y | Y |
| • 500 - 2000 ESALS/hr<br>1. Only by overloading<br>2. Limited by operational system<br>3. Only by using trailing axles or devices | Q[1] | Q[1] | Q[2] | Q[1] | Y | Q[3] |
| • > 2000 ESALS/hr<br>1. Only by overloading<br>2. Only by using trailing axles or devices | Q[1] | Q[1] | Y | Q[1] | Y | Q[2] |
| Wander (simulation)<br>1. Limited by geometry | Y | Y | Q[1] | Y | Y | Y |
| Variation in sequential axle loading<br>1. Must add axles | N | N | Y | N | Y | Q[1] |
| Gradient simulation<br>1. Could operate on 3% - simulates less<br>2. Limited to 3%<br>3. Limited by mechanical forces | N | Q[1] | Q[2] | N | Q[3] | Y |
| Braking simulation<br>1. Limited by mechanical forces | N | N | N | N | Q[1] | Q[1] |
| Drive axles<br>1. Motor not equivalent to normal truck drive | N | Q[1] | Y | N | Q[1] | Y |

B ESTABLISHMENT OF TEST PAVEMENTS

| | HVS | ALF | MLS | LTR | CIR | SP |
|---|---|---|---|---|---|---|
| Permanent research location<br>1. May be limited by environmental regulations | Y | Q[1] | Q[1] | Y | Y | Y |
| Ability to test in-service roads | Y | Y | Y | N | N | N |
| Prepared length of test section | | | | | | |
| • 5 - 10 m<br>1. Construction problematic | Y | Y | Y | Y | Q[1] | Y |
| • 10 - 15 m<br>1. Construction problematic | N | Y | Y | Y | Q[1] | Y |
| • 15 - 25 m | N | N | N | N | Y | Y |
| • > 25 m<br>1. Counter productive due to reduction in load applications per hour | N | N | N | N | Q[1] | Q[1] |
| Use of normal construction equipment for test sections<br>1. No problems when testing highways<br>2. Geometry could limit | Q[1] | Q[1] | Q[1] | Y | Q[2] | Y |

C ENVIRONMENTAL INFLUENCE FACTORS

| | HVS | ALF | MLS | LTR | CIR | SP |
|---|---|---|---|---|---|---|
| Temperature variation<br>1. Feasibile with adaptations ambient<br>2. Economic feasibility depends on radius except for ambient | Y | $Q^1$ | Y | Y | $Q^2$ | $Q^2$ |
| Surface water (Simulated/actual) | Y | Y | Y | Y | Y | Y |
| Sub-surface water (Simulated) | Y | Y | Y | Y | Y | Y |
| Wind (Simulated)<br>1. Economic feasibility questioned | Y | $Q^1$ | Y | Y | $Q^1$ | $Q^1$ |
| Humidity (Simulated)<br>1. Economic feasibility questioned | Y | $Q^1$ | Y | Y | $Q^1$ | $Q^1$ |
| Geographically varying field environments | Y | Y | Y | N | N | N |

## II PAVEMENT TEST VARIABLES

A ASPHALT

| | | | | | | |
|---|---|---|---|---|---|---|
| Alternative surface seal coats<br>1. Limited by scale and number of loads | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | Y |
| Rejuvenation application | Y | Y | Y | Y | Y | Y |
| Aggregate-Bitumen interaction<br>1. Limited by scale of load | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | Y |
| Natural aging of AC<br>1. Limited to fixed site location | Y | Y | Y | $Q^1$ | $Q^1$ | $Q^1$ |
| Artificial aging of AC | Y | Y | Y | Y | Y | Y |
| Asphalt mix composition | Y | Y | Y | Y | Y | Y |
| Friction between layers<br>1. Limited by degree of overloading | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | Y |

B PORTLAND CEMENT CONCRETE

| | | | | | | |
|---|---|---|---|---|---|---|
| Aggregate-PCC interaction<br>1. Limited by scale of load<br>2. Limited by number of loads | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | $Q^2$ |
| Natural aging (curing) of PCC<br>1. Limited by fixed site location | Y | Y | Y | $Q^1$ | $Q^1$ | $Q^1$ |
| Artificial accelerated aging of PCC | Y | Y | Y | Y | Y | Y |
| Variation in reinforcing steel in CRCP | Y | Y | Y | Y | N | Y |
| Concrete mix composition | Y | Y | Y | Y | Y | Y |

C PAVEMENT COMPOSITIONAL & STRUCTURAL VARIATION

| | HVS | ALF | MLS | LTR | CIR | SP |
|---|---|---|---|---|---|---|
| Variation in pavement type | | | | | | |
| • Asphaltic bases<br>1. Requires ability to vary temperature may not be feasible (depends on building) | Y | Y | Y | Y | Q[1] | Q[1] |
| • Flexible bases<br>1. Concerns about overload to do acceleration due to stress dependency | Q[1] | Q[1] | Y | Q[1] | Y | Y |
| • Lime-treated bases | Y | Y | Y | Y | Y | Y |
| • Cement-treated bases<br>1. Acceleration by overload limits scope since material may fail in compression | Q[1] | Q[1] | Y | Q[1] | Y | Y |
| • Recycled asphalt | Y | Y | Y | Y | Y | Y |
| • Plain concrete pavement<br>1. Limited by joints and geometry of pavement joints | Y | Y | Y | Y | Q[1] | Y |
| • Jointed reinforced concrete pavement- (JRCP)<br>1. Limited by geometry of pavement | Y | Y | Y | Y | Q[1] | Y |
| • Continually reinforced concrete pavement (CRCP)<br>1. Limited by geometry of pavement | Y | Y | Y | Y | Q[1] | Y |
| Different material layer thicknesses | Y | Y | Y | Y | Y | Y |
| Different structural compositions | Y | Y | Y | Y | Y | Y |
| Voids beneath concrete<br>1. Limited by geometry of pavement | Y | Y | Y | Y | Q[1] | Y |
| Effect of shoulders | Y | Y | Y | Y | Y | Y |
| Variation in construction quality<br>1. Requires conventional construction methods-geometry could inhibit | Y | Y | Y | Y | Q[1] | Y |

D OTHER VARIABLE MATERIAL/PAVEMENT CHARACTERISTICS

| | HVS | ALF | MLS | LTR | CIR | SP |
|---|---|---|---|---|---|---|
| Subgrade compaction<br>1. Requires conventional construction | Y | Y | Y | Y | Q[1] | Y |
| Subgrade stiffness<br>1. Requires insitu subgrade conditions | Y | Y | Y | Q[1] | Q[1] | Q[1] |
| Subgrade plastic behavior<br>1. Limited by need to overload | Q[1] | Q[1] | Y | Q[1] | Y | Y |
| New/special materials/mixtures<br>1. Depends on nature of material | Q[1] | Q[1] | Y | Q[1] | Q[1] | Q[1] |
| Statistical material variability<br>1. Requires conventional construction conditions | Y | Y | Y | Y | Q[1] | Y |
| Rehabilitation strategies<br>1. Requires ability to test insitu pavement | Y | Y | Y | Q[1] | Q[1] | Q[1] |
| Axle load equivalency<br>1. Requires ability to do acceleration without overload | Q[1] | Q[1] | Y | Q[1] | Y | Y |
| Joint seal materials/designs<br>1. Concern about overloads | Q[1] | Q[1] | Y | Q[1] | Y | Y |

## III OUTPUT MEASUREMENTS

A RESPONSE PARAMETERS

| | | | | | | |
|---|---|---|---|---|---|---|
| Deflection<br>1. May be affected by geometry | Y | Y | Y | Y | Q[1] | Y |
| Stress<br>1. May be affected by geometry | Y | Y | Y | Y | Q[1] | Y |
| Strain<br>1. May be affected by geometry | Y | Y | Y | Y | Q[1] | Y |

B PERFORMANCE PARAMETERS

| | HVS | ALF | MLS | LTR | CIR | SP |
|---|---|---|---|---|---|---|
| Load associated cracking<br>1. Concern about need to overload for acceleration | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | Y |
| Non-load associated cracking (ie. D-cracking)<br>1. Limited by climatic effects, scale and number of loads | Y | Y | Y | $Q^1$ | $Q^1$ | $Q^1$ |
| Cracking due to load and non-load interactive causes<br>1. Limited by fixed site locations | Y | Y | Y | $Q^1$ | $Q^1$ | $Q^1$ |
| Rutting<br>1. Concern about need to overload for acceleration<br>2. Concern about surface shear | $Q^1$ | $Q^1$ | Y | $Q^1$ | $Q^2$ | Y |
| Skid resistance<br>1. Surface shear may aggravate condition<br>2. Limited by number of loads | N | N | Y | N | $Q^1$ | $Q^2$ |
| Surface condition (Riding quality)<br>1. Requires special precedures to simulate long wave lengths<br>2. Limited by vehicle dynamics | N | N | $Q^1$ | $Q^1$ | $Q^2$ | $Q^2$ |
| Residual life (Structural integrity)<br>1. Limited by scale of load | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | Y |
| AC-stripping<br>1. Limited by scale and number of loads<br>2. Limited by number of loads | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | $Q^2$ |
| Edge drain efficiency | Y | Y | Y | Y | Y | Y |
| Joint seal behavior<br>1. Limited by scale of load | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | Y |
| Load transfer at PCC joints<br>1. Limited by scale of load<br>2. Limited by geometry of joints | $Q^1$ | $Q^1$ | Y | $Q^1$ | $Q^2$ | Y |
| Delamination of layers<br>1. Limited by scale of load | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | Y |
| Steel concrete bond<br>1. Limited by scale of load | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | Y |
| Wear of aggregate<br>1. Affected by scale and number of loads<br>2. Limited by number of loads | $Q^1$ | $Q^1$ | Y | $Q^1$ | Y | $Q^2$ |

testing. Experience has shown that once accelerated pavement testing begins it has a tendency to grow in scope rather than shrink. Now that mechanistic design is showing great promise and computer power is cheap enough to understand and model pavement behavior, accelerated pavement testing is cost effective and affordable. There has to be some transition from going from the laboratory to actual construction specifications and practices. The ability of APT to determine, in the field, how a pavement will perform has made it highly desirable. The Workshop on Accelerated Pavement Testing showed that many states have active programs or are interested in starting APT programs in the near future.

Major advantage:

1. Costs Nothing.

Major disadvantages:

1. Nothing is accomplished.
2. None of the Florida DOT Needs are accommodated.
3. No savings are achieved as a result of pavement testing.
4. A rapid and powerful aspect of pavement engineering is left unexplored.

## OPTION 2. HVS ON LOAN OR LEASED

The South African HVS fleet has proven to be very cost beneficial and has made a significant impact on pavement engineering. However, the fleet had to be withdrawn from operation during 1992 due to economic constraints facing the country. The feasibility of obtaining one machine for exploratory purposes was investigated during the TxDOT study. At the time it was determined that it would cost $100,000 to ship the machine to the US and back to South Africa. The owners were also willing to loan the machine free of charge on the basis of it being returned to South Africa at a future date. Trained staff could also be provided if necessary.

Major Advantages:

1. Low cost option.
2. Provides a unique opportunity to enter the APT scene.
3. Could be quickly implemented.
4. Can be utilized on an in-service highway.
5. Good for studying rutting.

Major Disadvantages:

1. Limited capability of meeting needs of FDOT.
2. Applies overload to accelerate.
3. No simulation of vehicle dynamics.

## OPTION 3. UPGRADE THE CIRCULAR TEST DEVICE AT UCF

The circular testing device built by Professor Kuo at the University of Central Florida is a good facility for the purpose for which it was designed. It has many limitations and has experienced a few start-up problems. Some of the limitations were in budget restrictions and some are in the design itself. However, it is a unique facility that has a capability not duplicated by any other device. It is probably the best facility in use today for the testing of small bridge panels or bridge joint seals. It has a high application rate and if fully staffed it could operate 24 hours a day. The loading can be adjusted from 10,000 to 30,000 pounds per half axle. The device was designed to operate at speeds up to 30 mph (48 kph), but it currently operates at 15 mph (24 kph) or below for safety considerations.

However, extensive modifications would probably be necessary to permit meaningful testing on pavements. The test track as designed is 15 inches of concrete with two small span bridges. In its present form the test track is only useful for small span bridges, abrasion testing of striping, or possibly thin asphalt overlays or seal coats.

It might be able to reduce the high shearing forces present with some of the sophisticated cambering and suspension changes provided in the New Zealand device. The New Zealand designers claim that a radius of 46 feet (14 m) is necessary to overcome the effect of shear, but this device has been designed for a 25-foot (7.6 m) radius. Because of the shearing forces developed there will always be some question of the validity of the results and their applicability to real traffic loadings. If the results of the testing were to be used to implement a policy decision, such as restriction on the use of super single tires, the validity of the testing would be questioned by the users.

The current data acquisition system and sensors are in need of upgrade if additional testing is planned. The test site as designed would have to be redesigned to accommodate testing and instrumentation of subgrades, bases, and flexible pavements. A problem with a high water table at the site would also have to be addressed. This option could be implemented either with or without another option.

Major advantages:

1. Low cost option.
2. Provides a unique capability to test bridge components and bridge joints.
3. Option could be implemented quickly.
4. Inexpensive to operate.
5. Can provide high application rates.
6. High wheel loads possible.

Major disadvantages:

1. Has a problem with high shearing forces.
2. Does not represent the loading conditions on pavements very well.

3. Difficult to quantify the results relative to actual performance.
4. Only a very limited amount of Florida DOT needs can be met.

## OPTION 4. BUILD A SMALL LINEAR DEVICE.

Unlike the circular tracks the small linear devices such as the TRRL in the United Kingdom, LINTRACK in the Netherlands, and the Accelerated Testing System (ATS) at Purdue University do not have a problem with radial shearing forces. These devices were generally designed for limited testing programs. The ATS at Purdue University was designed by Professor Thomas White for the single purpose of testing thin asphalt overlays on concrete pavements. Rutting is the principal distress which is induced. Accelerated testing is promoted primarily from two effects: operating at slower speeds which increases the rate of rutting, and heating the pavement to a higher temperature which softens the asphalt, permitting faster rutting. The ATS currently uses only a 9000 pound dual wheel but the load can be increased by purchasing larger springs. Super single tires can also be tested but have not yet been tried.

The AVS device does not have a high application rate, with a bi-directional cycle time of about ten seconds. The starting, acceleration to speed, deceleration, and stopping limits the speed and length of the test section. Higher speeds would require a design of longer length, longer lengths also increase cycle time, therefore the cycle time of the device can not be significantly improved.

The ATS was built on a limited budget and costs to operate are small. Indiana DOT and Purdue University probably would make the plans available to Florida DOT if it was chosen as the device to build, however, there is no official response to that question yet. The device was built in the Purdue University machine shop out of off-the-shelf purchased items. Assembly was done with a rented crane. The software to operate the device was written by a Professor of the University. The device was a one of a kind item and it took 1.5 years to construct.

This device is very similar to the device in the U.K., being somewhat of a miniature version of the TRRL. The ATS at Purdue has a unique design which utilizes a constant load and slow speed to minimize dynamic effects. Adding the capabilities to test with full axle or dual axles to this type of device is feasible, but this could occur only after additional design.

The testing, now just underway, suggests that slow speeds increase the rate of rutting for conventional tire loads. Although this is a way of accelerating the rutting it also makes it difficult to apply the 5 mph (8 kph) testing to normal traffic speeds. With such a low speed of application the effect of relaxation time versus load time on subgrades, bases and flexible pavements would make a impact upon the modeling and analysis of pavement designs for Florida. Therefore, additional testing or translation curves may have to be developed to translate accelerated testing results to predict field results.

Major advantages:

1. Not a problem with radial shearing forces.
2. Inexpensive to build and operate.
3. Good simulation of slow speed.

Major disadvantages:

1. Slow rate of application especially uni-directional.
2. No dynamic simulation.
3. Slow speed may not reflect actual traffic.
4. Only a limited amount of Florida DOT Needs can be met.

## OPTION 5. PURCHASE A HVS DEVICE

Currently the owners of the HVS fleet in South Africa were compelled to park the HVS devices due to the economic situation there. A previous offer was made to provide a device to Texas DOT if they would pay for the shipping costs. Texas declined and we offered to seek the same offer for Florida DOT at our initial meeting. At that time the committee suggested that it was too early to make any decisions.

The cost of operating the HVS is estimated to be $500,000 per year. Furthermore, the HVS devices were built in the 1970s and are hydraulically operated. Breakdowns due to hydraulics occur. In fact, a test section could be ruined by the flooding of hydraulic fluid on the asphalt pavement. However, a hydraulic fluid substitute made from vegetable oil could be investigated for this application.

The HVS uses a bi-directional application of loads and can be set for either standard loading or overloading to accelerate testing. The application rate is not very high, therefore overloading is normally reduced . A uni-directional loading has been developed for the HVS which permits the return trip of the wheel to roll on the test section but with no hydraulic load applied.

The HVS is capable of only half axles and could accommodate dual or single wheels. Tandem axles have not been tried. Additional design changes may be required to reach Florida DOT needs. We have not pursued the prospect of modifying the South Africa HVS device nor the prospect of building a new HVS device. This option would be only to receive an existing device an use it either at a facility or in the field for some of Florida DOT testing needs. This option could be implemented either with or without another option.

Major advantages:

1. Immediately available.
2. Can be moved to field pavements.

3. Can be acquired or borrowed cheaply.
4. FDOT would be able to share in the large database of the South Africans.

Major disadvantages:

1. Slow application rate- unless overloaded.
2. Hydraulically driven.
3. Poor simulation of vehicle dynamics.
4. Use of overloading required for high ESAL application rate.
5. Only some of Florida DOT Needs can be met.

## OPTION 6. PURCHASE A CIRCULAR TEST DEVICE

The circular test track at the University of Canterbury in New Zealand probably represents the state of the art in circular test tracks. The video of the New Zealand facility was shown at the first meeting with the committee. Dr. Ian Wood of New Zealand is actively pursuing the export of the device he has built. He has provided us and the committee with some technical information on the device.

Major advantages:

1. High application rates.
2. Inexpensive operations
3. Long sections

Major disadvantages:

1. Test sections are circular
2. Difficult to use standard construction practices and equipment
3. Always a question of shear forces
4. Limited to half axle
5. Can only test while all sections remain serviceable
6. Only some of Florida DOT Needs can be met.

## OPTION 7. PURCHASE AN ALF DEVICE

In order to fully explore the possibility of purchasing an ALF device to meet the needs of Florida DOT, CTR met with Mr. Hank Berry, President of Engineering Incorporated, the manufacturer of the ALF in the United States. Engineering Incorporated owns the patent rights to the ALF design in the United States and any device built would be required to be built by them. Engineering Incorporated's primary business is the manufacture of devices for the structural testing of aircraft airframes.

Engineering Incorporated provided a brochure of the device and showed the FHWA video tape of the ALF. They claim to have the capability to modify the device to meet just about any requirement if you are willing to spend the money. However, no information was given to CTR about the cost or delivery time of an ALF, as Mr. Berry considered that confidential information. Mr. Berry declined to give pricing information for the FHWA ALF, the Louisiana ALF, the cost to Florida DOT, or the cost of modifications. He would not estimate the delivery time, but he informed us that the Louisiana ALF took 18 months to deliver.

On the discussion of vehicle dynamics, Mr. Berry pointed out that there is an amount of test pavement where the tire is still accelerating to speed which is not used for testing purposes. The motor on the wheel is used to maintain constant speed across the center portion of the test section. If a higher load is applied to the ALF then the maximum speed must be reduced. The speed is dependent upon gravity. Mr. Berry considered the newly developed cam system, used to lower the wheel to the pavement, instead of the ramp system previously used as proprietary, and he was unwilling to discuss it with us.

The limitations on the ALF included loads from 9,000 pounds to 24,000 pounds. The ALF uses steel plates to adjust the weight above 9,000 pounds. The mass uses an airspring suspension with shock absorbers. However, a 50,000 pound load was possible if bi-directional travel was used, meaning the bogie would not be lifted. According to Mr. Berry, a tandem half axle could be retrofitted to the ALF, however it had not been engineered. His discussions indicated that it could just be bolted on, however when pressed for details, it seemed that it would be more involved that he initially considered. He also claimed the capability to use a full axle, but it would require widening the frame and several other modifications. The excess weight of the frame would probably require cutting the frame into two parts.

The ALF requires a 21 foot (6.4 m) height clearance to operate. If a heavy load is applied, the speed is reduced. The speed can be increased by raising the height of the bogie higher at the start, but practical limits would not permit very much of an increase. The increase in speed would not increase the cycle time, because, as in a pendulum, the height would increase but the time remains the same.

The problem with the ALF remains its slow cycle time in the uni-directional mode. There is no way to speed up the cycle time, as the process is basically a motor assisted gravity pendulum. Modifying the ALF to accept a tandem axle or a full axle would be expensive and require serious modifications. The dynamics are suspect, as discussed in Chapter 4, because the weight is entirely supported by the wheel, reducing its freedom to bounce.

The results obtained by FHWA using the ALF to test super single tires on asphalt pavements have been seriously questioned by the trucking industry. The extrapolation from accelerated testing by overloading to actual field prediction is dependent upon assumptions of the fourth power law which does not hold constant for all levels of stress and strain. The validity of accelerated testing of subgrades, bases and flexible pavements, when subjected to overloading, has often been questioned.

Major advantages:

1. Experience sharing with FHWA and LTRC.
2. Can be moved to field pavements.
3. Possibly could be modified for full axle.

Major disadvantages:

1. Slow rate of application.
2. Requires overloading with fourth power law to provide adequate ESAL.
3. Adds induced dynamic effects to test section.
4. Question of realism.
5. Only some of Florida DOT Needs can be met.

## OPTION 8. PURCHASE A TxMLS

The Texas Department of Transportation, after careful study, has decided to build a new generation accelerated pavement testing device rather than purchase an ALF. Several different concepts were studied and the current design was chosen. The Center for Transportation Research is tasked with the development of the device for the TxDOT.

At the end of Phase I, the design of the device was about 50 percent complete, with construction being concurrent with design for several items. The TxMLS device is scheduled for initial testing during April 1993 with implementation scheduled immediately after final testing. TxDOT 10-year budget forecast includes the purchase and operation of five TxMLS devices, one of which would be located at a permanent accelerated pavement test facility The plans for the facility are in a preliminary state, but currently include a 100 acre site with facilities for test tracks and IVHS testing as well.

The advantages of the TxMLS are attributed to the full axle design with repetition of tandem axles or single axles at a variable rate from crawl speeds to 25 mph (40 kph) with 20 mph (32 kph) being normal operating speed. The rate of 8,800 or more axles every hour permits normal load, or up to 25 percent overload, at rates that simulate 20 years traffic on high volume roads in as little as three months. Using actual truck suspensions and a load rail loading system which permits close simulation to actual truck-pavement dynamics. The device has received favorable response from the Truck Maintenance Council of the trucking industry because, if policy is determined from accelerated testing, they want the device that most closely simulates actual truck loading to perform the accelerated testing.

The device is being designed such that short distance movement from the testing location can be accomplished without break down of the device. The device will have to be broken into two half sections to be transported to test sites in order to alleviate height clearance problems. The device is ideally suited for either fixed site locations or road locations. Set-up time will be considerably less than the ALF, and sophisticated instrumentation is being added to the design.

The device is a fully enclosed box during testing and could be environmentally controlled, although the capability is not being added to the first TxDOT device. The enclosure will reduce noise and provide added safety for the work area and the traveling public.

TxDOT has said that they are willing to license or provide other states with the plans to the device at little or no cost, after they have proven that the device works as claimed. The device is currently being built by Victoria Machine Works in Victoria, Texas.

Major advantages:

1. Uses full axles.
2. Uses truck suspensions.
3. High application rates.
4. Most realistic simulation.
5. Experience sharing with TxDOT with advantage of a developed system.
6. Can be used either fixed or mobile locations.
7. Can meet almost all Florida DOT needs.

Major disadvantages:

1. Device will not be complete until 1994.
2. Not field proven yet.

## OPTION 9. DESIGN AND BUILD A LOOP TEST TRACK (SPANISH FACILITY)

The Spanish race track type accelerated pavement test facility is truly unique. The facility took ten years to develop, design, and build. The concept is that a monorail provides power and guidance to a powered truck half axle loaded by dead weight. The primary difference in the race track concept is that long straight sections can be tested, but only all at the same time. This long straight section eliminates the shearing problem of circular test tracks and permit the use of normal paving equipment to construct test sections. However, if aging, curing, or instrumentation of any of the test sections is required then testing cannot be conducted during this time.

The application rate is determined by the number of bogies, the length of the track, and the speed of travel of the bogies. The site in Madrid has only one bogie with a maximum speed of 31 mph (50 kph) and design test speed of 19-28 mph (30-45 kph). Therefore, the bogie takes 24 to 36 seconds to complete one cycle. This rate would be very slow and test sections could take years to complete if millions of axle applications are necessary. The first test in Spain took approximately 37 months to achieve one million axle applications on the six test sections. This rate could be adjusted by design of the track length and number of bogies. Future tests should also go faster since the system is now fully debugged.

The race track concept has difficulty controlling environmental variables. The track is probably too large to completely climate control and a partial control system would have to deal with bogies that enter and exit the climate controlled area. Also, since testing takes longer to accomplish, environmental control is more costly.

The Spanish test facility could be redesigned for enhanced operations. Some possible enhancements could include: the inclusion of full axles, tandem axles, several bogies, or added trailing bogies behind the powered bogies. The more complicated the enhancement, the longer time required to design and build the facility.

Major advantages:

1. Can use normal construction practices.
2. Could be modified for full axles.
3. Can be operated at higher speeds.
4. Capable of long test sections.
5. Can meet almost all Florida DOT needs.

Major disadvantages:

1. Existing system would have to be modified for additional bogies.
2. Can only test while all sections remain serviceable.
3. Slow application rates, but multiple bogies could be used simultaneously.
4. Requires large amount of land.
5. Difficult to control environment.
6. High investment cost.

# CHAPTER 6. POSSIBLE SITE LOCATIONS FOR THE ACCELERATED PAVEMENT TEST FACILITY

The following three site visits were conducted by Michael McNerney to gather information on possible locations for an accelerated pavement test facility for Florida DOT. Two locations (Tallahassee and Gainesville) were previously recommended as possible locations by Florida DOT. The third location (Orlando) was visited because a circular test track has been built there by the University of Central Florida. As a result of these visits, CTR has made a preliminary evaluation of all three sites as possible locations for the APT facility. None of the three sites visited would be acceptable as an accelerated pavement test facility without additional modifications. Each location has its own individual advantages and disadvantages that will be discussed in this chapter in the order that they were visited.

The three site visits conducted were the following:

| | |
|---|---|
| August 19, 1992 | Florida Department of Transportation<br>Florida A & M University/ Florida State University<br>Tallahassee, Florida |
| August 20, 1992 | Florida DOT State Material Office<br>University of Florida<br>Gainesville, Florida |
| August 21, 1992 | University of Central Florida<br>Orlando, Florida |

## POSSIBLE SITE LOCATION 1

FAMU/FSU College of Engineering, Tallahassee, FL

The following people were contacted during this visit:

| | |
|---|---|
| Richard Long | Florida DOT, Director of Research |
| Dr. Virgil Ping | Assistant Professor CE, FAMU/FSU |
| Dr. Soronadi Nnaji | Chairman, Department of CE, FAMU/FSU |
| Dr. Ching-jen Chen | Dean of Engineering, FAMU/FSU |
| Ted Gaupin | President, Innovation Park |
| Jack Crow | Director, National High Magnetic Field Laboratory |
| Brenda Robinson | FDOT, Structural Research Center |
| Joseph Lannutti | Director, Super Computations Research Institute |

### *Physical Location*

The specific location that was investigated is adjacent to the College of Engineering campus of Florida A&M University/ Florida State University. The College of Engineering is two miles from the main FSU campus and a new road is to open to make it more direct. Shuttle bus service is available. The College of Engineering is rapidly growing and is located in a special research park called Innovation Park.

Innovation Park is a university research park that is actively recruiting new high technology government and private industry concerns. The land is state owned and, as a result of legislative mandate, is administered by a nine member board called the Leon County Research and Development Authority. The Authority has the mandate, and goal, for the park to be a center for economic development in the areas of research, development, testing, education ,and high tech product assembly. The park is mandated to work to bring about an interchange of ideas between the universities, government, and private industry. The Authority, through competitive negotiations, selected Southern Technology Development Corporation to be its exclusive developer in construction, management, and leasing of facilities. Since 1985 Mr. Ted Gaupin has had the responsibility for management of the park and was very enthusiastic about the possibility of locating the APT facility in Innovation Park. In fact, Mr. Gaupin and Dr. Ping recently visited the FHWA Turner Fairbanks ALF test site to get better prepared to develop the Innovation Park site for Florida DOT.

Four possible sites are available to build an accelerated loading facility at Innovation Park. Two of the sites are within a short walking distance (less than 1/4-mile) of the engineering building. Figure 6.1 shows a map of Innovation Park. The sites available include areas from 8 to 40 acres. Additional sites are also available just off the map. Also located adjacent to the park is a railroad spur that can be accessed and also has space available for storage of aggregates and soils in large quantities. There is sufficient space available to provide the full development of all types of accelerated pavement testing devices considered in this study, including the race track concept similar to the Spanish accelerated pavement testing facility.

Innovation Park is also located within 20 miles (32 km) of a barge facility which could be used to receive aggregates shipped by barge. Other physical facilities of the park include a 50 Megawatt power substation, fiber optic communication terminals, and, a soon to be constructed, special power generation plant to provide surge power upon demand for the park.

There are several other tenants of Innovation Park which could provide a synergistic effect in the operation of an accelerated pavement test facility. The other tenants include the Florida DOT Structural Research Laboratory, the National High Magnetic Field Laboratory, and the FSU Super Computations facility.

The FDOT Structural Research Laboratory was built for the department by Southern Technology Development Corporation and is leased at a very favorable rate to the department. The facility is operated by the department and research is conducted by researchers from both the University of Florida and FAMU/FSU. Cooperation between the Structural Research Lab and the Accelerated Pavement Test Facility could result in productivity savings especially in the instrumentation area.

The National High Magnetic Field Laboratory, which is nearing completion, is a world-class research facility which includes $70 million dollars of state funding. It will have the world's strongest magnetic force and will attract research scientists from all over the world. The center will be set up for 24 hour testing operations and will eventually have a hotel or guest house to house visiting scientists and technicians on-site. The facility will also have an excess of chilled water at 41 °F (5 °C) and steam which might make environmental control of an accelerated pavement test facility very efficient. I met with the director of the facility and he was very cooperative and very favorable of having an accelerated pavement test facility in Innovation Park.

The FSU Super Computations Research Institute computer is also located at Innovation Park, and the university has an excess of computer time that could be used if necessary for the facility. The Institute is headed by Dr. Joseph Lannutti who was responsible for starting the College of Engineering of FAMU/FSU and served as its first dean. He was also supportive of an accelerated pavement test facility at Innovation Park.

# Innovation Park
# Tallahassee

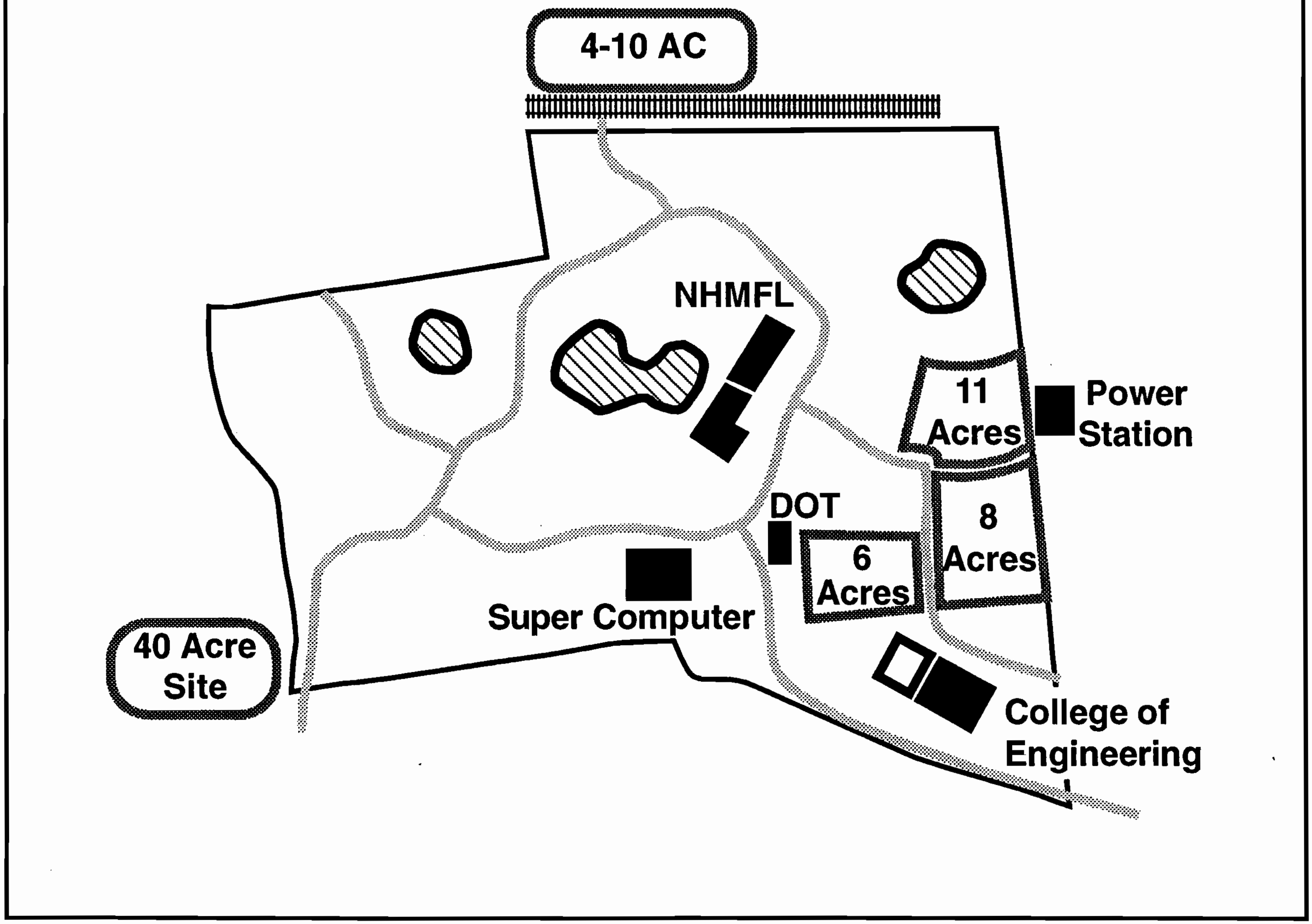



Figure 6-1

### *Technical Expertise*

The College of Engineering of FAMU/FSU is a joint engineering program from two universities. Research programs would qualify for Federal HPR funds for the Historically Black College and University program (HBCU). Discussions with Richard Long indicated he was very interested in the TxDOT research program, especially the way in which the master contract is administered with the University of Texas Office of Sponsored Projects through which individual projects are approved at a lower level. A similar type arrangement with universities in Florida would significantly reduce the paper work in generating research projects. Currently, individual research projects require a full contractual process, with standardized contract, full technical proposal, and full review and signatures at the highest levels. A small project at the $15,000 funding level would not be even attempted because of the administrative expense.

The FAMU/FSU Civil Engineering Department has eight full-time and seven adjunct faculty and has plans to add three or four more full time faculty positions within two years. The department has 350 students including 80 graduate students with student enrollment growing rapidly. The College of Engineering is planning a Ph.D. program in civil engineering but currently offers degrees only to the Masters level. The current facilities are expected to double with the addition of a second module to the current building in 2-3 years. The primary focus of the CE department is environmental, pavement, and structures. Dr. Virgil Ping is championing the selection of the Innovation Park site, and he is well supported by the Department of Civil Engineering Chair and the Dean of the College of Engineering.

### *Other Factors*

Some special incentives exist for locating at Innovation Park. One incentive is the special financing which is available to the state through a bond program at rates of three percent or less. This would permit financing the site at very favorable rates. Southern Technology Development Corporation also provides turn-key construction which would expedite the time to construct the facility.

The site is convenient to the Capitol and Legislature and has received support from the Legislature in the past. If it was important to get legislators to view a completed accelerated pavement test or the test facilities, it would be much easier to do so at the Innovation Park site than any other site. In fact, several legislators have visited the National High Magnetic Field Laboratory on the site even though it is not yet fully operational.

Possible problems are noise considerations and the architectural review committee. These issues would probably pose only a minimum problem as the typical building costs are $45 per square feet, trees are available to act as a noise buffer, and a test track could be located at the edge of the park with buildings in-between the rest of the park and the test site to act as a noise buffer. Noise considerations should be studied but could be solved.

Another shortcoming of this site is the lack of adequate laboratory facilities. The current laboratory facilities of the College of Engineering would be inadequate for testing in asphalt materials and pavements as envisioned. However, expansion is planned and could be tied to the facility to serve a dual purpose.

## POSSIBLE SITE LOCATION 2

State Materials Office and University of Florida, Gainesville, FL

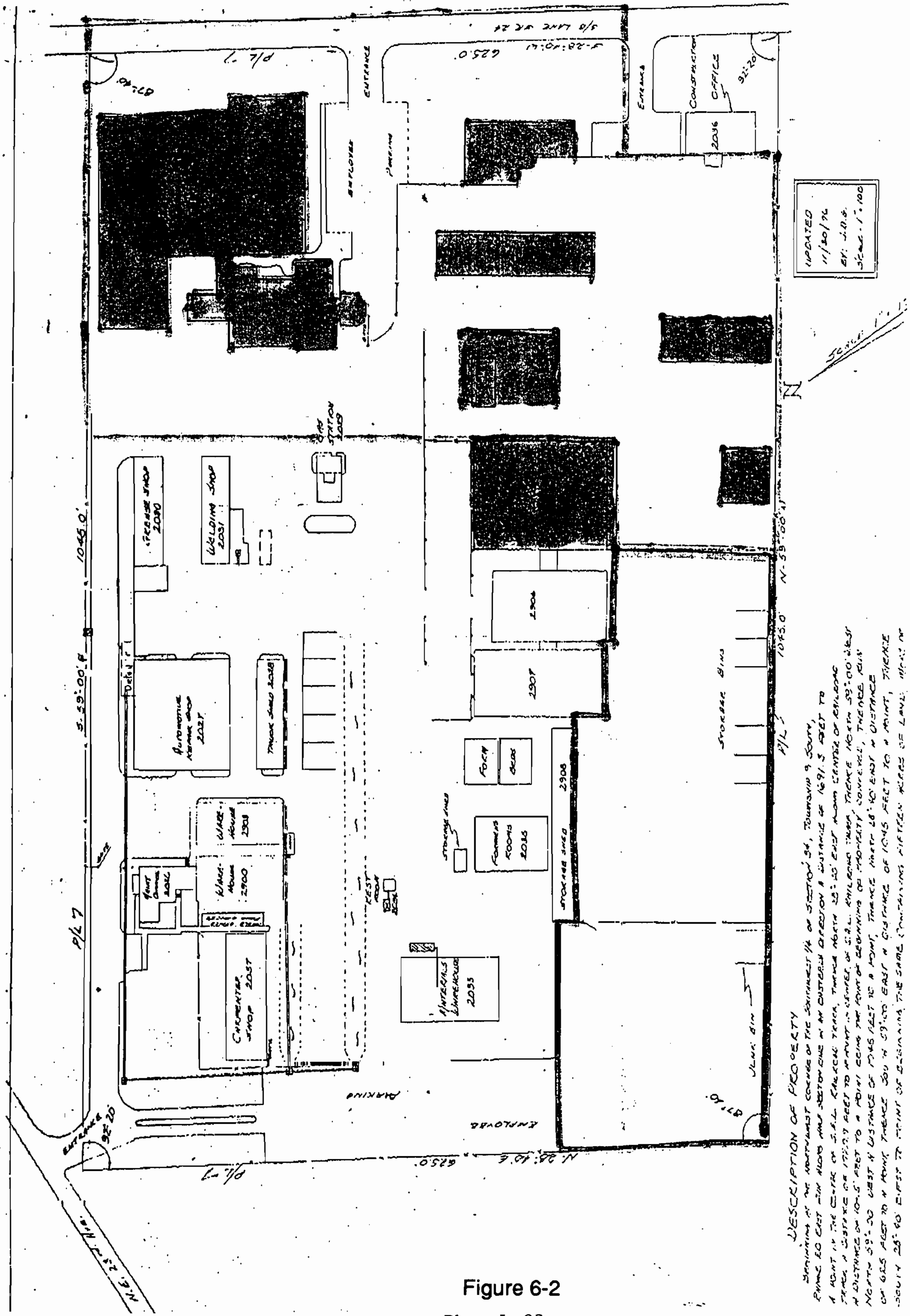
The following people were contacted:

| | |
|---|---|
| Larry Smith | FDOT, Director State Materials Office |
| Dr. Paul Thompson | Chairman CE, University of Florida |
| Dr. Mang Tia | Professor CE, University of Florida |
| Dr. David Bloomquist | Assistant Professor CE, University of Florida |
| Walter Zimpfer | Assistant Professor CE, University of Florida |
| Gale Page | FDOT, Bituminous Materials |
| William Miley | FDOT, Pavement Evaluation |
| Dr. Robert Ho | FDOT, Soils |
| Dr. Jamshid Armaghani | FDOT, Rigid Pavements |

### *Physical Location*

The State Materials Office is located in Gainesville, Florida, approximately five miles from the University of Florida. The laboratory facilities at the Materials Office include some of the best equipment in the US. The asphalt lab does over 500 validations of mix design per year and even more liquid asphalt testing. All aggregates and aggregate sources for Florida are tested by the Materials Office. The eight District Offices do not have their own asphalt laboratory facilities. The office is also responsible for the pavement evaluation function. The Materials Office pavement evaluation section has the only FWD that is used exclusively for research. Space is severely limited and a concrete durability lab has been constructed in half of a warehouse.

Proposed sites for an accelerated pavement test facility included the other half of the warehouse next to the concrete lab and a 5.6 acre portion of the maintenance yard as shown in Figure 6.2. The half warehouse is too small and has a height limitation of 14-foot. The 5.6 acre portion of maintenance yard being vacated would not support the test



WELDING SHOP 2031
AUTOMOTIVE REPAIR SHOP 2027
CARPENTER SHOP 2057
STORAGE SHED 2908
STORAGE BINS
JUNK BIN
DESCRIPTION OF PROPERTY


**Figure 6-2**

track concept due to its small size. Also it may not support a concept that used paving lanes and required large soil processing pads.

At the time of the CTR visit to the Gainesville site, there was concern that space would be somewhat limited there. However, it has since been determined that the entire maintenance yard would probably be made available, making space limitations less of an issue for this site. In addition, some buildings and structures still exist at this site which would need to be removed to accommodate some of the larger APT options.

### *Technical Expertise*

The big advantage of locating an APT facility in Gainesville is the experience of the Materials Office and the experience of the University of Florida facility. The most important assets of the State Materials Office are the wealth and depth of knowledge and expertise in pavements and materials, test equipment, instrumentation capabilities, and profound understanding of Florida materials and environment. The pavement experts at the State Materials Office, Pavement Management Office, and the districts would work together in formulating the variables for the facility. However, space limitations are a problem. The University of Florida campus has excellent asphalt lab facilities and an excellent asphalt-experienced faculty . They are trying to build a new civil engineering laboratory facility on campus.

The interaction of the Materials Office and the University of Florida has a synergistic effect for both. Materials Office research projects are written with the capability to add consulting expertise from University of Florida faculty to assist the Materials Office on problems that develop. The research projects also help to sponsor student research and Department personnel have the opportunity to seek advanced degrees and gain additional working knowledge toward their jobs.

The FDOT State Materials Office developed the accelerated pavement component facility in 1962 (Test Pit). Florida DOT's fundamental base design criteria is a direct result of this Test Pit research extending over a 30+ year span. Additionally, the FDOT has been evaluating its pavement system since the 1970's (Skid and Pavement Condition).

The University of Florida Civil Engineering Department is one of largest in the US. especially considering that separate departments exist for environmental and coastal engineering. They also have a separate department in surveying and mapping sciences which offers a degree in surveying. In the future, all surveyors to be registered in Florida will be required to have completed a degree program in surveying. The Surveying and Mapping Sciences Department has a good Geographic Information System (GIS) lab and has Global Positions System (GPS) equipment.

Of the 35-member Civil Engineering Department faculty headed by Dr. Paul Thompson, 20 positions are in the Environmental Engineering Department. The main focus of the CE department is Geotechnical and Materials. Dr. Bryon Ruth is well known for his work in asphalt materials. Other faculty members endorsing the Gainesville location were Dr. Dave Bloomquist, Walt Zimpfer, and Dr. Mang Tia.

## POSSIBLE SITE LOCATION 3

University of Central Florida, Orlando, Florida

The following people were contacted:

| | | |
|---|---|---|
| Dr. Shiou Kuo | (407) 823-2280 | Assistant Professor, CEE |
| Dr. Essam Radwan | (407) 823-2841 | Chairman, CEE |

### *Physical Location*

The UCF campus was built in 1965 and has a significant amount of property available. as shown in Figure 6.3. The campus is not in an urban environment and has a significant amount of land designated for research. Approximately 25 acres have been set aside specifically for civil and environmental field research adjacent to where the current circular test track is located, as shown in Figure 6.4. However, much of the land would have a problem with a high water table and a drainage path which would require elevating the test site to permit testing of subgrades and bases. Additional land may be available adjacent to the University as the site is not fully developed.

Dr. Shiou Kuo has constructed a circular test facility on campus which is used primarily to test bridge expansion joints and joint seals. The facility is unique in its design and has the capability to apply a high number of applications of dual wheel loads at loads of up to 30,000 pounds per half axle. The facility is too small to meet all the needs of FDOT pavement testing and is limited in its current configuration. Significant amounts of improvements could be made which could make it suitable for some accelerated pavement testing. A more complete description of the test facility and device is given in Chapter 3.

The circular test track is operating effectively after several start up problems and has the capability of applying high application rates very cheaply. The current testing program appears to be developing successful comparisons of joint seal life but is lacking in its quantification of the results as applied to real service lives.

Although the University has been supportive of Dr. Kuo's test facility it took almost six months to obtain approval from the University. No official inquiries have been made to determine if the university would support a DOT sponsored accelerated pavement test facility on campus. It is also not known how long it would take for approval for such a facility to be constructed.

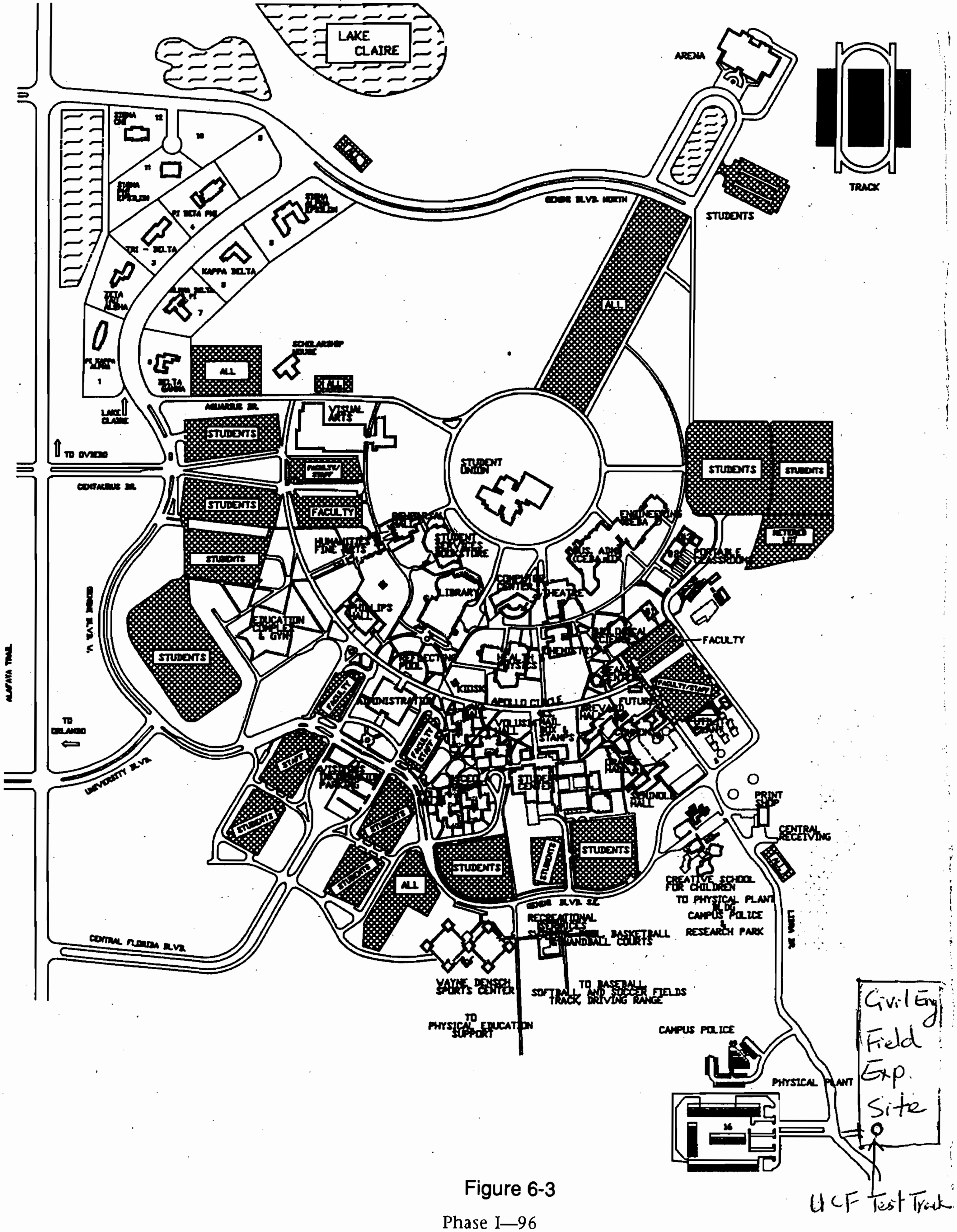

LAKE CLAIRE
ARENA
TRACK
STUDENTS
ALL
SCHOLARSHIP HOUSE
VISUAL ARTS
STUDENT UNION
FACULTY
KAPPA DELTA
TRI - DELTA
PI BETA PHI
DELTA GAMMA
LAKE CLAIRE
TO OVIEDO
CENTAURUS DR.
AQUARIUS DR.
HUMANITIES & FINE ARTS
EDUCATION COMPLEX & GYM
LIBRARY
COMPUTER CENTER
THEATRE
PHILLIPS HALL
REFLECTING POOL
ADMINISTRATION
KIOSK
APOLLO CIRCLE
HEALTH PHYSICS
CHEMISTRY
PORTABLE CLASSROOMS
RETIRED LOT
ALAFAYA TRAIL
TO ORLANDO
UNIVERSITY BLVD.
FACULTY/STAFF
STAFF
VISITOR INFORMATION PARKING
BREVARD HALL
SEMINOLE HALL
PRINT SHOP
CENTRAL RECEIVING
CREATIVE SCHOOL FOR CHILDREN
TO PHYSICAL PLANT BLDG. CAMPUS POLICE & RESEARCH PARK
CENTRAL FLORIDA BLVD.
RECREATIONAL SERVICES
HANDBALL COURTS
WAYNE DENSCH SPORTS CENTER
TO BASEBALL SOFTBALL AND SOCCER FIELDS TRACK, DRIVING RANGE
TO PHYSICAL EDUCATION SUPPORT
CAMPUS POLICE
PHYSICAL PLANT
16
Civil Eng Field Exp. Site
UCF Test Track

Figure 6-3

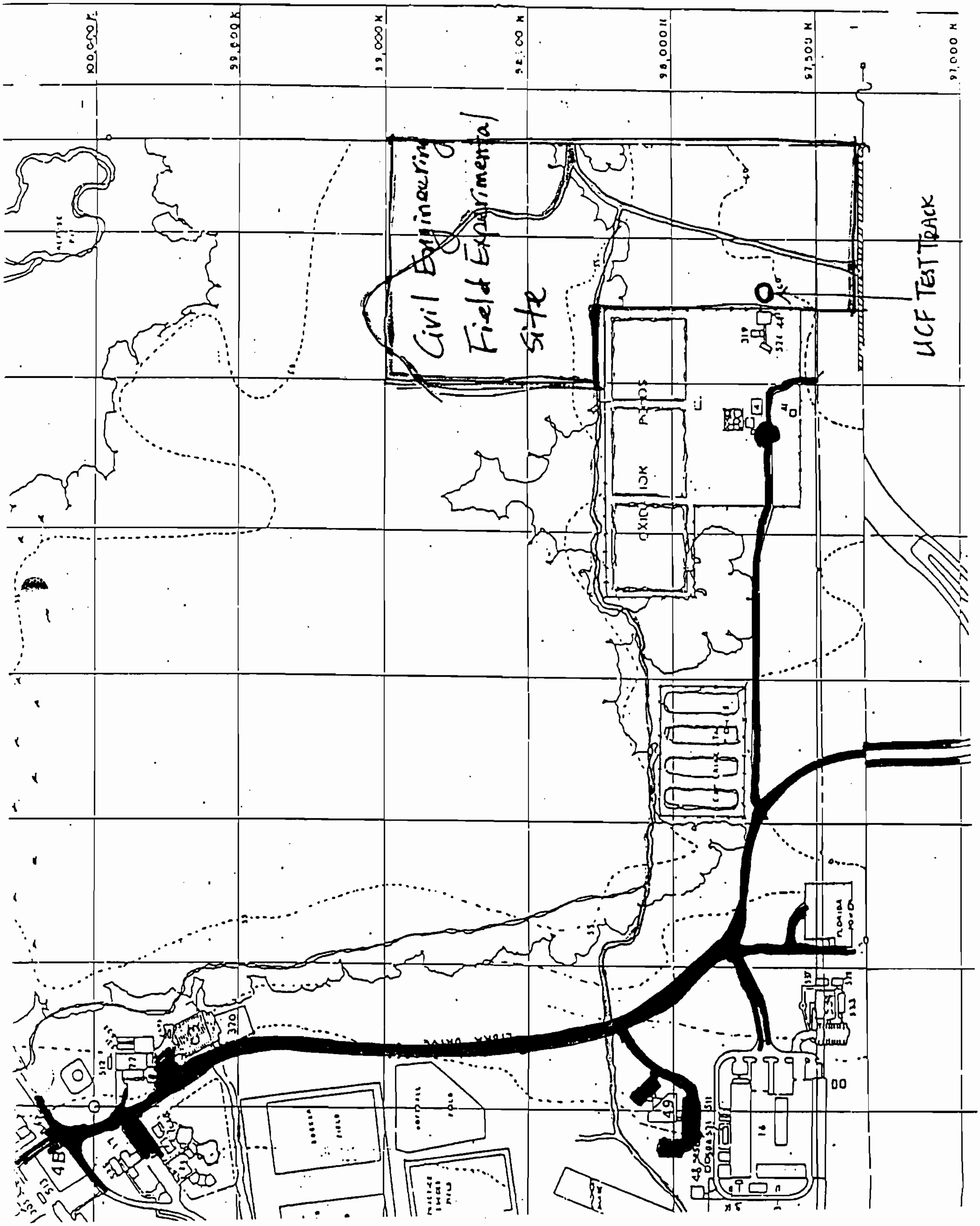



Figure 6-4

The Florida DOT has no major presence near the university and the university laboratories would be inadequate, alone, to support such a test facility.

### *Technical Expertise*

The Civil and Environmental Engineering (CEE) department has 18 full time faculty positions. The department has over 500 civil engineering students enrolled including over 100 graduate students. It has both Masters and Ph.D. degree programs. The CEE chairman and Assistant Dean for the College of Engineering are supportive of the current test facility.

Dr. Kuo is the only faculty member with accelerated testing experience. The facility built by Dr. Kuo has been on a very limited budget and testing is limited to less than eight hours a day because of staffing levels of only one part-time student to conduct testing and maintain the device.

## COMPARISON OF THE THREE SELECTED SITES

From an analysis of the information obtained during the site visits, it was possible to compare the attributes of the respective sites. A summary of these is shown in Table 6.1. All three sites have pros and cons and the final selection of a specific site would depend upon the weighting placed by FDOT on the various attributes. However, it is also possible that a specific site would have to be precluded because it could not meet a specific requirement.

The most significant observations of the comparisons of the site visits that FDOT must consider are space available, how difficult would it be to build, available infrastructure at the site, laboratory facilities, and the accessibility and quality of researchers. Regardless of which site is selected some additional support facilities will probably have to be constructed such as laboratory space, instrumentation space and data analysis equipment.

The operational concept of each site is also important. The Orlando site does not have a significant FDOT presence. If it was a necessary concept of operations to have FDOT be the principal owner and operator of the device with university sponsored researchers, the Orlando site would be at a definite disadvantage, while either the Tallahassee or Gainesville sites could easily be owned and operated primarily by FDOT. The unit within Florida DOT which should logically operate the device, or control the schedule of testing, is the Pavement Evaluation Section. However, that does not necessarily mean that the Pavement Evaluation Section has to remain within the State Materials Office.

Texas DOT plans to operate all the TxMLS devices through the Pavement Management Section. Although there is also some discussion within Texas DOT of reinstituting a Research Division that performs research in-house.

## COMPARISONS OF POSSIBLE APT FACILITY LOCATIONS

| **Proposed Location** | Tallahassee | Gainesville | Orlando |
|---|---|---|---|
| Specific site | Innovation Park R&D Center | State Materials Office | Undeveloped research area of Campus |
| **Physical Limitations** | | | |
| Are existing facilities sufficient? | N | N | N |
| Is sufficient land over 15 acres* available? | Y | N | Y |
| What amount of land available (acres) | 60 | 2 | 20 |
| Is land State owned | Y | Y | Y |
| Availability of rail delivery | Y | N | N |
| Availability of barge facility | Y | N | N |
| Available electrical power | Y | Y | Y |
| Available chilled water | Y | N | N |
| Available steam | Y | N | N |
| Architectural limitations | Y | N | Y |
| Problems with noise levels | Y | Y | Y |
| Security | Y | Y | N |
| Operational 24 hours | Y | N | N |
| Problems with water table | N | N | Y |

**Technical Expertise**

| | | | |
|---|---|---|---|
| Florida DOT presence | Y | Y | N |
| Pavement testing experience | Y | Y | Y |
| Accelerated testing experience | N | N | Y |
| Number of Civil Engineering Faculty | 15 | 35 | 18 |
| Number of CE graduate students | 80 | 130 | 100 |
| Ph.D. program | N | Y | Y |
| Emphasis of CE Department | Pavements<br>Structures | Materials<br>Geotechnical | Materials<br>Geotechnical |

* This would depend upon the type of facility selected by FDOT. Clearly a facility such as LINTRACK could be accommodated on a much smaller site.

**Other Factors**

| | | | |
|---|---|---|---|
| Close to Legislature | Y | N | N |
| Construction in 1 year | Y | N | N |
| Special Financing | Y | N | N |
| Turnkey Construction | Y | N | N |
| Laboratory Facilities Available | N | Y | N |
| NDT Pavement testing available | N | Y | N |
| FDOT operated | Y | Y | N |
| University operated | Y | N | Y |

# CHAPTER 7. SYSTEM COSTS

This chapter presents preliminary estimates of the cost of acquiring an accelerated pavement testing device for the Florida DOT testing facility. Each of the possible nine options will be explored and preliminary estimates of the cost of the device alone will be given with an explanation of the capability of any modifications. The information has also been depicted graphically in Figure 7.1. From the figure it can be seen that with an increase in investment there is a relative increase in ability to satisfy the needs of Florida DOT.

The improvement in each of the respective facilities is also shown. In this regard it is interesting to note that for most of the facilities the growth trend is remarkably linear. It should however be remembered that full cost details of the Spanish facility are not yet available and the information in the figure is therefore subject to further ratification. Noteable exceptions are the New Zealand Circular device and the TxMLS, which seem to have a different growth trend. This is probably related to the advanced technical nature of the devices.

The HVS-loan option is also somewhat out of line but this is of course due to the unique possibility of obtaining the machine at such a low cost.

## OPTION 1. DO NOTHING

Cost : Nothing

## OPTION 2. ACQUIRE AN HVS ON LOAN

The cost of obtaining one HVS machine from South Africa for exploratory purposes would be $100,000 to ship the machine to the U.S. and back to South Africa. The rental for the machine would have to be negotiated but is likely to be very reasonable on the basis of it being returned to South Africa at a future date. Trained staff could be provided if required.

## OPTION 3. UPGRADE THE CIRCULAR TEST DEVICE AT UCF

The Circular Test facility at the University of Central Florida costs approximately $250,000 for design construction and testing. Several of the components (e.g., the axles) were used parts. A complete upgrade to include a new track, better instrumentation, a camber system for the wheels, replacement axles and gear drives, and other unspecified modifications could cost between $100,000 and $300,000. The replacement cost of the existing facility, if design and construction was done by a private company, would be between $400,000 and $800,000.

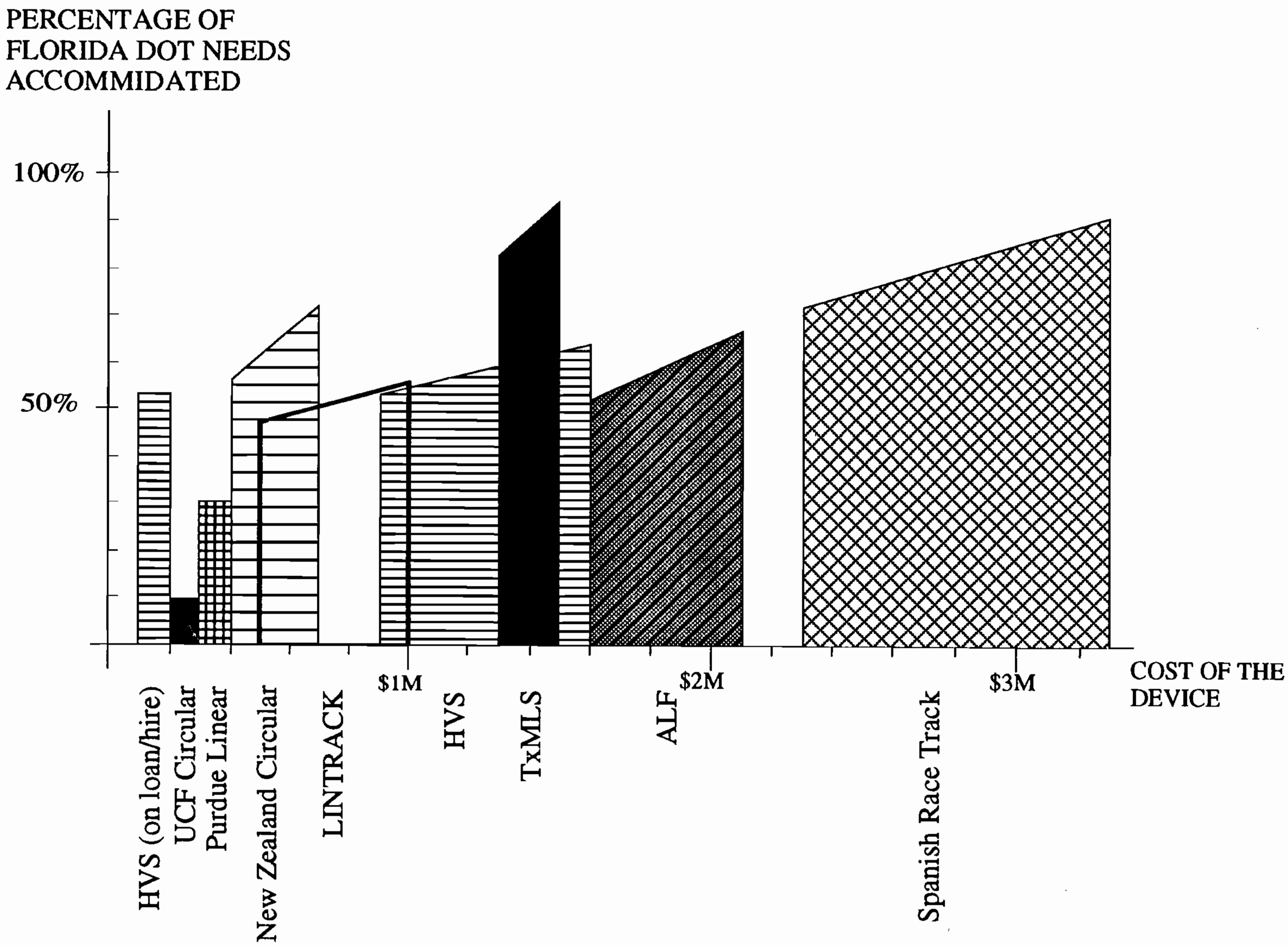



FIGURE 7-1 COST PERFORMANCE OF APT DEVICES

## OPTION 4. BUILD A SMALL LINEAR DEVICE

The small linear test device constructed by Purdue University cost approximately $140,000 for the device and its building. Many parts were designed and fabricated by the University machine shop (a rented crane was used for construction). The control software was also written in-house. The replacement cost for the design and fabrication of the device alone, if contracted to an outside company, would probably be between $350,000 and $600,000.

If the test sections were increased in size from 20 to 30 feet with additional pavement area for acceleration and deceleration at each end as per the ALF, the cost of the design and manufacture of such a device capable of 15 mph would probably exceed $1,000,000. If full axles were needed the cost would also increase. For comparison purposes the LINTRACK device in the Netherlands which operates at 12 mph and has a usable test area length of only 3.4 meters cost approximately $500,000 to build over 4 years in the University machine shop. They also claim that the British spent approximately $2,000,000 for the construction of their linear device at TRRL.

## OPTION 5. PURCHASE AN HVS DEVICE

The government of South Africa would probably lend Florida DOT an HVS device until FDOT had acquired an accelerated pavement testing device. IF a now idle HVS was acquired from South Africa the cost would probably only be the cost of shipping the unit. This is a bargain price but the real cost comes in the operation of the device. The cost of the purchase of the device would probably be from $900,000 - $1,600,000.

## OPTION 6. PURCHASE A CIRCULAR TEST DEVICE

We have no data on the cost of the purchase of the New Zealand circular test track type device. Determination of such a cost could be explored upon request from Dr. Ian Wood in New Zealand. A ball park estimate is the device could be built for about $400,000 -$700,000. The total with a completely enclosed facility could be $500,000 to $1,000,000.

## OPTION 7. PURCHASE AN ALF DEVICE

The cost of the purchase of a basic ALF device similar to the one purchased by Louisiana Transportation Research Center (LTRC) based upon notes from the Austin APT Workshop was $1,826,300. The cost with site development on the three acre site was an additional $550,000.

## OPTION 8. PURCHASE A TxMLS

The cost of the TxMLS based upon the current Target Costs for construction of the first TxDOT device is approximately $1,400,000 (see updated device cost in Phase II of this report) which includes two spare instrumented bogies and the complete instrumentation and electrical control system. Additional costs will include the data acquisition system, the cost of a transportation system to the test site, and a trailer for the control facility. If used as a fixed facility there would, of course, be additional expenditure.

## OPTION 9. DESIGN AND BUILD A LOOP TEST TRACK (SPANISH FACILITY)

Currently, not enough information is available to estimate the cost of building a duplicate of the Spanish Test Track or an enhanced system with full axles and multiple bogies. An estimate obtained during discussions with the Director put the cost at $3,500,000 for the entire facility. Ballpark estimates range between $2,000,000 to $4,000,000.

The results of the current replacement cost of each option and the estimate of an enhanced system is presented in Table 7.1. (This table has be superceded by Figure 5.5 in Phase II of this report.)

| Option | Estimated Cost | Enhanced Cost |
|---|---|---|
| 1. Do Nothing | $0 | $0 |
| 2. HVS on Loan | $100,000 | $100,000 |
| 2. Upgrade UCF circular | $300,000 | $400,000 |
| 3 Purdue small linear | $400,000 | $1,000,000 |
| 4..New Zealand circular | $500,000 | $1,000,000 |
| 5. HVS (purchase) | $900,000 | $1,600,000 |
| 6. ALF | $1,900,000 | $3,000,000 |
| 7. TxMLS | $1,400,000 | $1,800,000 |
| 8. Spanish Race Track | $2,300,000 | $4,000,000 |

# CHAPTER 8. OPERATIONAL COSTS

First, we should note that the information in this chapter is very preliminary. It is not possible to estimate the operational costs of an accelerated pavement testing facility that has not been defined for either (1) the scope of its testing, (2) the device to be used for testing, or (3) the location of the facility (if a fixed facility is to be developed). After the advisory committee has given guidance on the best options to pursue in Phase II, these estimates can be examined in much more detail. The following information is relevant to preparing a budgetary estimate based on the device and scope of the testing program that Florida DOT envisions will meet their needs.

The scope of testing is very important in sizing the facility. If testing of the pavement structure consists of preparing and placing a subgrade material (such as heavy clay at a specific CBR or moisture content), then a very large amount of space is needed for processing the material. Accelerated testing at Tyndall AFB indicated that the clay must be spread, moistened, tilled, and sun dried. Similar space was needed for any material that was carefully controlled in moisture content or gradations. The Tyndall testing experience indicated that a carefully controlled test section of only 20 by 20 feet could take two weeks to prepare and required the following construction equipment:

- a Gradall
- a front end loader
- a dump truck
- a grader
- a tractor with rotary tiller
- a vibratory compactor
- a water truck or trailer

The layout and concept of testing has a big influence on productivity. A layout of linear test sections such as at the FHWA Turner Fairbanks permits the construction of adjacent test sections while testing or instrumentation is in progress. FHWA has decided to increase the number of test sections on site from 12 to 36, because of the time required to prepare a test section. Conversely the layout of the test track concept (such as the Spanish facility) allows simultaneous testing of six sections, but must be completely shut down if any test section fails, if any section needs maintenance or instrumentation changes and during the initial construction and instrumentation phase. A way of overcoming this would be to have a twin facility with the APT device moving from one to the other after completion of a test thus maintaining full production.

## SMALL LINEAR OPERATIONAL COSTS

The operating costs at Purdue University are included in the current research program of 9-month duration. Indiana DOT has one engineer who operates the device and does the instrumentation. Testing is planned for weekday operation during normal work hours only.

## HVS OPERATIONAL COSTS

The information on the cost of testing in South Africa using the HVS is not officially available, but Dr. Hugo has estimated that it would cost about $500,000 in U.S. currency per year to run the HVS. The HVS is staffed for 24-hour operation, with at least two people on site.

## NEW ZEALAND CIRCULAR OPERATIONAL COSTS

The market brochure for the CAPTIF circular test track claims that the operating cost of their device is 1/3 that of the ALF. In general, circular devices are more efficient than linear back-and-forth devices. However, their claim can be based upon the amount of tested length as well. Although costs are not known, the CAPTIF brochure equates their operational costs as equal to the construction cost of 0.06 miles (0.1 km) of roadway per 1,000 hours of operation. This could be in the range of $400,000 – $500,000 per year with 24-hour operations. They also claim unattended operation to help keep costs low.

## ALF OPERATIONAL COSTS

The FHWA Turner Fairbanks test site is operated under contract to the ALF manufacturer, Engineering Incorporated. They are responsible for instrumentation, recording of cracking and rutting, and operation of the device. The device must be stopped every 25,000 passes for lubrication. Staffing requires two people on site. The letter from the FHWA Associate Administrator for Research and Development states the annual cost of ALF testing was $275,000.

## TxMLS OPERATIONAL COSTS

Texas DOT has prepared budget estimates for the cost of running the MLS for one year at $800,000. This is also based on 24-hour operations and travel to existing roads and highways throughout the state. TxDOT has a staffing plan for the MLS to support 24-hour operations seven days a week, with two people on site at all times. The Texas staffing plan calls for 9.2 man years effort that includes administration, training, laboratory and NDT testing, data reduction, and operation of the device. These figures may be conservative, as they were prepared for justifying the hiring of new personnel to operate the TxMLS. An in-depth discussion of the previous itemized TxMLS operational costs and operational impacts was provided in Chapter 8 of the report of the MLS study previously provided to the committee (ref. 1246 report).

## RACE TRACK OPERATIONAL COSTS

The operation of the Spanish CEDEX test track has an annual budget for testing of approximately $1,300,000 in US currency. They have a staff of two technicians and two operators in addition to the research staff. It was entirely possible that the actual cost of operation was significantly lower in cost than the estimated budget.

## CLOSURE

It is clear that it will only be feasible to present a comprehensive and accurate budget once Florida DOT has decided upon the future development of the project. However, provisionally it should be assumed that the annual operational cost will be in the range of $400,000 - $500,000 for any of the large scale facilities and the economy will depend upon the rate of production of the facility.

# CHAPTER 9. REGIONAL FACILITY CONCEPT

At the initial project meeting, Mr. Richard Long, after providing the Center for Transportation Research with copies of letters from the Federal Highway Administration, asked CTR to look into the concept of a regional test facility for accelerated pavement testing. Specifically, the comments of Mr. Charles Miller, Associate Administrator for Research and Development, were passed along in cover letters.

The point of Mr. Miller's letter was that the high cost of constructing and operating an accelerated pavement test facility may impact the department's overall ability to conduct research in other areas. He therefore suggested that pooled funding from other states may be solicited to help finance the project. He concurred with the purpose of this study and offered the assistance of FHWA staff in providing information. He also remarked that new devices developed since FHWA's original study should be considered in this study.

In response to the request from the advisory committee to pursue the study of a regional concept, CTR contacted Mr. Bryon Lord, Chief of the Pavements Division of the Turner-Fairbanks Research Center. CTR had several conversations with Bryon Lord on this subject, including a briefing to him on the TxMLS and Texas' proposed accelerated pavement testing facility. In response to the increased interest in accelerated pavement testing expressed by several state departments of transportation, Bryon Lord arranged the first annual accelerated pavement workshop, which was held in Austin on July 24 and 25, 1992. The purpose of this workshop was to inform interested individuals of the activities being planned and carried out by the major players in accelerated pavement testing in the United States. Mr. William Lofroos and Mr. William Miley of the Flordia DOT attended the workshop.

An additional agenda item served to address the concerns of FHWA and to promote the concept of regional testing facilities. FHWA will provide a set of workshop videotapes to each participating agency.

As a result of recent conversations with Bryon Lord on the subject of regional accelerated pavement testing facilities, the following items have been determined:

1. FHWA has no formal program for advocating, promoting, or funding regional APT centers.
2. The FHWA's suggestion to establish a regional facility stems only from the fact that many states cannot afford a facility on their own, and the opportunity for pooled funding may be beneficial for many states. If a state thought that it could not conduct enough testing on its own to keep the facility utilization rate high, then pooled resources may be the answer.

3. The APT facility on the campus of Louisiana State University at Baton Rouge is to be operated by Louisiana Transportation Research Center (LTRC). This program was funded using HPR funds and was approved through the Division Office of FHWA. The breakdown of funding was given in Chapters 7 and 8.
4. If Florida DOT was to construct and operate an accelerated pavement test facility, the program would have to be submitted to the Division Office of FHWA and be approved. Whether the facility was considered a state only, regional, or international facility would have no effect on the federal approval or funding of the program.
5. Bryon Lord suggested that Greg Schiess could obtain and provide to Florida DOT the complete information on the LTRC program approved by the Division Office to purchase and operate the ALF, which they expect to receive.

# PHASE I — APPENDIX A

# METHODOLOGY
# "DESCRIPTION OF TASKS AND TIME SCHEDULE"

In response to a request from Florida DOT the original proposal was divided into three phases of approximately four months each. Interim reports will be made at the end of Phase I and II and a final report submitted at the end of Phase III.

## TASK 1 ASSESS THE NEEDS OF THE FLORIDA DOT

The project is administered by an Advisory Committee that is composed of members from several different technical areas within Florida DOT. It is not always easy for a committee to decide upon the needs of the Department. CTR briefed the committee on the finer technical aspects of accelerated pavement testing to include dynamic effects and environmental factors. CTR decided to interview and submitted questionnaires to the committee to assist the committee in formulating an assessment of needs.

## TASK 2 REVIEW CURRENT STATE-OF-THE-ART DESIGNS FOR ACCELERATED LOADING DEVICES.

The Center for Transportation Research project team was experienced in the current state-of-the-art of accelerated pavement testing devices and gave an initial snap shot of the capabilities of such devices in a generic manner to the Advisory committee at the first meeting. With the guidance of the committee, several site visits were established to visit several devices and gather information specific to Florida DOT needs. These devices were either videotaped or photographed to provide additional information for the committee. A Technical Memorandum describing some of the devices was prepared and sent to the committee to serve as an easy to use reference document to stimulate discussion within the committee.

## TASK 3 COMPARE PRELIMINARY DESIGNS AND COST ESTIMATES

It is likely that no existing device will fulfill all the needs of Florida DOT. Therefore, the accumulated experience and knowledge of the research team will be used to determine the feasibility of adapting the most promising devices to meet the needs of Florida DOT. A cost-benefit study will be performed to determine the cost-benefit ratio of those needs that are harder to meet without excessive modification. Using the results of the needs analysis, the cost-benefits, and testing experience, CTR will provide sufficient information for the committee to narrow the field to one or two devices. As the committee formalizes the Florida DOT needs, a Specific Operational Requirements (SOR) of the device can be drafted. Using the committee approved SOR, the specifications of the device can be determined and the costs can be estimated with better precision.

## TASK 4 DEVELOP PRELIMINARY ALTERNATE PLANS FOR THE TEST FACILITY AND THE OPERATIONS.

Using information gained from the site visits, the Florida needs assessment, and the Specific Operational Requirements, CTR will explore possible layouts of test sections for efficient operations. Working with the committee, a draft implementation plan or test schedule will be used to develop specific site plans for the site recommended by the advisory committee. Estimates will be made of the capability of the site to support the instrumentation or environmental control specified in the SOR.

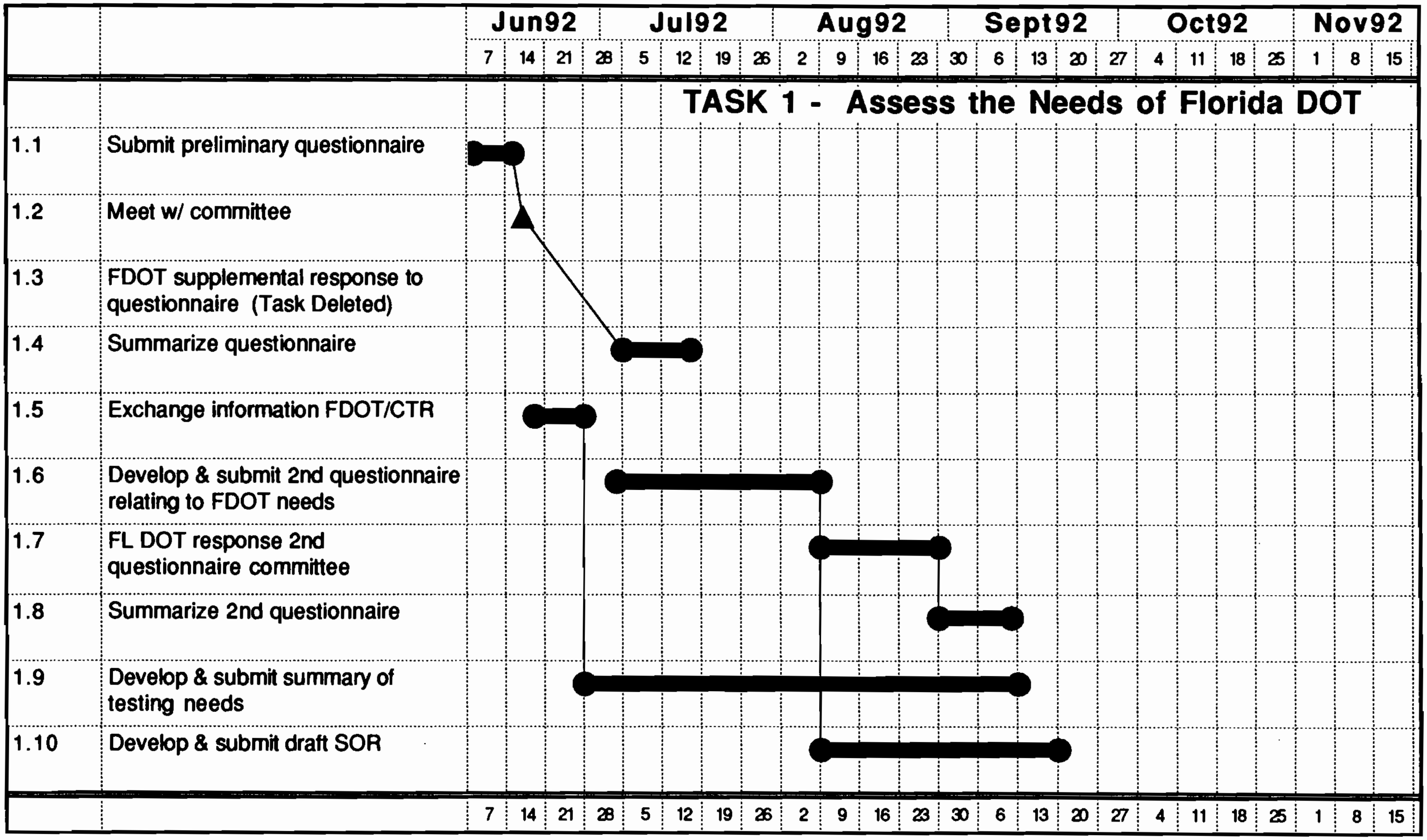
## TASK 5 COMPARE THE ALTERNATIVES FOR LOCATION, OPERATION, AND MAINTENANCE OF THE FACILITY

CTR using input from the Advisory Committee considered four possible sites in Florida for the APT facility. Three sites, Tallahassee, Gainesville, and Orlando were visited and evaluated as possible APT facilities. CTR prepared the advantages and disadvantages of the three possible sites and prepared a presentation to the committee based upon a generic testing device. CTR has also gathered information of the location and staffing of several other APT facilities for comparison purposes. After the Advisory Committee has approved the Florida DOT Needs assessment and the Specific Operational Requirements of the facility, it will be possible to evaluate the sites which the committee wishes to consider with respect to the specific device and operational concept decided on by the committee. The economic benefits of the facility can be determined.

## TASK 6 PREPARE INTERIM AND FINAL REPORTS

CTR will prepare Interim Reports and presentations at the conclusion of Phases I and II. After the committee has made recommendations at the end of Phase II the Interim reports will be expanded into the Final Report. The Final Report will include the results of all the work and the justifications for the recommendations of the committee for specification of the device, location of facility, and staffing required for operation. Copies of slides and videotapes will also be provided to the project manager at the conclusion of the study.

Oct 2, 1992



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TASK 1 - Assess the Needs of Florida DOT
1.1 Submit preliminary questionnaire
1.2 Meet w/ committee
1.3 FDOT supplemental response to questionnaire (Task Deleted)
1.4 Summarize questionnaire
1.5 Exchange information FDOT/CTR
1.6 Develop & submit 2nd questionnaire relating to FDOT needs
1.7 FL DOT response 2nd questionnaire committee
1.8 Summarize 2nd questionnaire
1.9 Develop & submit summary of testing needs
1.10 Develop & submit draft SOR
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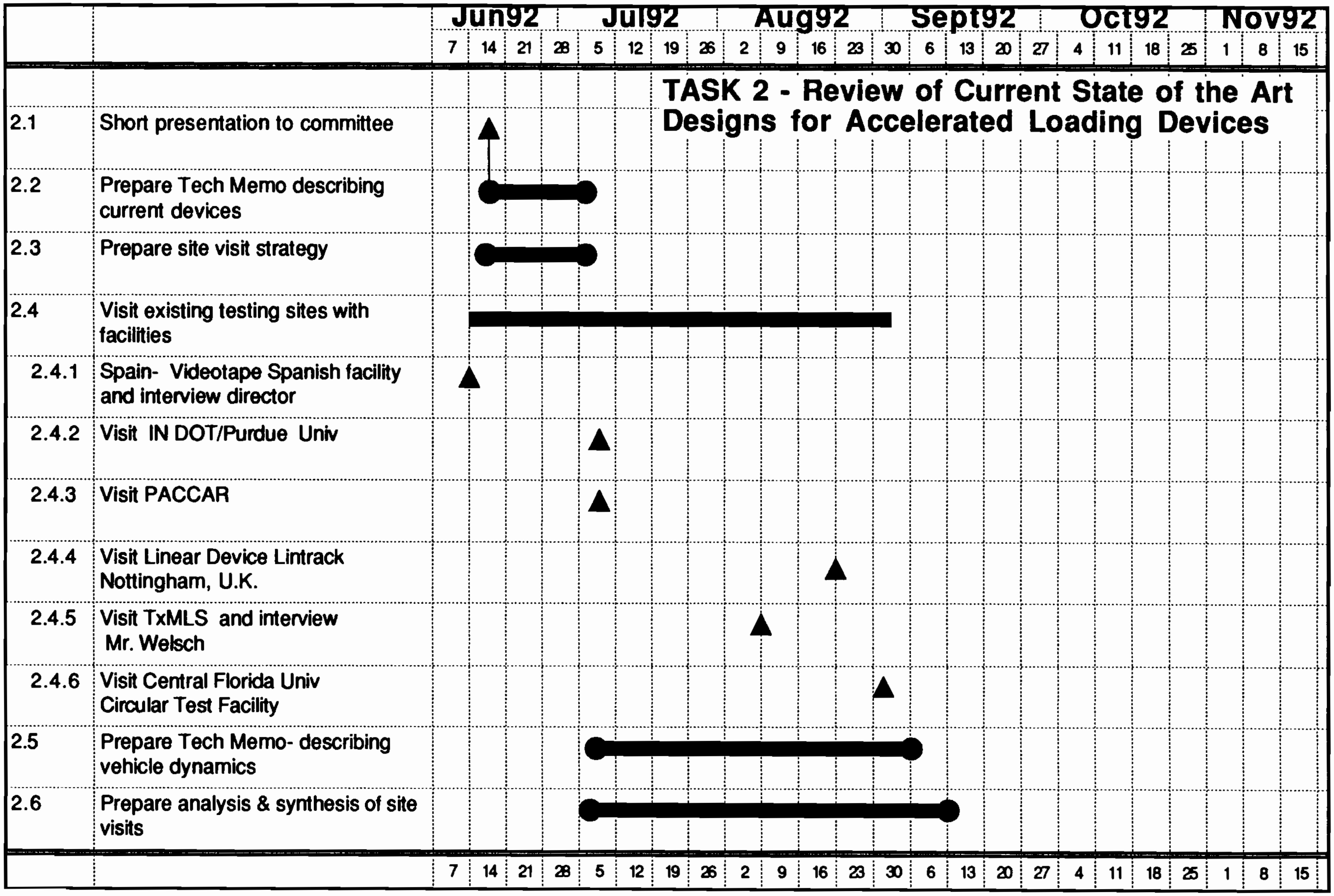
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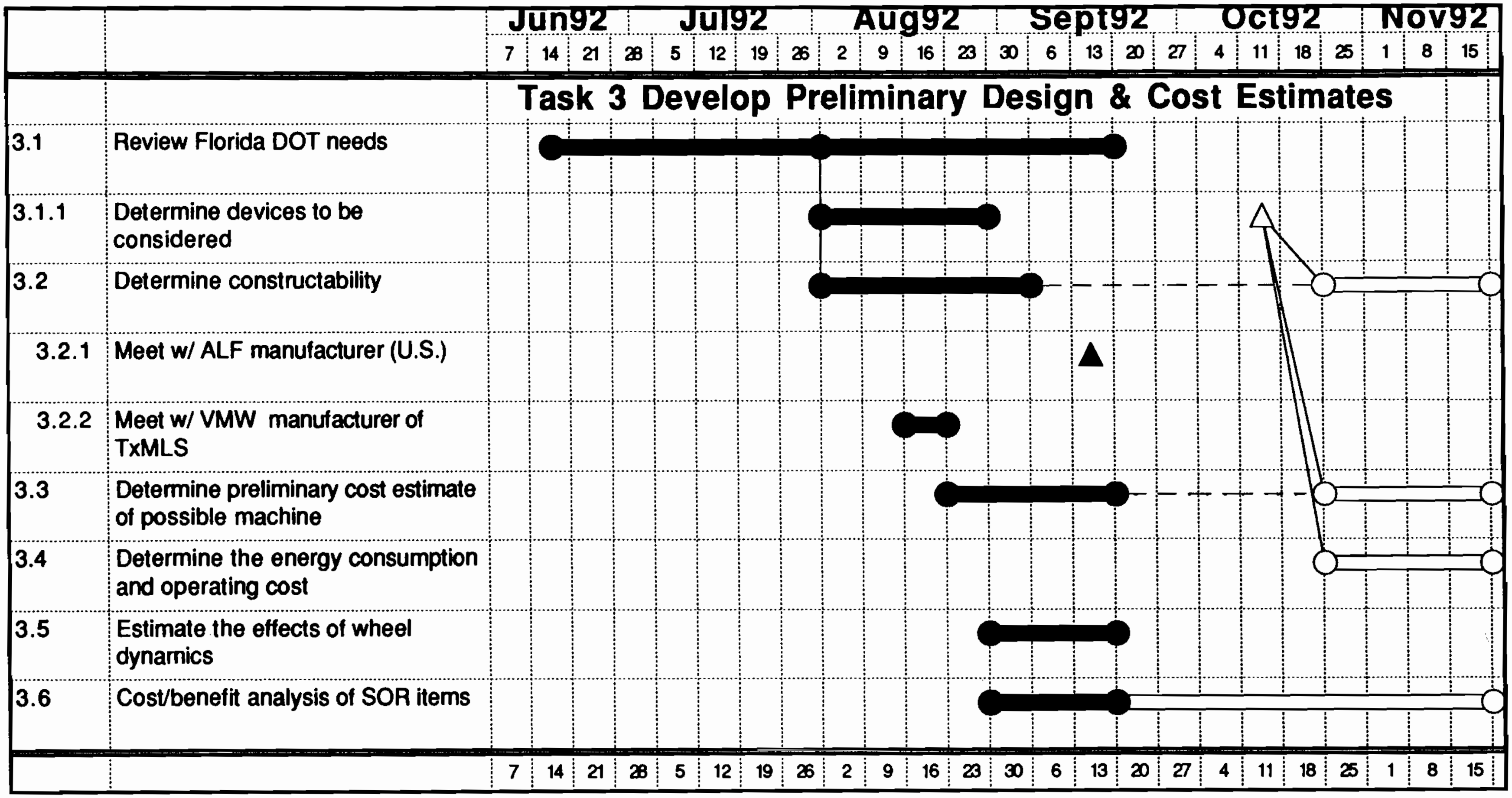
TASK 2 - Review of Current State of the Art Designs for Accelerated Loading Devices
2.1 Short presentation to committee
2.2 Prepare Tech Memo describing current devices
2.3 Prepare site visit strategy
2.4 Visit existing testing sites with facilities
2.4.1 Spain- Videotape Spanish facility and interview director
2.4.2 Visit IN DOT/Purdue Univ
2.4.3 Visit PACCAR
2.4.4 Visit Linear Device Lintrack Nottingham, U.K.
2.4.5 Visit TxMLS and interview Mr. Welsch
2.4.6 Visit Central Florida Univ Circular Test Facility
2.5 Prepare Tech Memo- describing vehicle dynamics
2.6 Prepare analysis & synthesis of site visits

Oct 2, 1992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Task 3 Develop Preliminary Design & Cost Estimates
3.1 Review Florida DOT needs
3.1.1 Determine devices to be considered
3.2 Determine constructability
3.2.1 Meet w/ ALF manufacturer (U.S.)
3.2.2 Meet w/ VMW manufacturer of TxMLS
3.3 Determine preliminary cost estimate of possible machine
3.4 Determine the energy consumption and operating cost
3.5 Estimate the effects of wheel dynamics
3.6 Cost/benefit analysis of SOR items
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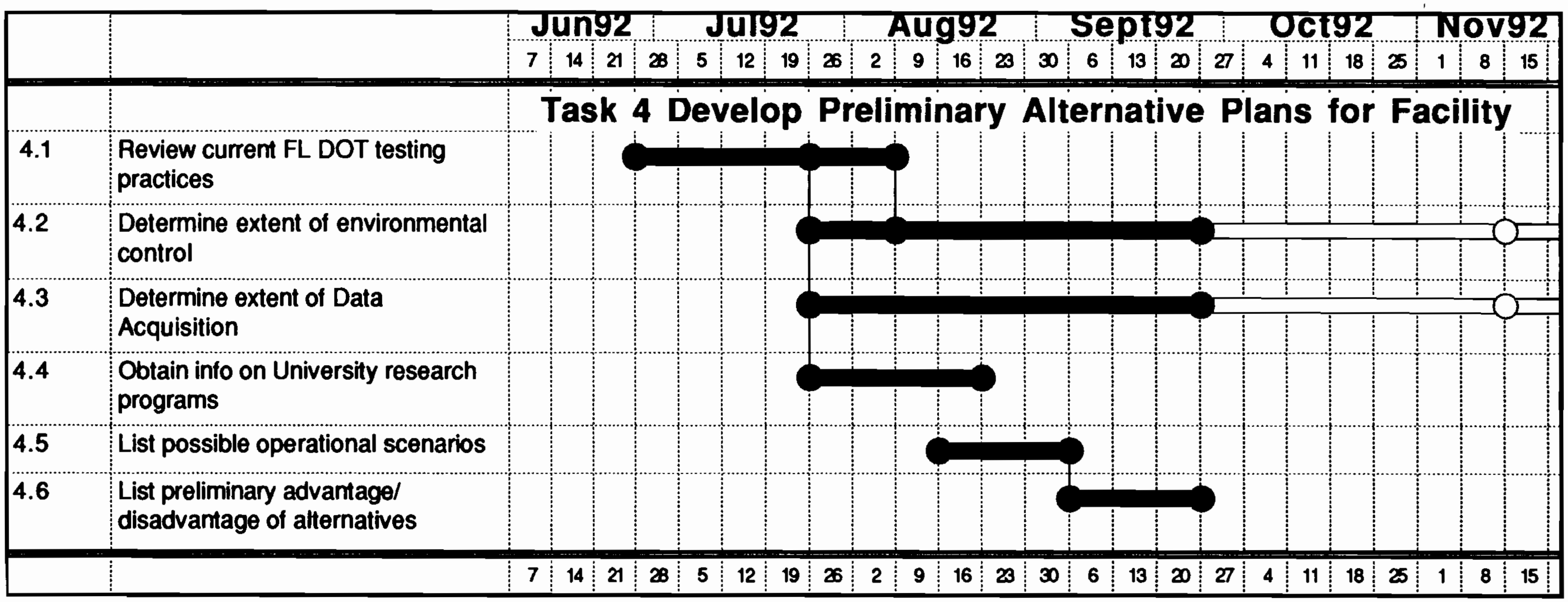

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Task 4 Develop Preliminary Alternative Plans for Facility
4.1 Review current FL DOT testing practices
4.2 Determine extent of environmental control
4.3 Determine extent of Data Acquisition
4.4 Obtain info on University research programs
4.5 List possible operational scenarios
4.6 List preliminary advantage/ disadvantage of alternatives
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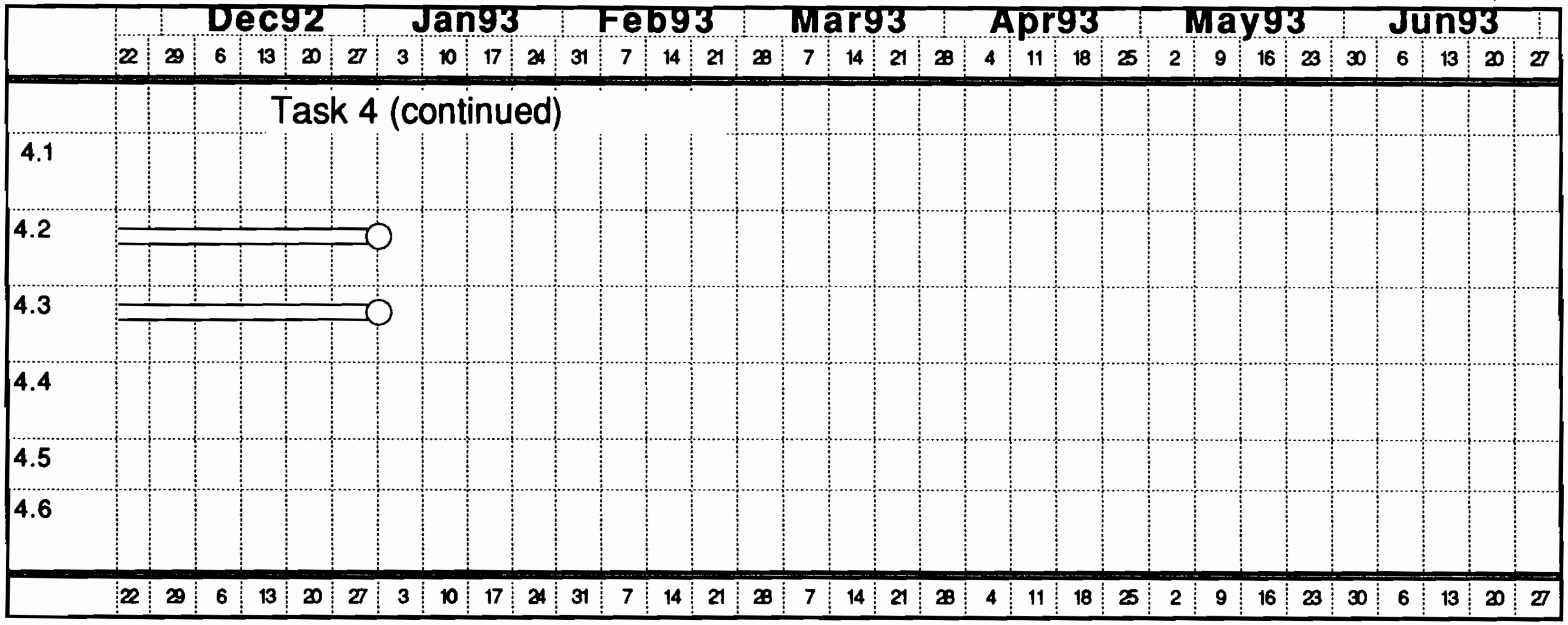
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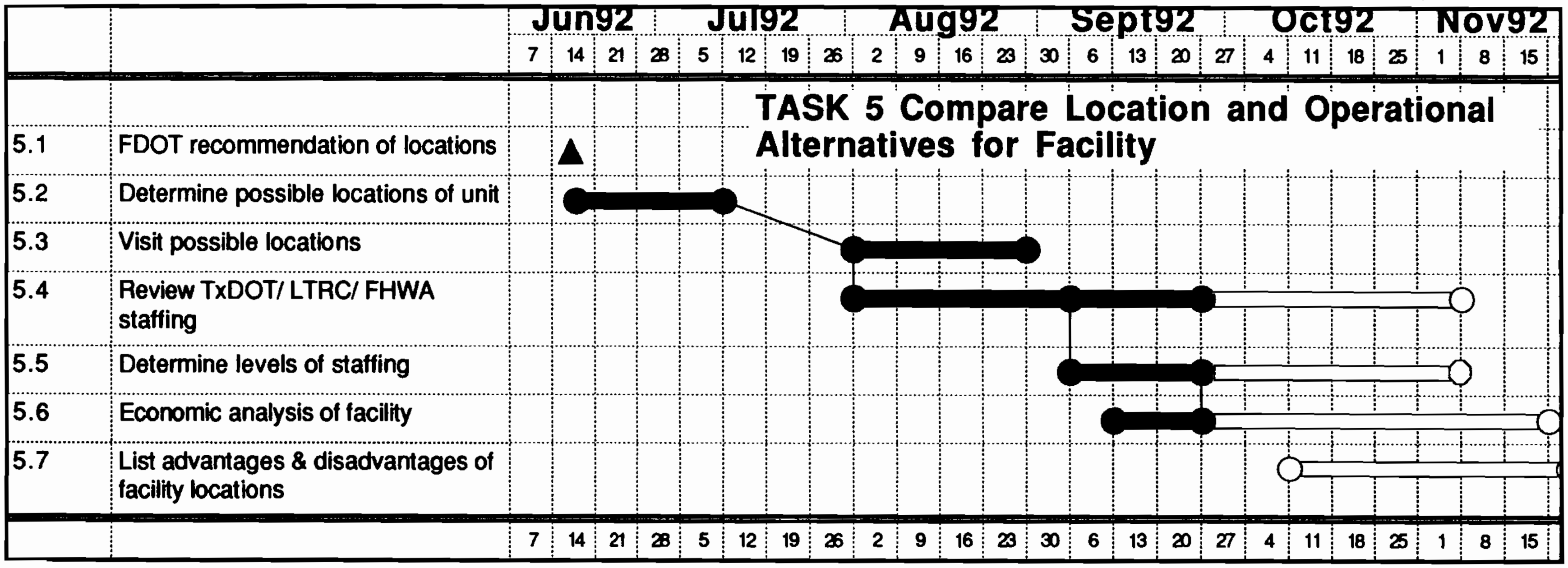
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TASK 5 Compare Location and Operational Alternatives for Facility
5.1 FDOT recommendation of locations
5.2 Determine possible locations of unit
5.3 Visit possible locations
5.4 Review TxDOT/ LTRC/ FHWA staffing
5.5 Determine levels of staffing
5.6 Economic analysis of facility
5.7 List advantages & disadvantages of facility locations
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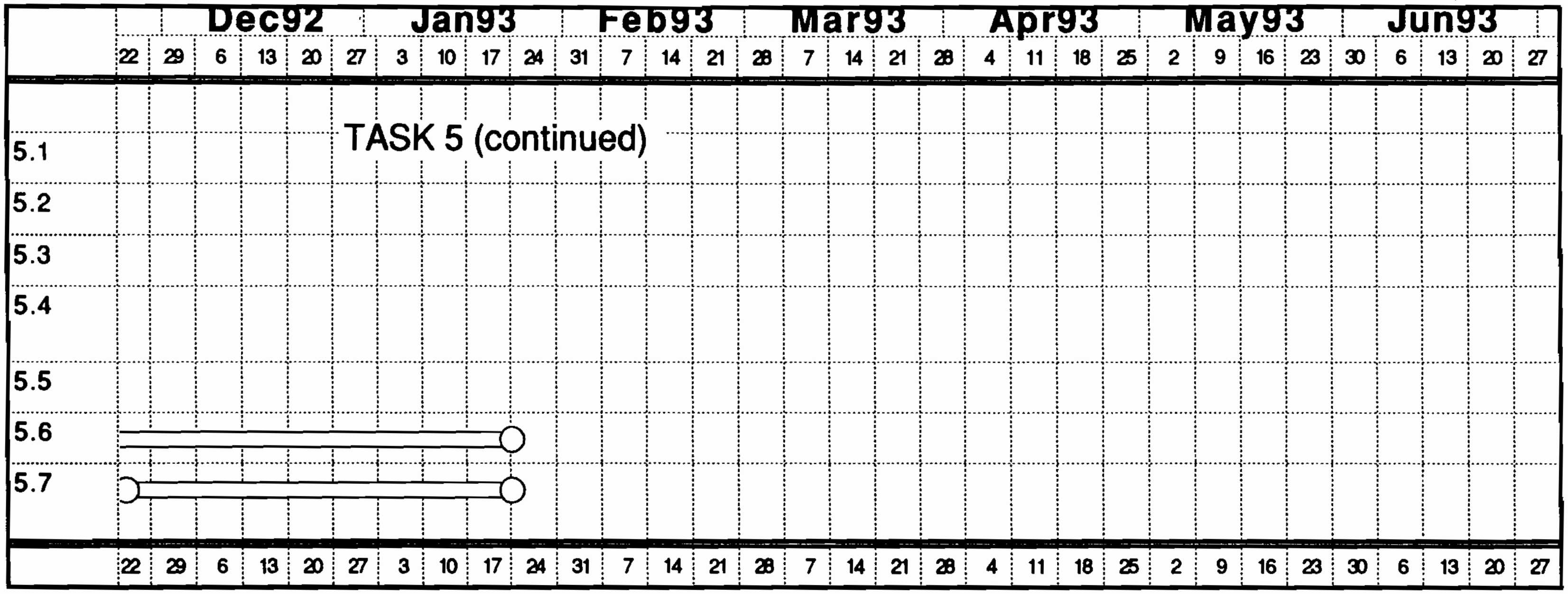
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TASK 5 (continued)
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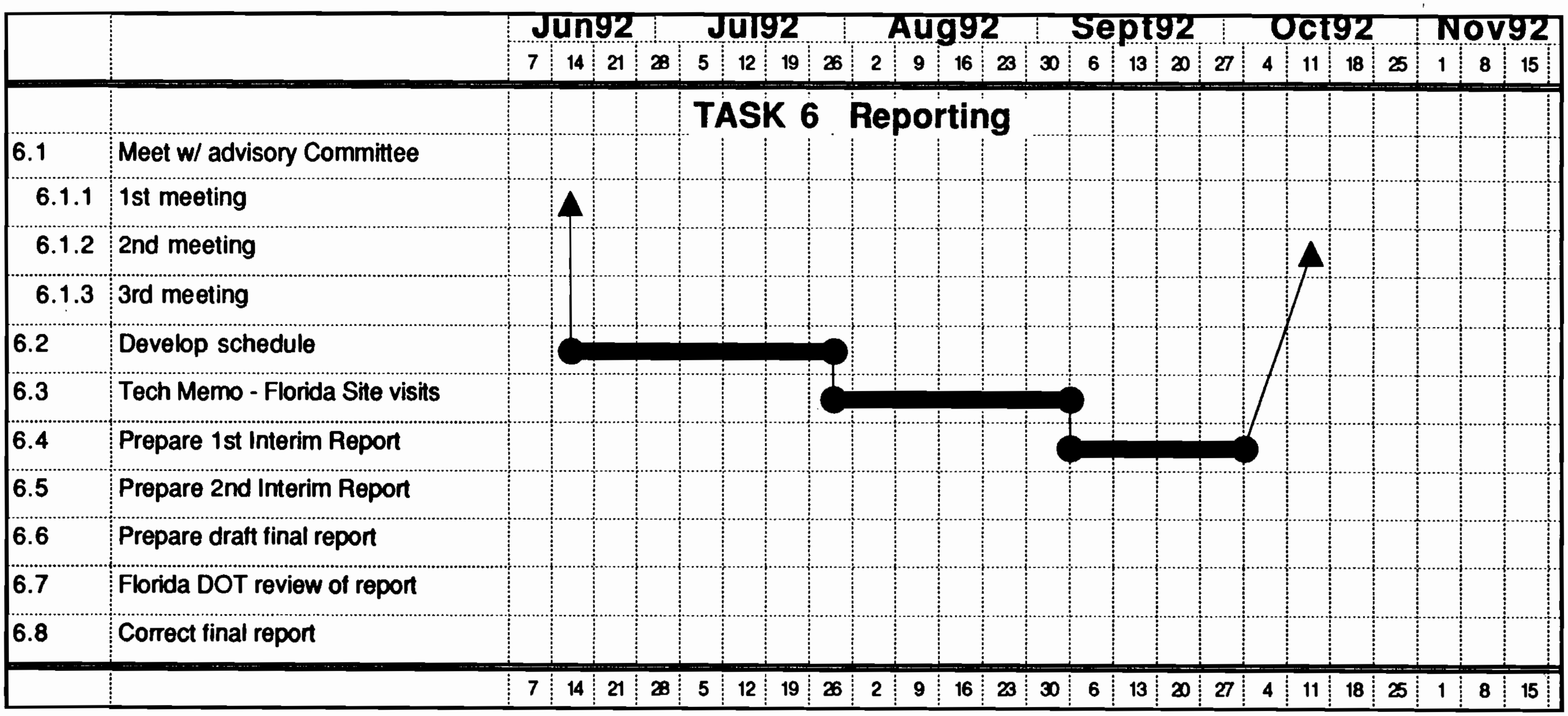

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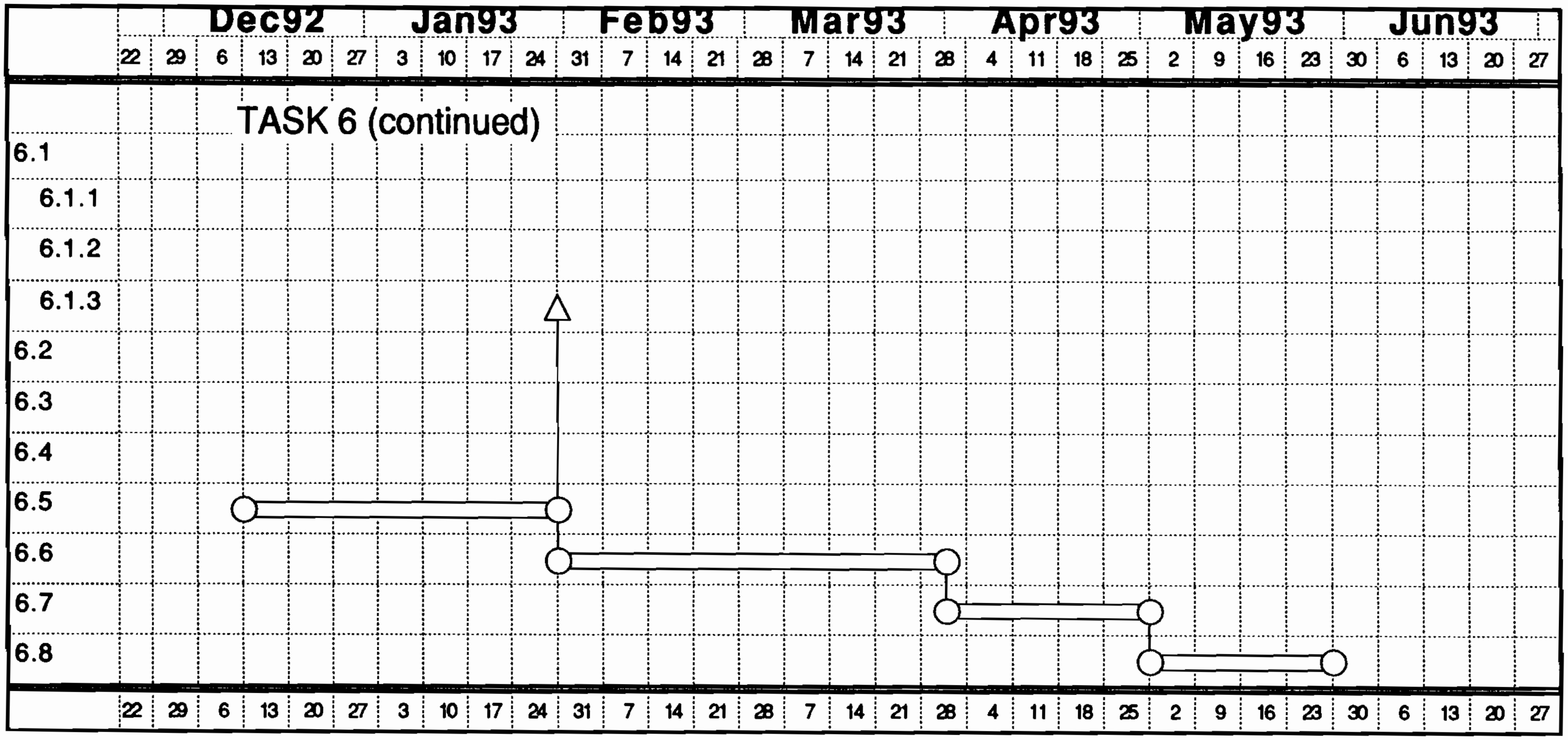
TASK 6 Reporting
6.1 Meet w/ advisory Committee
6.1.1 1st meeting
6.1.2 2nd meeting
6.1.3 3rd meeting
6.2 Develop schedule
6.3 Tech Memo - Florida Site visits
6.4 Prepare 1st Interim Report
6.5 Prepare 2nd Interim Report
6.6 Prepare draft final report
6.7 Florida DOT review of report
6.8 Correct final report
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15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TASK 6 (continued)
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6.8
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# PHASE I—APPENDIX B

# FLORIDA DEPARTMENT OF TRANSPORTATION ACCELERATED PAVEMENT TESTING SURVEY

This questionnaire was completed by Florida DOT advisory committee to prioritize test variables for application of an Accelerated Pavement Load Simulator Device.

The results of the advisory committee's reponses are given in the following pages with a total score group for each question. The areas have been shaded that correspond to the committee,s responses in the following manner.

2 = Received a score of 15-17 items considered low priority

3 = Received a score of 20-23 items considered neutral

4 = Recieved a score of 24-27 items considered important

5 = Received a score of 28-35 items considered most important

# I INPUT VARIABLES

A Wheel Loading

| | | | | | |
|---|---|---|---|---|---|
| Selection of test machine load variables or desirables | | | | | |
| Half axle | | | ▒ | | |
| Full axle | | | | | ■ |
| Tandem axles | | | | | ■ |
| Multiple axles | | | | ▒ | |
| Single tire | | | ▒ | | |
| Super single tires | | | | ▒ | |
| Dual Tires | | | | | ■ |
| Tire pressure | | | | | ■ |
| Truck type suspension | | | | ▒ | |
| Variable suspension | | | | | ■ |
| Limited device-induced dynamics | | | | ■ | |

| | | | | | |
|---|---|---|---|---|---|
| Load | | | | | |
| • Normal legal truck load | | | | | █ |
| • 25% overload | | | | | █ |
| • > 25% overload | | | | | █ |
| • Selectable load | | | | | █ |
| Speed of load application | | | | | |
| • < 10 mph | | ░ | | | |
| • 10 - 20 mph | | | ▒ | | |
| • 20 - 30 mph | | | | ▓ | |
| • > 30 mph | | | | | █ |
| Rate of application of ESALS | | | | | |
| • < 500 ESALS/hr | | ░ | | | |
| • 500 - 2000 ESALS/hr | | | | ▓ | |
| • > 2000 ESALS/hr | | | | | █ |
| Wander | | | | ▓ | |
| Wheel configuration | | | | | |
| • Limited | | ░ | | | |
| • Extensive | | | | ▓ | |
| Gradient simulation | | | ▒ | | |
| Braking simulation | | | | | █ |

B Alternative Test Configuration

| | | | | | |
|---|---|---|---|---|---|
| Permanent research location | | | | | |
| Portable testing machine with ability to test in-service roads | | | | | |
| Test section length | | | | | |
| • 5 - 10 m | | | | | |
| • 10 - 15 m | | | | | |
| • 15 - 25 m | | | | | |
| • > 25 m | | | | | |
| Use of normal construction equipment for test sections | | | | | |

C Control of Environmental Variables

| | | | | | |
|---|---|---|---|---|---|
| Temperature | | | | | |
| Surface water | | | | | |
| Sub-surface water | | | | | |
| Wind | | | | | |
| Humidity | | | | | |
| Geographically varying field environments | | | | | |

## II PAVEMENT ENGINEERING TEST VARIABLES

A Asphalt pavement variables

| | | | | | |
|---|---|---|---|---|---|
| Alternative surface seal coats | | | | | |
| Rejuvenation application | | | | | |
| Aggregate-AC interaction | | | | | |
| Natural aging of AC | | | | | |
| Artificial aging of AC | | | | | |
| Asphalt mix composition | | | | | |
| Friction between layers | | | | | |

B Portland Cement Concrete Pavement Variables

| | | | | | |
|---|---|---|---|---|---|
| Aggregate-PCC interaction | | | | | |
| Natural aging (curing) of PCC | | | | | |
| Artificial accelerated aging of PCC | | | | | |
| Variation in reinforcing steel in CRCP | | | | | |
| Concrete mix composition | | | | | |

C Pavement Compositional & Structural Variation

| | | | | | |
|---|---|---|---|---|---|
| Variation in pavement type | | | | | |
| • Asphaltic bases | | | | | |
| • Flexible bases | | | | | |
| • Lime-treated bases | | | | | |
| • Cement-treated bases | | | | | |
| • Recycled asphalt | | | | | |
| • Plain concrete pavement | | | | | |
| • Jointed reinforced concrete pavement (JRCP) | | | | | |
| • Continually reinforced concrete pavement (CRCP) | | | | | |
| Different material layer thicknesses | | | | | |
| Different structural compositions | | | | | |
| Voids beneath concrete | | | | | |
| Effect of shoulders | | | | | |
| Variation in construction quality | | | | | |

D Other Material/Pavement Characteristics

| | | | | | |
|---|---|---|---|---|---|
| Subgrade compaction | | | | | ■ |
| Subgrade stiffness | | | | | ■ |
| Subgrade plastic behavior | | | | ▒ | |
| Behavior of anisotropic material | | | ▒ | | |
| Oyster shell | | | ▒ | | |
| New materials/mixtures | | | | | ■ |
| Statistical material variability | | | | ▒ | |
| Maintenance strategies | | | | ▒ | |
| Rehabilitation strategies | | | | ▒ | |
| Axle load equivalency | | | | | ■ |
| Joint seals | | | ▒ | | |

## III OUTPUT MEASUREMENTS

A Response

| | | | | | |
|---|---|---|---|---|---|
| Deflection | | | | | ■ |
| Stress | | | | | ■ |
| Strain | | | | | ■ |

B Performance

| | | | | | |
|---|---|---|---|---|---|
| Load associated cracking | | | | | ■ |
| Non-load associated cracking (ie. D-cracking) | | | ▒ | | |
| Cracking due to load and non-load interactive causes | | | | | ■ |
| Rutting | | | | | ■ |
| Surface roughness | | | | ▓ | |
| Riding quality | | | | ▓ | |
| Skid resistance | | | | | ■ |
| Structural condition (integrity) | | | | | ■ |
| Surface condition | | | | | ■ |
| Residual life | | | ▒ | | |
| Change in surface friction | | | | ▓ | |
| AC-stripping | | | ▒ | | |
| Edge drain efficiency | | | | ▓ | |
| Joint seal behavior | | | ▒ | | |
| Load transfer at PCC joints | | | ▒ | | |
| Delamination of layers | | | | ▓ | |
| Steel concrete bond | | ▒ | | | |
| Wear of aggregate | | | | ▓ | |

# PHASE I—APPENDIX C

# DEVELOPMENT OF THE SPECIFIC OPERATIONAL REQUIREMENTS OF AN APT-DEVICE FOR FLORIDA DOT

The results of the FDOT needs analysis provided a basis for a first draft of the Specific Operational Requirements of an APT device. It is apparent that a fully detailed SOR can only be compiled once FDOT has finally formulated its testing system. Therefore generic definitions will be presented with details only given where they already are available or appropriate.

## FIRST DRAFT SPECIFIC OPERATIONAL REQUIREMENTS (SOR)

Compiled October 4, 1992

It is apparent that all requirements of such an SOR will not necessarily be met by any of the existing APT's. Accordingly it will be necessary to scrutinize the attributes of each of the available facilities to determine which facility, if any, offers the best possibility of an optimal solution. This can only be achieved by an iterative process of review and compromise. The attributes and limitations of existing facilities will therefore be presented in Chapters 3 and 4. Chapter 5 will then present the feasible options available to the FDOT.

## I APT-DEVICE ATTRIBUTES

The following features should be available when testing pavements:

### *A Wheel Loading Characteristics*

- Full axles
- Tandem axles
- Multiple axles
- Super single tires
- Dual tires
- Variable tire pressure
- Variable truck type suspensions
- Limited device-induced dynamics

#### *Load Scope*

- Normal legal truck load

  Single axle 90 kN (22000 lb)

  Tandem axle 196 kN (44000 lb)
- Ability to select load and overload with 25% or more

#### *Speed of Load Applicaton*

- 32 - 48 kph (20 - 30 mph) and preferably > 48 kph (30 mph)

### *Rate Of Application Of ESALs*

- 500 - 2000 ESALS/hr and preferably > 2000 ESALS/hr

  Allowance shall be made for transverse wander of wheels

### *Wheel and axle configuration*

- Extensive variability required

  Provision to be made to simulate braking

## *B Alternative Test Configuration and Preparation*

APT is to be portable with ability to operate at a permanent research location and on an in-service highway

- Test sections (not necessarily test lengths) are to be 15-25 m long or if possible > 25 m

  Normal construction equipment is to be used for preparation of test sections

## *C Control of Environmental Variables*

The following environmental test features should be variable but controlled and measured:

- Temperature
- Surface water
- Sub-surface water

In addition, the APT-devices should be capable of testing in different geographically varying field environments.

## II PAVEMENT ENGINEERING TEST VARIABLES

The APT must be capable of testing the following pavement features (in order of preference):

- Asphalt/Concrete mix compositions
- Asphalt bases
- Flexible bases
- Recycled asphalt
- Differing structural compositions
- Differing material layer thicknesses
- New materials/mixtures
- Axle load equivalency
- Subgrade compaction
- Subgrade stiffness
- Aggregate-AC interaction
- Variation in construction quality
- Artificial aging of AC
- Lime treated bases
- Plain concrete pavement
- Statistical material variability
- Maintenance strategies
- Rehabilitation strategies
- Artificial accelerated aging of PCC
- Cement treated bases
- Subgrade plasticity
- Voids beneath concrete
- Effect of shoulders
- Friction between layers

## III OUTPUT MEASUREMENTS

Provision should be made for measuring the following:

### *A Response Variables*

- Deflection
- Stress
- Strain

### *B Performance Variables*

- Rutting
- Structural condition (integrity)
- Load associated cracking
- Change in surface friction (skid resistance)
- Surface condition (riding quality, roughness)
- Cracking due to load and non-load interactive causes
- Wear of aggregate
- Edge drain efficiency
- Delamination of layers

# PHASE II

# CHAPTER 1. INTRODUCTION

Accelerated pavement testing (APT) has proven useful in the design and evaluation of all types of pavements. APT has been further enhanced by recent advances in computational power and electronic instrumentation, resulting in an increased capability to model the effects of truck loading on pavements. With changes in truck loadings and possible heavier axle loads (a result of new axle configurations, suspension systems, and tire advances), the need for accelerated pavement testing has become evident to most state highway agencies.

The purpose of accelerated pavement testing is to determine pavement life (in terms of realistic traffic) and to identify the variables that effect pavement design. Accelerated pavement testing can be used either as a research tool or as a management tool to determine the best management and rehabilitation strategies for pavement design, maintenance, and rehabilitation. This report is the third report in a three-phased study to determine the feasibility of constructing an accelerated pavement testing facility in Florida for the Florida Department of Transportation.

## STUDY OBJECTIVES

In order to determine the feasibility of APT by the Florida Department of Transportation, it was necessary to determine (1) the need for such a facility, (2) what would be tested, (3) who might conduct the testing, (4) and what benefit was anticipated from the testing. After the needs and expectations had been established, they could be compared with the capabilities of known or planned accelerated pavement testing devices to determine potential solutions for implementation.

The Florida DOT, recognizing that they have a need for accelerated pavement testing that cannot be met by construction of test roads or by continued testing of base course materials in test pits, decided to contract for a research and development effort. After evaluating proposals written in response to their Request for Proposal, the Florida DOT selected the Center for Transportation Research to perform this feasibility study. The objectives of the study (as defined by the Request for Proposals and as clarified in the CTR Proposal) included the following:

1. Review the accelerated pavement testing (APT) needs of Florida DOT.
2. Review and compare current state-of-the-art technology and designs for accelerated loading devices.
3. Compare the advantages and disadvantages of candidate accelerated loading devices so that the committee can recommend a preliminary design to the department. Prepare preliminary cost estimates of the applicable loading devices that the committee might recommend.

4. Develop preliminary alternate plans for the test facility and the operations of the facility.
5. Compare the alternatives for location, operation, staffing, and maintenance of the facility.
6. Prepare interim reports and make presentations to the committee; prepare a final report at the conclusion of the study.

## SCOPE OF THE STUDY

The CTR proposal for this study provided for six detailed tasks—divided into Phases I, II, and III—that coincided with the study objectives. Phase I, the largest portion of the work, included all of Task 1 (Assess the Needs of the Florida DOT) and Task 2 (Review Current State-of-the-art Designs for Accelerated Loading Devices). Florida DOT had the option at the end of Phase I to either conclude the study at that point or continue with Phases II and III.

CTR began Phase I on June 10, 1992, and continued on schedule. At the conclusion of Phase I, Dr. McCullough and Mr. McNerney made a presentation to the Advisory Committee that was directing the research project. An interim report (Research Report 997-1) was also prepared and distributed at that meeting. A short summary of Phase I results, provided in the next section, details the methodology and the nine possible options for acquiring an accelerated pavement testing device.

At the conclusion of Phase I, Florida DOT and the Advisory Committee instructed CTR to continue with Phases II and III of the study. The letter of instructions from the Project Manager, dated October 27, 1992, instructed CTR to focus Phase II on (1) the detailed analysis of a linear device similar to the MLS being built in Texas, and (2) the test track concept similar to that in use in Spain. However, CTR was directed to wait for a possible redirection of the Phase II efforts, which was later confirmed in a letter (from the Project Manager) dated November 19, 1992. The letter required that the Phase II effort be directed at studying an MLS-type device and a modified Purdue-type facility (which, together, would be capable of more ESAL's per hour and modified to meet Florida DOT needs as identified in Phase I).

After work had commenced on the detailed evaluation of both the MLS and the Purdue facility, CTR was asked to draft an amendment to the contract. This amendment was to include a detailed analysis of the Spanish Test Track facility and a detailed consideration of the potential for commercialization (or selling of facility testing time to help off-set operating costs). CTR submitted a proposal to Florida DOT on February 4, 1993, and received approval February 24, 1993, to proceed in accordance with this amendment.

The scope of Phase II was to continue with:

Task 3: Develop Preliminary Design and Cost Estimates;

Task 4: Develop Preliminary Alternative Plans for the Facility;

Task 5: Compare Operational Alternatives for the Facility; and

Task 6: Reporting.

## SHORT SUMMARY OF PHASE I RESULTS

All Phase I results are reported in Research Report 997-1 (October 1992). The introduction to the report gives a thorough overview of the history, need, and justification for accelerated pavement testing, including its role in the design, maintenance, and rehabilitation of pavements. The introduction also explains the objectives of the study and the limitations imposed upon Phase I. CTR was directed not to recommend a final device, but to conduct an impartial analysis of all the devices and potential facility locations, and to present the options to the Advisory Committee. Florida DOT would review the advantages and disadvantages of each of the potential options for accelerated pavement testing devices and facility locations, as presented by CTR.

CTR conducted a needs analysis of Florida DOT by interview and by the analysis of two questionnaires completed by the Advisory Committee. Using experience gained in field testing, the research team analyzed and presented Florida DOT needs. The items considered most necessary pertaining to selecting an accelerated pavement testing device were the following:

- ability to simulate tandem and full-axle truck bogies;
- ability to vary the load, tires, suspension, and speed;
- ability to test actual contractor-prepared test sections of rigid and flexible pavements;
- ability to test using a high application rate of normally loaded axles; and
- ability to conduct testing of the complete pavement structure and multiple failure types.

Phase I also included a complete review of the state-of-the-art in accelerated pavement testing devices. Several APT devices were inspected and either videotaped or photographed. A short video was presented to Florida DOT showing the current operation of several APT devices. The devices studied in Phase I included the five devices directed to be studied by contract, as well as several others of which the research team had in-depth knowledge.

The following nine existing facilities were investigated and reported on in Phase I:

1. Full-Scale Test Tracks
   a. CEDEX race track design in Madrid, Spain
2. Circular Testing Devices
   a. New Zealand CAPTIF-I
   b. University of Central Florida CATT
3. Linear Testing Devices
   a. UK TRRL and Netherlands LINTRACK
   b. Purdue ATS
   c. South African HVS
   d. FHWA ALF
   e. TxDOT TxMLS

The Phase I report contains a thorough evaluation of the capabilities of each of the above APT devices. In addition, the study team assessed the ability of each of the devices to meet the needs of the Florida DOT. As required in the contract, no recommendations were made by the research team. However, our listing of the full advantages and disadvantages of each device will hopefully assist the Advisory Committee in deciding which device or devices has the best potential for meeting Florida DOT needs.

The research team inspected current devices and visited three Florida sites suitable for an Accelerated Pavement Testing facility. The three sites selected for in-depth study were:

1. Innovation Research Park in Tallahassee (adjacent to FAMU/FSU College of Engineering).
2. State Materials Office in Gainesville.
3. Campus of the University of Central Florida in Orlando.

The research team pointed out that none of the three sites had all the facilities needed to conduct APT to meet the needs of Florida DOT at this time, though each of the three sites each had its own advantages and disadvantages. There was a potential problem with the groundwater table at the Orlando site, and a potential problem at the Gainesville site that related to available space and proximity to residential neighborhoods. (The space problem was later resolved when it was determined that the Materials Office would gain control of the entire maintenance yard.)

At the beginning of Phase II, CTR was directed to limit the potential sites for further consideration to Tallahassee and Gainesville. CTR was also given to understand that Florida DOT would own and operate the APT facility.

## OBJECTIVE OF THE PHASE II REPORT

Since none of the existing APT devices met all of the Florida DOT needs, Phase II of the study concentrated on reviewing the economic viability of each of the needs, and on determining the ability of each of the recommended devices (with or without modification) to meet the adjusted needs of Florida DOT. Again, the responsibility of CTR was not to make a recommendation but to list each option studied and list the advantages and disadvantages of each.

CTR was also directed not to perform an additional study of the Tallahassee and Gainesville sites, as the location would most likely be determined at a level above that of the Advisory Committee. CTR was additionally directed to look very closely at the ability of the facility to recover some operating expenses through the commercial sale of testing time to other states or contractors (though some members of the committee voiced a concern that there was enough testing to be accomplished by the Department).

To accomplish the Phase II objectives, CTR prepared a list of tasks and sub-tasks and a proposed schedule for tasks 3 through 6, which are shown in Phase II—Appendix A (Figures II—A-1 through A-4). The Phase II tasks were completed. There was, however, a major delay in the fabrication and final design of the Mobile Load Simulator, which is being built for Texas DOT. Since the MLS's capabilities and fabrication cost were integral to the completion of Phase II, there was a significant delay in the scheduled completion of Phase II.

The research team has in-depth knowledge of the Mobile Load Simulator. The MLS, as designed by CTR for Texas DOT, is a mobile test device that simulates truck traffic more effectively than any other APT device and which can apply legal axle loads at high application rates. This in-depth knowledge of the MLS was a significant advantage, as it enabled the team to communicate to Florida DOT all the potential problems of the MLS design and evaluate the potential enhancements to the device to meet additional needs for Florida DOT. At the same time, the research team sought to remain totally unbiased as to which device the Florida DOT would select to meet its need as a fixed-site testing facility. The research team currently has no financial interest in any of the devices that Florida DOT would select for APT. The primary interest of the research team is to promote the capabilities of APT devices as a solution to research needs.

To obtain equivalent knowledge of the other APT devices, the study team inspected the Purdue and Spanish CEDEX facilities. The assistant Director of CEDEX, Mr. Aurellio Ruiz, was very helpful and generously provided his time and staff.

Chapter 2 of this Phase II report reviews the Florida needs and the APT devices capable of meeting those needs. Chapter 3 reviews the devices and lists options that include potential modifications to the devices to meet the needs of Florida DOT. Chapter 4 lists the costs involved in fabricating the device, building and staffing the facility, and maintaining and operating the device and facility. Chapter 5 lists some of the potential impacts of implementing an accelerated pavement testing facility, including a possible facility layout, the potential schedule to construct a facility, and the potential for commercial use of the facility. Chapter 6 presents a summary of the report.

# CHAPTER 2. RELATING FLORIDA DOT NEEDS TO APT DEVICES

The first item that had to be determined for the second phase of the study was the extent to which the three APT devices were able to meet the needs of Florida DOT. Once this was accomplished, it would be possible to formulate strategies to enhance the existing devices either by improving their performance or by increasing their ability to meet FDOT needs. It should be recalled that CTR had been instructed to focus primarily on the linear device (Purdue) and the vertical loop device (MLS). The scope was then expanded to include the horizontal loop (or Spanish device). Accordingly, the three devices were thoroughly scrutinized and reviewed relative to the FDOT's prioritized needs.

## MEETING THE NEEDS OF FLORIDA DOT

CTR first reviewed the needs analysis of Phase I in relation to the three selected devices, so that it would be possible to compare and adjudicate them. The next step was to determine the extent to which the three devices would fulfill the needs identified by FDOT in the survey. CTR also considered whether all of the needs, as set forth by the FDOT Advisory Committee, were completely necessary. Consideration was given to which of these needs might be trimmed, and to the consequences of these needs in terms of cost. Ultimately, FDOT should avoid spending unnecessary money on items which may be used infrequently. Also taken into consideration was how and what FDOT would actually want to measure and what was likely to be tested in the field.

Accelerated pavement testing really boils down to accelerating damage to the pavement through some means of condensing the time to accumulate that damage. The condensation of time can be done in several ways or through a combination of ways. For example, time can be condensed by high application rates of regular loading, pavements can be heated to reduce their resistance to damage, the load can be increased by overloading, or the deflection and load time can be increased by slower passes of the wheel. It has been estimated that there are over 120 variables that affect pavement life or pavement serviceability. In Phase I of this report we listed approximately 90 items that should be considered when selecting an APT device.

In order for Florida DOT to make an informed decision on the selection of an APT device, the specific needs that rated the highest in the Phase I needs assessment were reviewed with respect to the proposed devices and to the expected types of testing gleaned from the needs analysis. Some of the needs have a large impact upon the selection or design capability of the device, while others are common to most APT devices. Some of the needs identified in Phase I were rated as a high priority. However, the survey of needs was not based upon cost or feasibility. Based upon experience, CTR has distilled the parameters, needs, and capabilities down to a short list of items to be carefully considered in the selection or design of an APT device.

## CONSIDERATION OF SPECIFIC FDOT NEEDS

The Phase I needs analysis divided the needs into *high priority, lower priority,* and those which were *not really of concern.* CTR focused on validating those items extracted from that analysis that are high priority needs or are necessary considerations in choosing an APT device. The eight items to be reviewed in specific detail including the following:

1. Acceleration by overloading
2. Acceleration by axle volume
3. Environmental control
4. Multiple axles
5. Test speed
6. Wheel dynamics
7. Braking simulation
8. Testing in different geographic regions

### *Acceleration by Overloading*

Florida DOT will test materials which are stress dependent. To test any material which is stress dependent, acceleration by overloading should not be used unless the effects of overloading are clearly understood. There is a good chance that overloading materials which are stress dependent might cause the test results to be biased. If the results of the testing are related to fatigue cycles or to performance of viscoelastic materials (and quantitative results are desired), overloading can lead to results that are confounded with unexplained variables.

This has implications for the linear system, which is normally overloaded because of the slowness of the rolling wheel. No matter how fast a linear system is moved back and forth, the fact that it has to stop and go back and forth will always result in slow application rates. Therefore, unless you are simulating low traffic counts, such as found on low volume roads or airports, the linear systems are usually overloaded to condense time. The Spanish facility and the MLS facility are conventionally loaded with standard axle loads. However, the MLS and the Spanish facility have the flexibility to accelerate by partially overloading the axles as well. The linear device might only be acceptable under circumstances when acceleration by overloading is not considered to be of concern.

### *Acceleration by Axle Volume*

This item is linked to the previous need through its requirement for standard axles; however, this form of testing achieves acceleration by applying the greatest number of axle load applications in the shortest possible time. Thus, acceleration is achieved by axle volume, not axle overloading. The capability of acceleration by means of axle volume will feature very strongly in the remainder of the report.

Because of economic and time constraints, most devices are presently unable to achieve acceleration through axle volume. Of the three machines under discussion, the MLS is most capable of meeting this need, though the race track options have been enhanced in an attempt to match the capability of the MLS.

### *Environmental Control*

One of the needs that was highly rated was the need for environmental control of temperature, humidity, and surface and subsurface water. There is no question that environmental variables have a significant impact on pavement performance, especially asphalt pavements. The Heavy Vehicle Simulator (HVS) from South Africa (which may be considered equivalent to an enhanced Purdue device) has been used with an environmental chamber built around it to control temperature at field and fixed locations. Using an environmental chamber, a linear device and the pavement inside can be cooled or heated.

The MLS, which can be heated or cooled, has an exterior chamber specifically designed for a retrofit for that capability. To accomplish the same with the Spanish device, there must be some means for providing an enclosed chamber around the test sections to allow them to be cooled or heated. Since the device actually travels through the chamber, it would require some form of shear wind curtain at the entrance and exit.

Research findings strongly support the need to consider environmental factors in APT. Figure 2-1 shows micro viscosity of asphalt binders subject to different environments in several parts of the United States. The figure shows that a difference in the degree of binder aging depends upon the locality, and would therefore have a pronounced effect on the performance of the asphalt.

Figure 2-2 shows the rut depth of a specific asphalt surface developing over a number of years. This figure shows a sharp increase in rutting early in the life of the pavement that tapers off to a slower rate. This implies that during accelerated testing (i.e. when condensing time values), the event may not be linear in time. Condensing a non-linear event may be troublesome for APT and the conclusions reached may be questioned depending on the acceleration format. This is one reason that APT without environmental control has been criticized. Therefore, CTR strongly supports the Florida DOT desire to have environmental control in its APT facility.

### *Multiple Axles*

Another high priority need was the ability to deal with multiple axles. Why multiple axles? Among other reasons, it is the best simulation of the load actually applied to in-service pavements.

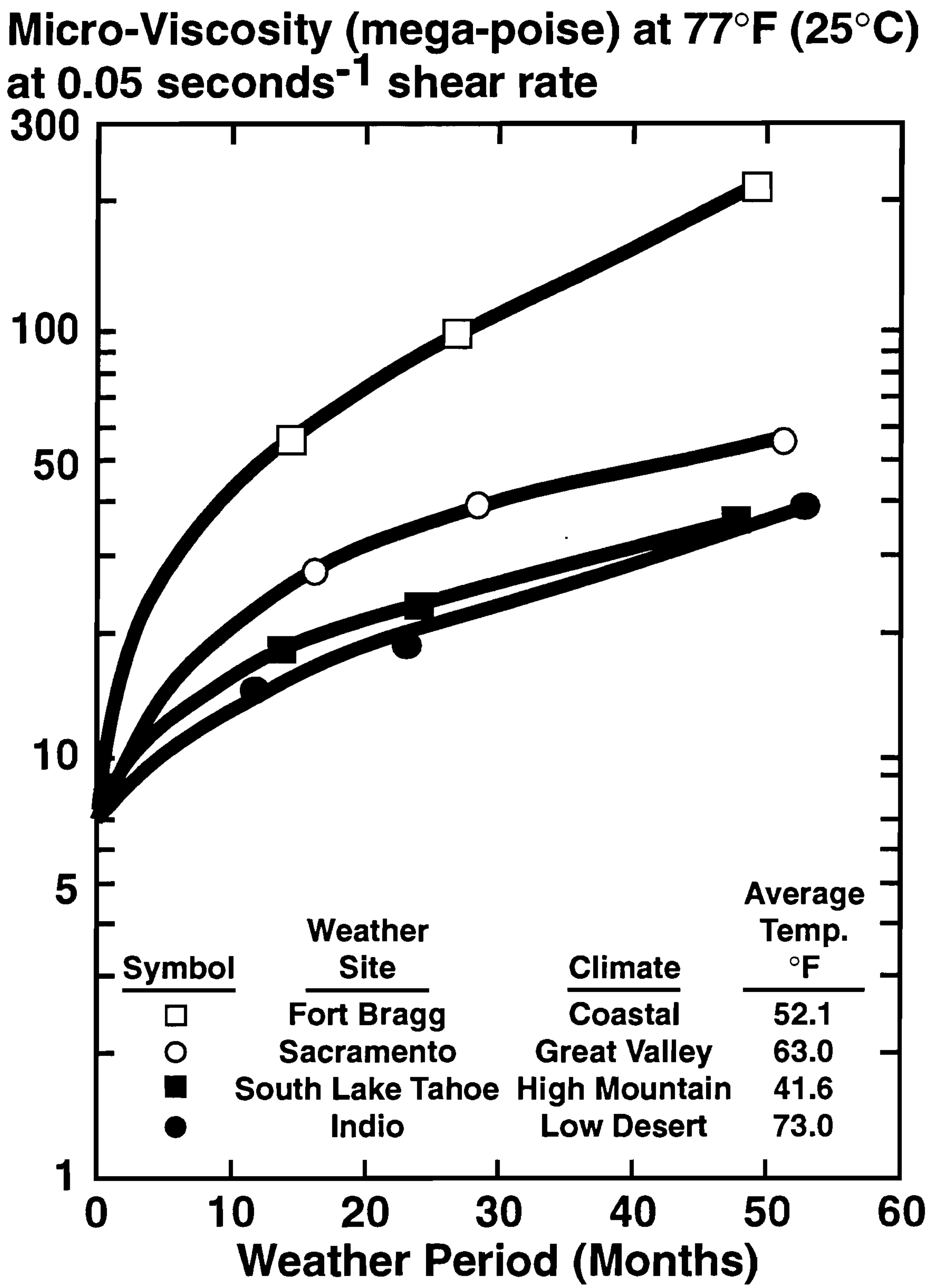
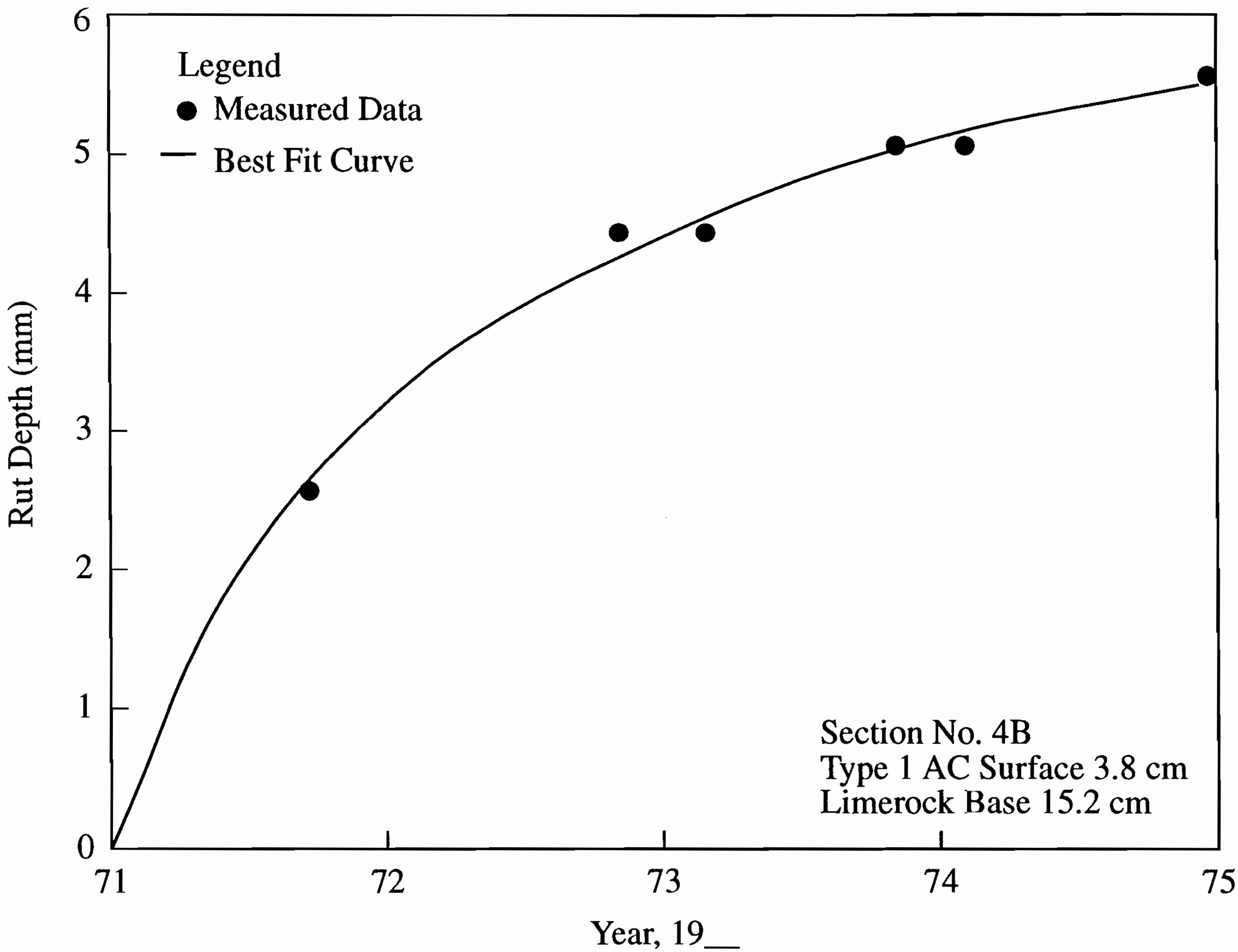



Figure 2-1

*Micro-Viscosity of asphalt binders*


Legend
Measured Data
Best Fit Curve
Rut Depth (mm)
0
1
2
3
4
5
6
71
72
73
74
75
Year, 19__
Section No. 4B
Type 1 AC Surface 3.8 cm
Limerock Base 15.2 cm

Presently the only machine of the three under investigation that applies multiple axles is the MLS. The linear device can probably operate with two axles or with a tandem axle system. The Spanish device has only been used with a single half axle so far, but the capability exists in the recent upgrade to handle a tandem half axle. Accommodating multiple axles can be accomplished in a racetrack type device by expanding the train (i.e. by adding trailing axles). Modifications to the Spanish option have been developed and will be explained in Chapter 3.

## *Higher Test Speeds*

As a result of the needs survey, the research team considered the possibility of testing the MLS at the higher speed of 32 mph (50 kph) (the normal operating speed is 20 mph, or 32 kph). The Spanish CEDEX facility is capable of operating at the higher speed (which it needs for productivity reasons). CTR did investigate this in depth and concluded that it was neither necessary nor cost effective.

Figure 2-3 shows some interesting results from the analysis. The figure is a time diagram developed to reflect the use of different axle configurations at different speeds. On the left hand axis four types of machines are compared. The middle two are typical trucks traveling at 38 mph (60 kph) and 30 mph (47 kph). The top one is the French circular device (LCPC), which can travel up to 62 mph (100 kph). The lower one is the MLS, which is traveling at 20 mph (32 kph). Considering the positioning of the bogies in the system, and relating the position of one bogie to the next, a time diagram can be drawn as follows:

First, consider the distance between one wheel and the next wheel in the time diagram. Then, if it is a multiple axle system, consider what the distance is in time to your next bogie. A three-bogie truck was analyzed, which simulates either a truck with a semi-trailer or the string of MLS bogies. The French circular track with its four arms extended and running at 50 kph (32 mph) was also analyzed. The results of each are compared to determine the effect of test speed on the APT device.

The distance between the fixed wheels in all four cases cannot be changed. The wheels are linked and traveling at a certain speed, so the rate of loading between the wheels can be determined. The French machine is running at 0.09 seconds when traveling at 32 mph (50 kph), which is the true speed required when they are using tandems. The MLS is running at 0.15 seconds. The typical truck bogies are varying between 0.08 and 0.10 seconds. All cases appear to be relatively equal.

The next measurement is the delay between one bogie and the next bogie. Figure 2-3 shows that the French system is 1.98 seconds between two bogies. An actual truck varies between 0.35 and 0.45 seconds, and the MLS is 0.40 seconds. The MLS is therefore right in the middle, equaling something between 30 and 38 mph (i.e., 47-60 kph). Looking at headways between one truck and the next truck, it can be seen that whereas a regular

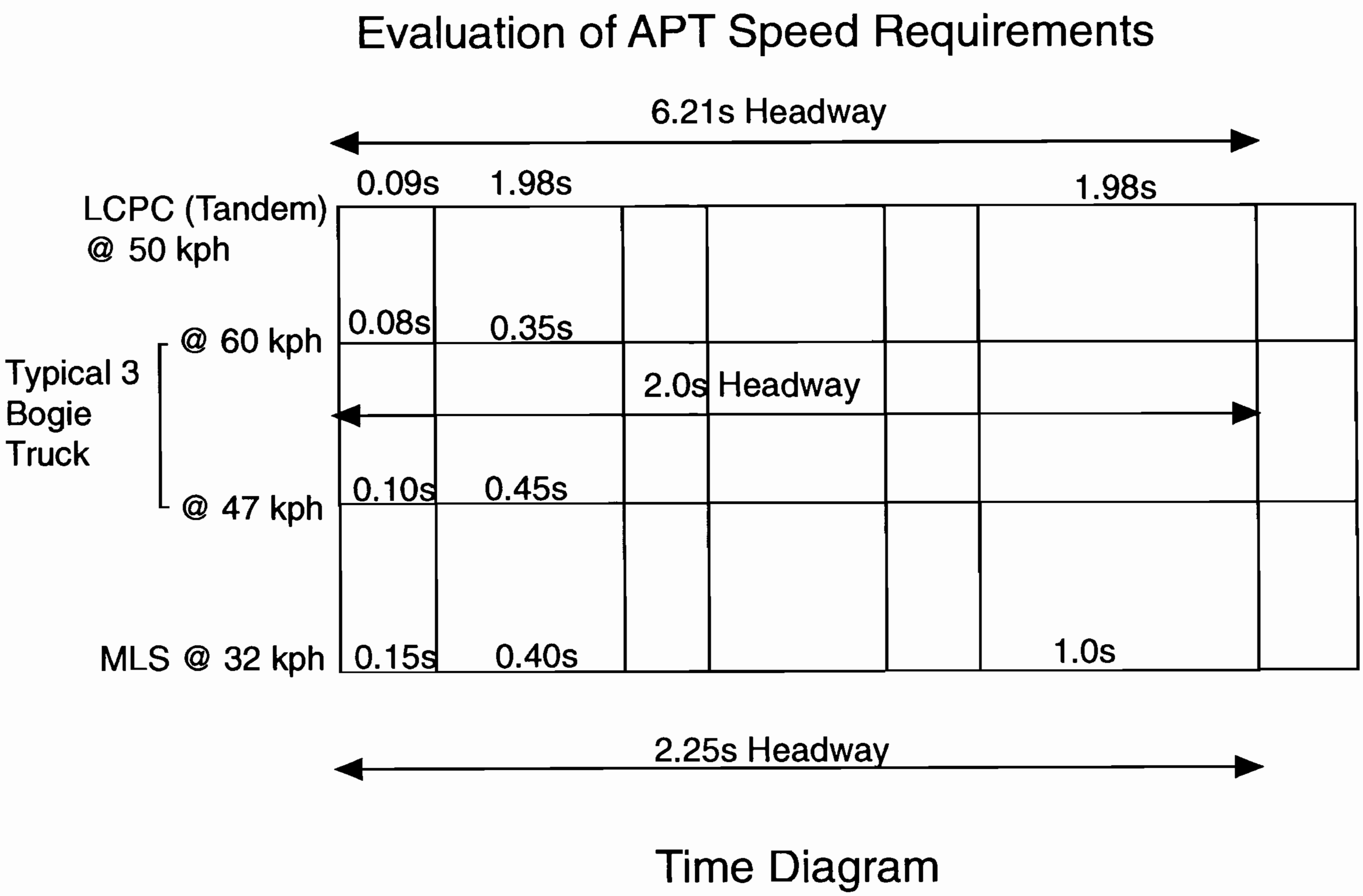



Figure 2-3

*Typical time delays between axle applications* truck might have 2.0 seconds headway, the MLS has 2.25 seconds, and the French system is 6.21 seconds. Again, the MLS provides an excellent simulation of the loading rate of an actual truck.

Full-scale testing of pavement response at different speeds also confirms the fact that it is not necessary to test at a speed higher than 20 mph (32 kph). Figure 2-4 shows the results from the Spanish test facility, where they were actually measuring deflection relative to speed. These results shows that deflection tends towards an asymptote as the speed is increased.

There are various ways to consider the aspect of speed versus deflection, but there is a separate response at crawling speed and another response at higher speeds. Therefore, it is a question as to what the testing is to accomplish. In this regard, one has to consider the characteristics of the machines under consideration. For example, the Purdue linear device is in the very slow range, whereas the Spanish and MLS devices are in the higher speed range. However, the MLS has the capability to operate in the 8 mph range without the significant loss of productivity that the racetrack options would have.

The CTR analysis thus concluded, for the above two reasons, that there is no need to consider going to a speed higher than 20 mph (32 kph). Going to a speed higher than 20 mph (32 kph) is possible with the MLS design, but has the penalty of the increased weight necessary to resist increased centrifugal forces.

### *Wheel Dynamics*

Wheel load dynamics was a high priority need that is very important in selecting an APT device. In fact, the Phase I report devoted an entire chapter to the applicability of load wheel dynamics to APT devices and to a comparison of the simulation with real life. Wheel load dynamics simply means that you need to have speed and mass, which are interacting with specific degrees of freedom. In the application of these loads, you therefore have to have a system which equates to a truck on real roads.

There are different ways of dealing with dynamics. However, when applying a dynamic wheel load, the response and the performance are related. This must be taken into account when analyzing the test results. One of the reasons that some of the researchers have purposely removed the dynamics from the system is because it's less complicated to do the analysis without the dynamics. They simply have a rolling wheel that equates to a static load at different speeds. The fact that it rolls does provide the added advantage of a transient load, which is important when considering residual stresses.

While simulating the load more accurately, with the device, renders the situation more complex, it is more real. It is a pay-off that has potential for real gains in knowledge. It is of course feasible to artificially generate, in a linear device, the dynamic loading by using some form of electro-hydraulics, but this method is not considered cost effective with the use of actual rolling wheels at this time. The decision has to be made, in selecting an APT

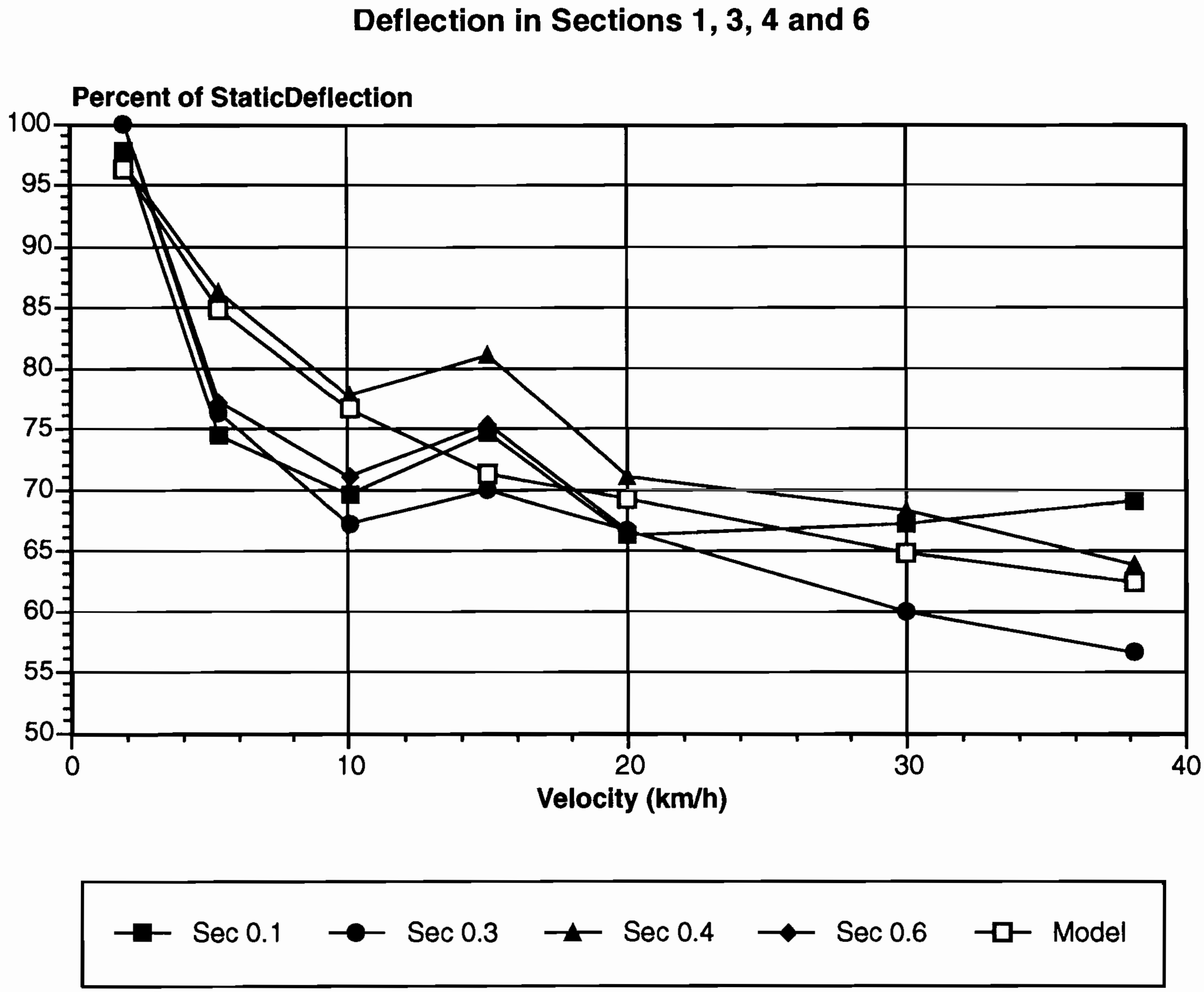



Figure 2-4

*Measured deflections vs. velocity at CEDEX facility* device, whether you want to simulate field conditions or not. It is evident that this has a bearing on whether you will be able to simulate longitudinal rutting and riding performance as it develops under actual traffic loads.

### *Braking Simulation*

Braking simulation is another element of wheel dynamics. At this time, braking simulation is not considered feasible for use as a test mode in any of the devices. Braking simulation in this context does not mean stopping a device by using some form of braking. Braking simulation is the repetitive deceleration, stoppage, and acceleration on the test section (related to the problem of shoving or surface wear). However, the very nature of braking simulation is in direct contrast with the normal APT goal of achieving as many axle load repetitions as possible.

Braking simulation, initially considered a possibility for the MLS, proved to be too expensive. If braking simulation is a high priority need, consideration should be given to building a special device to simulate it. We do not recommend trying to include braking with any of the options discussed in Chapter 3.

### *Testing in Different Geographic Regions*

The ability to test in varying geographic regions was rated as a high priority need by the Advisory Committee. This was somewhat surprising, since the emphasis had always been on a fixed-facility location. The important thing in meeting this need is the ability to physically take the machine to the area, or the ability to *"bring the area"* to the machine. In essence, there would be a need to test pavement performance in various locations in Florida if the APT had some form of mobility.

FDOT may not want this capability immediately. However, there is some utility in having a mobile device. Flexibility can be important in a research testing program, since research often leads to additional questions and ultimately to additional testing to find the solutions.

Clearly, linear devices can be made mobile. The MLS and the HVS were designed as mobile machines. But the Spanish facility is, by its nature, not a mobile machine. There is not a need to keep the MLS a mobile device. It can be designed for fixed operations only, or it can be designed such that trailers for a mobility option can be purchased at a later time when a requirement exists. In conclusion, the MLS device is flexible, but some of the options are mobile and some are not. It may be a cost-effective plan if an MLS device were chosen--its added mobility could prove important in the future.

## OTHER CONSIDERATIONS OF APT TESTING

The following aspects, closely related to the FDOT needs, should also be considered.

### *Measurement of Response and Performance*

With an in-service pavement, it is very difficult to install any device in the pavement. Therefore, it is customary to measure surface response and in-depth deflection only. Temperature gages can also be installed. The pavement performance is then monitored as the testing progresses. It is particularly difficult to simulate riding quality in short test sections. Depending on the length and shape of the test section, the performance measurements may be considered either fully equivalent or only partially equivalent to that of an actual pavement.

With controlled conditions such as a fixed site, the test sections are normally specially constructed. This permits strain and stress gages to be installed as well as other devices for monitoring and measuring pavement response. The following information can be monitored or measured when testing in-service pavements:

- Wheel load
- Load applications
- Speed
- Lateral distribution
- Surface deflection and curvature
- Surface profile (longitudinal/lateral)
- Elastic deflection of various pavement layers
- Plastic deformation of various pavement layers
- Material degradation
- Tests to determine structural integrity, e.g., shear strength, density, wave propagation, and cracking
- Material temperature, air temperature, and rainfall

FDOT will have to decide which of the responses and the performance characteristics it wishes to monitor. In addition, it is apparent that strain measurement is presently more easily done with the use of a fixed site. However, it should be understood that either fixed sites or in-service pavements can provide an excellent subject for the application of APT.

### *Use of the Model MLS*

As was discussed earlier, the number of variables that can be studied with APT devices is approximately ninety. Because of this the possibility of using scale models of the MLS to augment the full-scale APT devices is being explored. For example, it may be a cost-effective plan to design a complete factorial experiment (which is fully tested) with a less expensive model MLS and a partial factorial experiment to verify calibration with a full-scale device. The use of the model was further validated recently when Arizona State University purchased a model MLS. Their research findings should serve as an important additional database for this type of testing.

It must be clearly understood that the model testing is being done as a closed-loop system, i.e., engineering parameters of the model test pavements are, for example, being measured by conventional tests. These then serve as the basis for evaluating the pavement response and performance. In this way a basis for validation is being developed. In due course it should be possible to relate the results of the model machine and the full-scale machine. First steps have already been taken in this regard and some of the work has been reported. [1]

## CONCLUSIONS

1. The three APT devices provide for FDOT's needs to varying degrees, with the linear device limited in its ability to test all types of pavement structures.
2. Environmental control should be used for any proposed FDOT APT facility.
3. Braking simulation was found not to be cost effective for general purpose APT devices.
4. Testing speeds in excess of 20 mph (32 kph) are unnecessary for vehicle simulation in APT devices.
5. It is apparent that the devices capable of providing a high volume of standard axle applications have a distinct advantage.
6. The capability of using the Model MLS to augment full-scale APT testing should be further explored.

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[1] (Van der Merwe, Chris J, Hecther L Theyse, Emile Horak, Fred Hugo & Joseph A du Plessis, Evaluation of the rehabilitation design of a BTB pavement and the effects of artificial aging using accelerated wheel load testing, Proceedings of the 7th International Conference on Asphalt Pavements, Nottingham, 16-20 August 1992, Vol. Three, pp. 356-379).

# CHAPTER 3. APT DEVICE OPTIONS

In accordance with the instructions of the Advisory Committee, the Center for Transportation Research examined three accelerated pavement testing devices for Phase II of the study. Those three devices included the Texas Mobile Load Simulator, a Spanish CEDEX-type test track, and a small linear device comparable to the Purdue University APT.

In assessing the devices in terms of the needs of the Florida DOT, the Center for Transportation Research presented seven options for the Advisory Committee to review. (These seven options were developed to study alternatives to the Texas MLS and Spanish Racetrack. Because the small linear facility has great difficulty in meeting the needs of the Florida DOT, only one option was fully developed for this type of device.) This chapter discusses the seven options.

The Center for Transportation Research team personally observed the operation of the three devices during both Phase I and Phase II. The visit to the CEDEX facility in Madrid, Spain included a comprehensive review of the new modifications in progress at that time. These modifications included the replacement of the original testing device with two improved testing devices which are to be operated simultaneously on the CEDEX test track.

Options 1 and 4 are existing facilities on which there is an extensive amount of data. Additional data on Options 1 and 4 (the Texas MLS and the CEDEX facility) are presented in Phase II— Appendices B and C, respectively.

## OPTION 1: TEXAS MOBILE LOAD SIMULATOR

The first option is to purchase the Texas Mobile Load Simulator exactly as being built by Texas DOT (see Figure 3-1). There are several advantages in purchasing an MLS which is an *exact* duplicate of the TxDOT machine:

1. No additional engineering costs would be required.
2. This option would result in the fastest delivery of the device to Florida DOT.

The MLS, as is being fabricated, has been designed for a *normal* operating load and speed of 34,000 lb at 20 mph. The design *maximum* load and speed was set at 43,000 lb at 25 mph. The suspension purchased by TxDOT for the Texas MLS is a Rayco 4-spring heavy-duty suspension rated at 38,000 lb. Rayco does make heavier suspensions that have the same wheelbase dimensions as the current Texas MLS bogie suspension, including a suspension rated at 44,000 lb on a tandem axle. Because the manufacturer has designed the MLS to accommodate the 43,000 lb load at 25 mph, the device would be capable of sustained operations using 44,000 lb tandem axle loads at 20 mph. An upgrade

*Figure 3-1*

to the Rayco 4-spring heavy duty suspension (rated at 44,000 lb tandem axle loads) would not require a redesign of the MLS.

At this writing, the TxMLS is a working prototype. It is currently capable of a maximum continuous speed of 13 miles per hour (5700 axles per hour) and a peak speed of 16 miles per hour (7000 axles per hour). Even at these speeds the TxMLS is the most advanced APT device, capable of combining a high application rate with high fidelity load simulation.

In order to achieve the original design speeds of 20 miles per hour continuous, and 25 mph peak, the TxMLS is undergoing a modification to replace the AC motors and controllers with DC motors and controllers. This modification will be completed in May 1994 at which time the TxMLS is planned to be fully operational.

The advantages of Option 1 (the Texas MLS) are the following:

1. High axle production rate.
2. Acceleration without overloading.
3. Excellent simulation of truck loads.
4. Uses standard truck tires, suspension, and axles.
5. Variable load, speed, and suspension.
6. Can be operated as mobile or fixed site.
7. Capable of full axles.
8. Experience shared with TxDOT in operations and testing.
9. No additional engineering costs.
10. Fastest delivery to Florida DOT.
11. Low cost per axle.

The disadvantages of Option 1, (the Texas MLS), are the following:

1. No environmental control.
2. Cannot exceed 44,000-pound tandem axle loads.
3. Cannot exceed 20 mph at 44,000-pound loads.
4. Requires attended operation.

A detailed description of the Texas MLS as being constructed is provided in Appendix B. The specifications of this option are described in Table 3-1.

*TABLE 3-1 OPTION 1*

| | |
|---|---|
| Speed | 8-25 mph |
| Load | 10,000 - 43,000 lb per tandem axle |
| Load Mechanism | Adjustable spring |
| Axles | Full tandem axles |
| Suspension | Variable, 4-spring (normal) |
| Test Section Length | 36.5 feet |
| Environmental Control | None |
| Production | 8,800 axles per hour @ 20 mph<br>11,000 axles per hour @ 25 mph |
| Tires | Normal, low profile, super single |
| Total Weight | 260,000 lb |
| Mobility | Truck-driven trailers |

## OPTION 2: THE 44-KIP MLS WITH ENVIRONMENTAL CONTROL

This second option for the MLS is basically an upgrade to the Texas MLS (as being fabricated) to include environmental control and engineering design for a 44,000 lb rated 4-spring Rayco Suspension. The geometry remains the same as that in Option 1.

The modifications required for the current MLS design would include the following items: the development of an environmental control system to change temperature and humidity within the MLS structure; additional insulation within the MLS structure to reduce environmental conditioning operating costs; and additional engineering to accommodate higher design loads. The heavier loads and a 44,000 lb rating on the suspension would require some redesign of the MLS if the requirements are kept similar to the requirements set forth by TxDOT (e.g. operation at 25 mph with a 25-percent overload of a 44,000 lb design load).

If the 44,000-lb rated suspension was used, and if overloads beyond 44,000 lb and speeds greater than 20 mph are specified by Florida DOT, then significant additional redesign would be required. If Florida DOT specified a 44,000 lb maximum load and a 20 mph maximum speed, only minor redesigning of the loading system would be needed in order to accommodate the slightly heavier fatigue loading. Strengthening structural components of the MLS would result in a small increase in weight for transport.

The environmental control system for this option of the MLS would use the structural shell of the MLS as an environmental chamber having additional insulation. The design could accommodate the insulation either on the outside or inside, depending on the actual temperature requirements. A system to spray water on the surface of the test sections can be developed easily. All components of the current MLS design have been designed with the possibility of a retrofit for water spray within the MLS structure. Figure 3-2 shows a sketch of a possible configuration for the environmental control system of the MLS in Option 2. All other components of the MLS would remain the same as in Option 1.

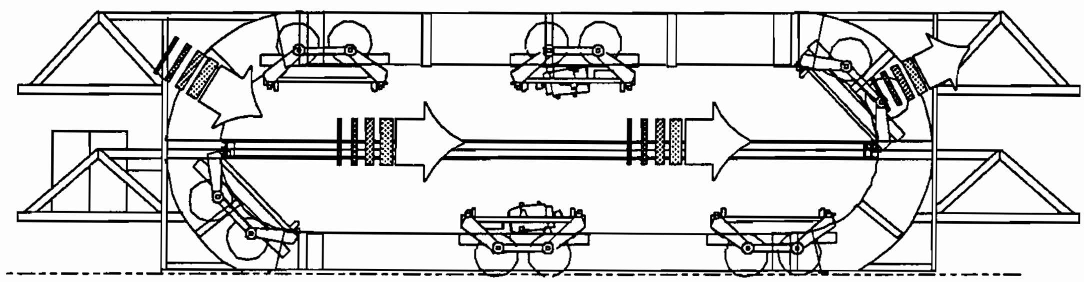


***Figure 3-2***
***Option 2 would include an environmental control system which uses the walls of the MLS as an environmental chamber.***

The advantages of Option 2 (44-Kip MLS) are the following:

1. High axle production rate.
2. Acceleration without overloading.
3. Excellent simulation of truck loads.
4. Uses standard truck tires, suspension, and axles.
5. Variable load, speed, and suspension.
6. Can be operated as mobile or fixed site.
7. Capable of full axles.
8. Experience shared with TxDOT in operations and testing.
9. Low engineering costs.
10. Quick delivery to Florida DOT.
11. Capable of full environmental control reasonably priced.
12. Low cost per axle.

The disadvantages of Option 2 (44-Kip MLS) are the following:

1. Heavier transport weight (to resist the 44-Kip loading).
2. Requires attended operation.
3. Maximum testing speed of 20 mph.

The specifications of this option are described in Table 3-2.

*TABLE 3-2 OPTION 2*

| | |
|---|---|
| Speed | 8-25 mph, 20 mph normal |
| Load | 10,000 - 50,000 lb per tandem axle |
| Load Mechanism | Adjustable Spring |
| Axles | Full tandem axles |
| Suspension | Variable, 4-spring (normal) |
| Test Section Length | 36.5 feet |
| Environmental Control | Temperature, humidity, surface water spray |
| Production | 8,800 axles per hour @ 20 mph<br>11,000 axles per hour @ 25 mph |
| Tires | Normal, low profile, super single |
| Total Weight | 275,000 lb |
| Mobility | Truck-driven trailers |

## OPTION 3: EXTENDED LENGTH MLS

This third option is a major redesign of the MLS for extended length and fixed site operations only. This option has been developed to accommodate the Florida DOT's need for testing longer sections. The potential advantage of a 72-foot test section is that it may be possible to measure the change in skid resistance in the test section, or possibly improve the measurement of the roughness or the serviceability index of the test pavement.

Longer test sections are also favored because (1) they allow the contractor to construct a longer section, and (2) they provide a better representation of actual field construction techniques. But while test sections can be constructed to whatever lengths desired, the length that is actually tested need not be longer than necessary to determine performance of the test section. Thus, a 72-foot test section could be tested just as quickly on two 36-foot sections (with some downtime required for maintenance or measurement of the test sections).

The large mass of the bogies traveling at 20 mph creates large centrifugal forces within the MLS structure. These forces would be especially problematic for an extended length machine (unless a mid span support was used). Since it is necessary to keep the stresses on the MLS structure very low (to resist the cyclic fatigue loading), it may be cost prohibitive to increase the length to a 72-foot test section without a center support structure. The current MLS design spans 62 feet during operation and 84 feet during transport for its 36-

foot test section. Adding an additional 36 feet of span to those conditions would require either higher strength steel, much larger cross sections, or both. Only detailed engineering analysis can answer the question of how best to accomplish this span length and what the additional cost would be.

The disadvantage of a center support structure is the potential stress and strain it can introduce onto the test pavement. A layered elastic theory analysis of the deflections and stresses for the current MLS indicated that the supporting jacks must be kept at least 10 feet from the test section. Not only could this present some problems at the mid-span support; it could also hamper the ability to construct test sections on adjacent paving lanes.

Another disadvantage of a center support section is that the jacks on the MLS are used to level the structure and make small adjustments to keep the desired load on the test pavement. It is far easier to adjust loading and leveling on a four-point base system than on a six-point base system.

Another important disadvantage of the extended test section MLS is the production capacity. If only six tandem axle bogies are used, the production rate will be reduced by 33 percent. Maintaining the same level of production of the standard MLS at 20 mph would require adding four additional tandem axle bogies. Adding additional bogies increases complexity to the control system, the structure, and the electrical power and instrumentation system.

The environmental control system for this option would be the same as that in Option 2. However, with the increased length comes a 71-percent increase in volume inside the MLS structure. Thus the size and cost of the environmental control system increases.

This extended-length version of the MLS would be used for fixed site operations only. Some advantages of fixed-site-only operations are the following:

1. The MLS need not be split into two halves (except during initial construction). Consequently, the jacking system must raise the MLS to a height of only 6 feet to permit the removal of bogies. The current MLS designs require the MLS jacks to raise the top half of the MLS to a height of 14 feet for field assembly.
2. The purchase of highway trailers and dollies can be simplified for shorter distances and would not be restricted to meeting geometric limitations for highways. A temporary rail system could be developed for moving the MLS laterally. Figure 3-3 shows such temporary rails constructed in a machine shop to transport a welding machine.

The advantages of Option 3 (Extended Length MLS) are the following:

1. High axle production rate.
2. Acceleration without overloading.
3. Excellent simulation of truck loads.

4. Uses standard truck tires, suspension, and axles.
5. Variable load, speed, and suspension.
6. Capable of using long test sections.
7. Capable of full axles.
8. Experience shared with TxDOT in operations and testing.
9. Capable of full environmental control reasonably priced.

The disadvantages of Option 3 (Extended Length MLS) are the following:

1. Fixed-site operations only.
2. Maximum operating speed of 20 mph.
3. Requires center support to span the longer test section length.
4. Ten bogies required for equal production.
5. Increased maintenance and increased initial cost.
6. Maximum load of 44,000 tandem axles.

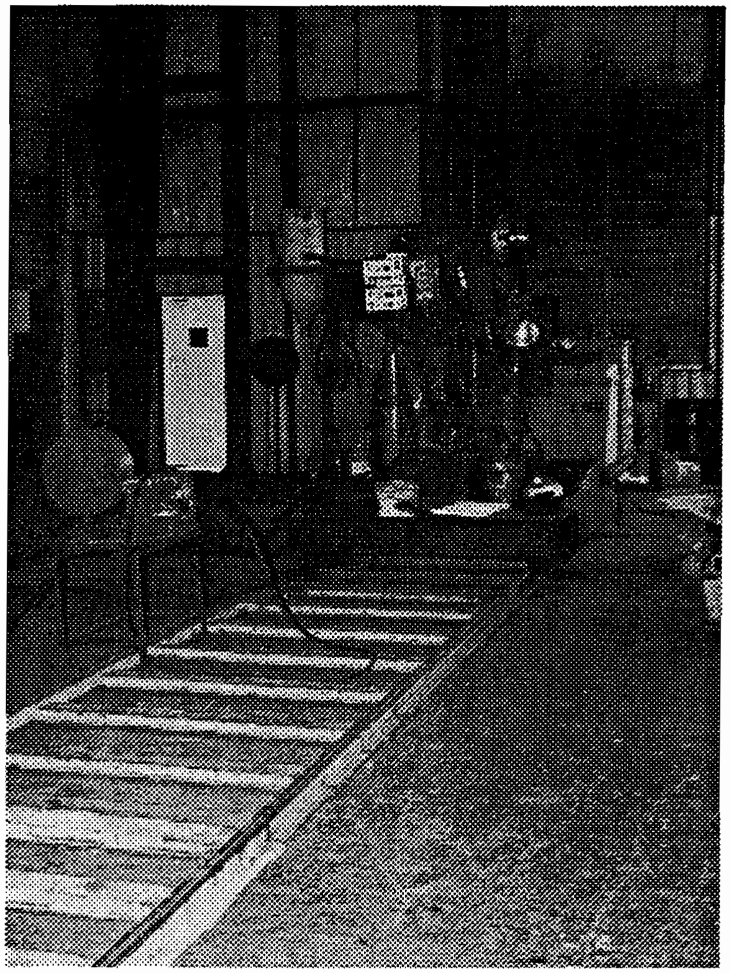


*Figure 3-3*
*An example of using temporary rails for the transportation of a large machine.*

*Figure 3-4 is a sketch of the Extended Length MLS with additional bogies. The specifications for this option are described in Table 3-3.*

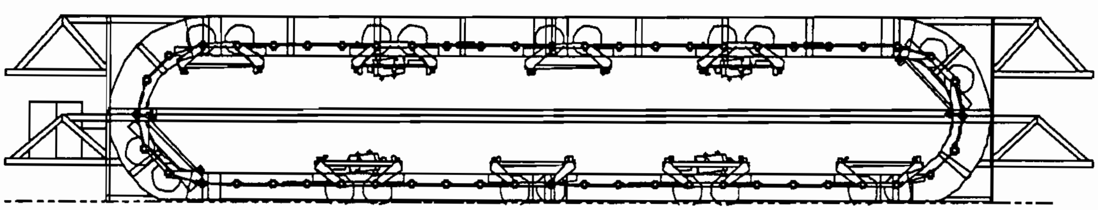


*Figure 3-4*
*Option 3 includes an extended-length version of the MLS.*

*TABLE 3-3 OPTION 3*

| | |
|---|---|
| Speed | 20 mph |
| Load | 10,000 - 44,000 lb per tandem axle |
| Load Mechanism | Adjustable Spring |
| Axles | Full tandem axles |
| Suspension | Variable, 4-spring (normal) |
| Test Section Length | 72 feet |
| Environmental Control | Temperature, humidity, surface water spray |
| Production | 10,500 axles per hour (10 bogies)<br>5,870 axles per hour (6 bogies) |
| Tires | Normal, low profile, super single |
| Total Weight | Approximately 400,000 lb |
| Mobility | Special tow vehicles |

## OPTION 4: SPANISH CEDEX FACILITY

This option is basically a duplication of the test track and device built by the Center for Road Research in Madrid, Spain. This facility, built after many years of design, opened in 1987 with a single load device using single half axles, as shown in Figure 3-5. Recently the track was modified to include two new devices which are a little more rugged and capable of loading tandem half axles. Specifically, this option is to build in Florida a test track similar to the CEDEX track, with one load device capable of loading a tandem half axle. The load device would be similar to, or a duplicate of, the new Spanish load device.

*Figure 3-5*
*The original CEDEX testing device.*

The basic configuration of the CEDEX device consists of the new gravity loaded machine (as shown in Figure 3-6) powered by an electric motor, which is guided around a 984-foot (300-meter) test track on a concrete rail. The actual loaded portion of the device is cantilevered out over the test section, while the main portion of the device straddles the concrete rail. The device rides the rails in the vertical and horizontal directions on rubber truck tires. It is capable of wander in the traffic lane by varying the amount of the cantilever in the load device.

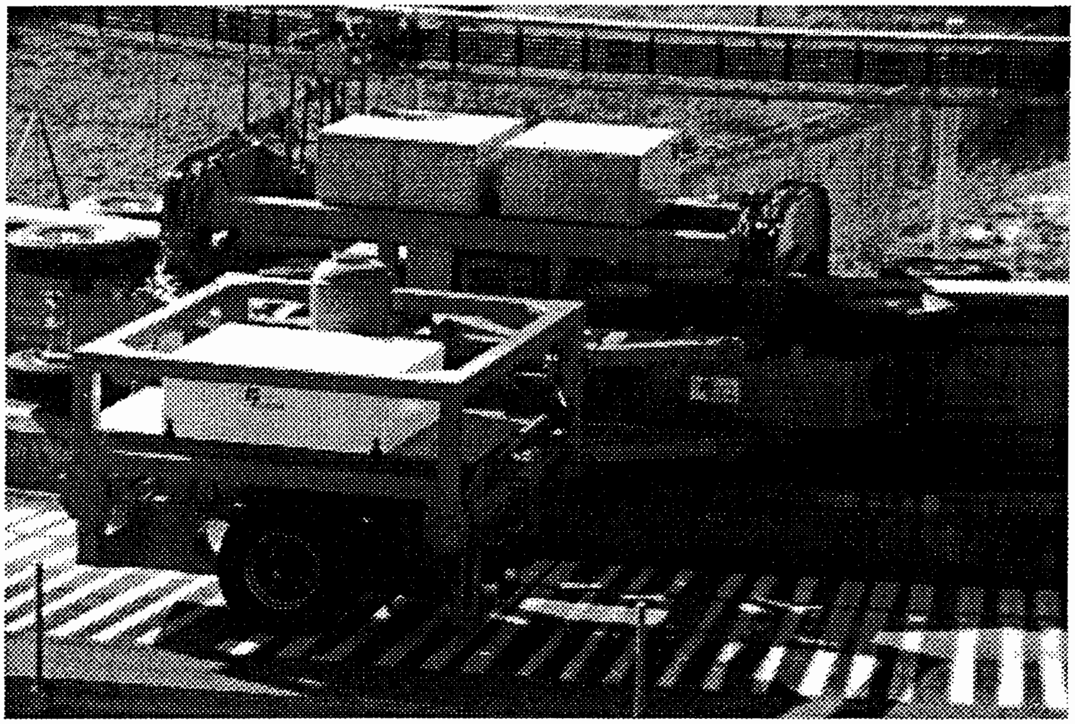


*Figure 3-6*
*The upgraded CEDEX testing device.*

Another possibility for production improvement of the Spanish option is to reduce the size of the test sections from 66 feet (20 meters) to 33 or 49 feet (10 or 15 meters). The TxMLS test sections are a minimum of 36.5 feet (11 meters) of tested pavement; however, a longer section must be constructed to avoid end or edge effects. Reducing the test track test sections to 33 feet (10 meters) would permit up to 12 sections on the test loop. It is important to note, however, that the roughness induced in the device from one section may carry over into the next section, possibly invalidating the results. Also, with 12 test sections, construction time would be longer, instrumentation time would be longer, and total downtime for construction and maintenance would be longer. Consequently, doubling the number of test sections on the track may not double productivity. For optimal commercialization, the test lengths should be studied carefully.

The operation of the CEDEX device is such that six test sections are tested at once. However, all testing must stop for repairs, construction, or measurement of any of the test sections. Therefore, production is a significant concern with the CEDEX device. Subsequent options will try to improve upon the production rate of this basic option.

A complete description of the Spanish CEDEX facility, along with the ongoing upgrades, is presented in Phase II—Appendix C. Basically, this option would design and build a facility and load device as close as possible to the system in place in Spain. The Spanish have been very cooperative in providing information on the facility.

However, constructing a duplicate facility in Florida would require additional engineering and cooperation in order to build a device and facility which meets U.S. and Florida specifications. Electrical equipment, control systems, and dynamic analyses will all have to be redesigned for a Florida application. One advantage of this option is that the device has been reliable through five years of testing. Obviously, through lessons learned, the improved model device has been built to withstand more fatigue loading.

The advantages of Option 4 (Spanish CEDEX Device) are the following:

1. Acceleration without overloading.
2. Unattended operations.
3. Capable of using long test sections.
4. Capable of testing six sections at once.
5. Experience shared with CEDEX in operations and testing.

The disadvantages of Option 4, Spanish CEDEX Device, are the following:

1. Fixed-site operations only.
2. Slow production rate.
3. Must stop testing for construction and maintenance of any test section.
4. Uses only half axles.
5. No environmental control except water.

The specifications of this option are described in Table 3-4.

*TABLE 3-4 OPTION 4*

| | |
|---|---|
| Speed | 5-30 mph |
| Load | 10,000 - 22,000 lb per tandem half axle |
| Load Mechanism | Gravity load |
| Axles | Tandem half axles |
| Suspension | Air bag |
| Test Section Length | 6 @ 20 meters each |
| Environmental Control | Surface water spray |
| Production | 200 axles per hour |
| Tires | Normal, super single |
| Total Weight | Unknown |
| Mobility | Fixed site only |

## OPTION 5: MODIFIED SPANISH CEDEX FACILITY

Option 5, basically the same as Option 4, uses additional load devices to increase the rate of production, uses full axles rather than half axles, and adds an environmental chamber to provide varying test conditions. The engineers at the CEDEX facility have not been satisfied with the production of axle repetitions at the facility. Their principal mission has been to test the pavement designs that are available in the their catalogue of possible designs. The first test took three years to achieve the desired million axle applications. Their current solution involves the addition of two new load devices (shown in Figure 3-6) and retire the old load device. The machine is testing approximately 20-22 hours per day. With the old device, 2,500 axle applications could be achieved per day for each of the six test sections.

The upgrade in progress will provide two load machines operating at approximately the same speed as before. They plan to continue with single half axles (though the new devices are capable of tandem half axles). They also have left open the possibility of refurbishing the old load device and using it as a third loading device sometime in the future. The current cost of the upgrade is approximately $3 million, which includes the design and fabrication of two new loading devices, a new control system to handle the two devices simultaneously, and new electrical control rails for the two new devices (see Figure 3-7).

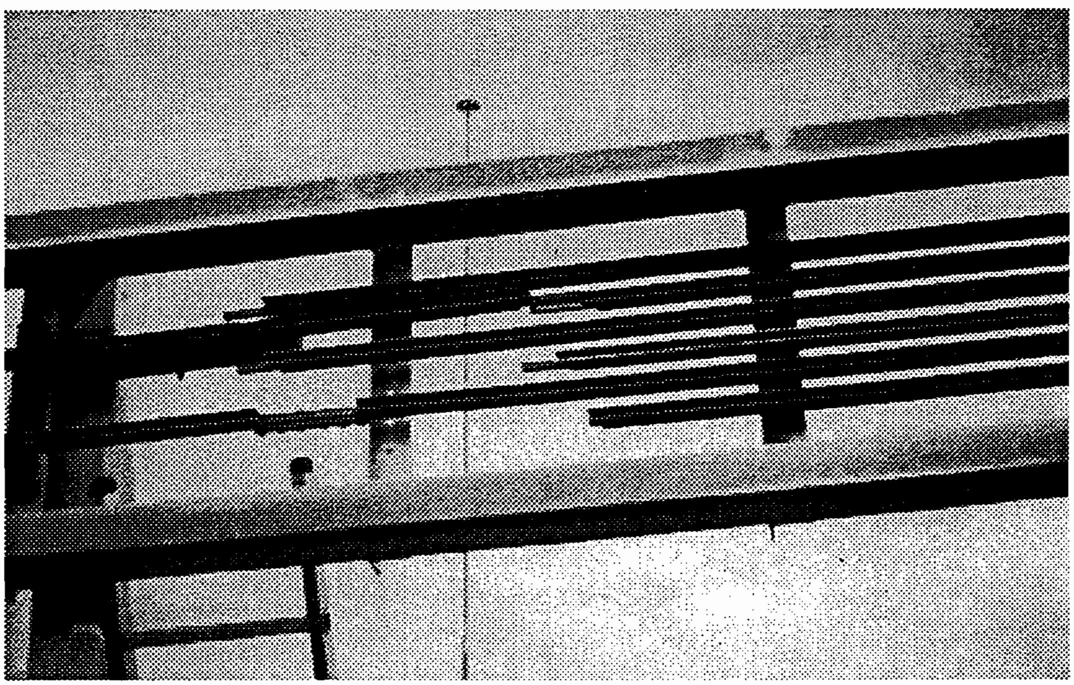


*Figure 3-7*
*New CEDEX power rails, capable of powering multiple testing devices.*

The rate of production of the Spanish-type facility is calculated with six test sections. This can be an advantage, since the number of axle loads applied can be increased sixfold by conducting six simultaneous tests. However, an inherent problem is that when the device is shut down for maintenance, repair, construction of a test section, testing of the pavements, or for any other reason, the delay is also for all six test sections. The current tests at CEDEX required the device to be idle for two months during construction of the test sections. The construction of some of the test sections with a cement-treated base and the installation of all the instrumentation consumed a significant amount of time. A significant downtime is currently being experienced as the facility is being upgraded to configure to the new load devices.

The enhanced design of a Spanish-type facility would use two load devices--each with a tandem full axle and each towing a tandem full axle loaded by gravity, as shown in Figure 3-8. The load devices would retain the design of a central concrete guide rail with cantilevered loading carriage using a gravity load. A portion of the track would be enclosed (as shown in Figure 3-9) in order to allow for the control of such environmental conditions as temperature and moisture levels.

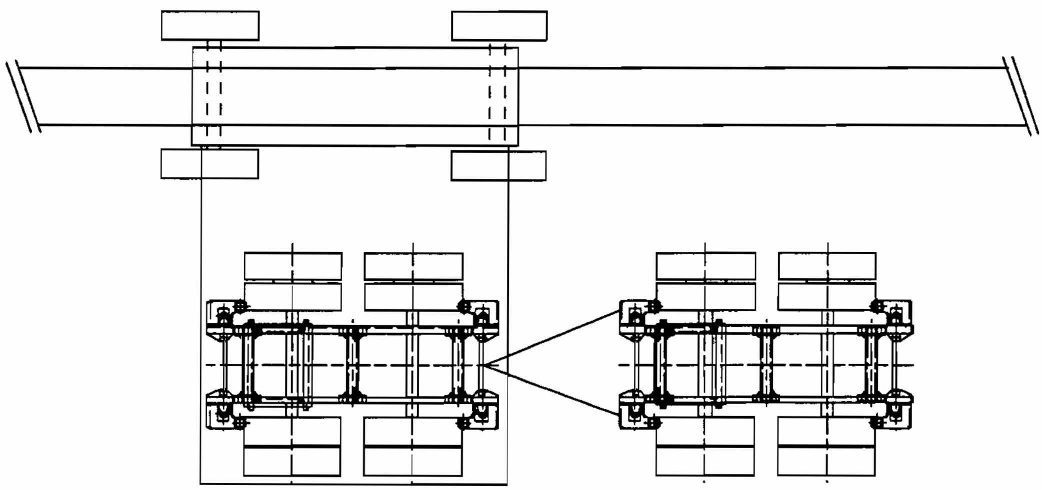


*Figure 3-8*
***Option 5 would include a new cantilevered device with a trailing bogie.***

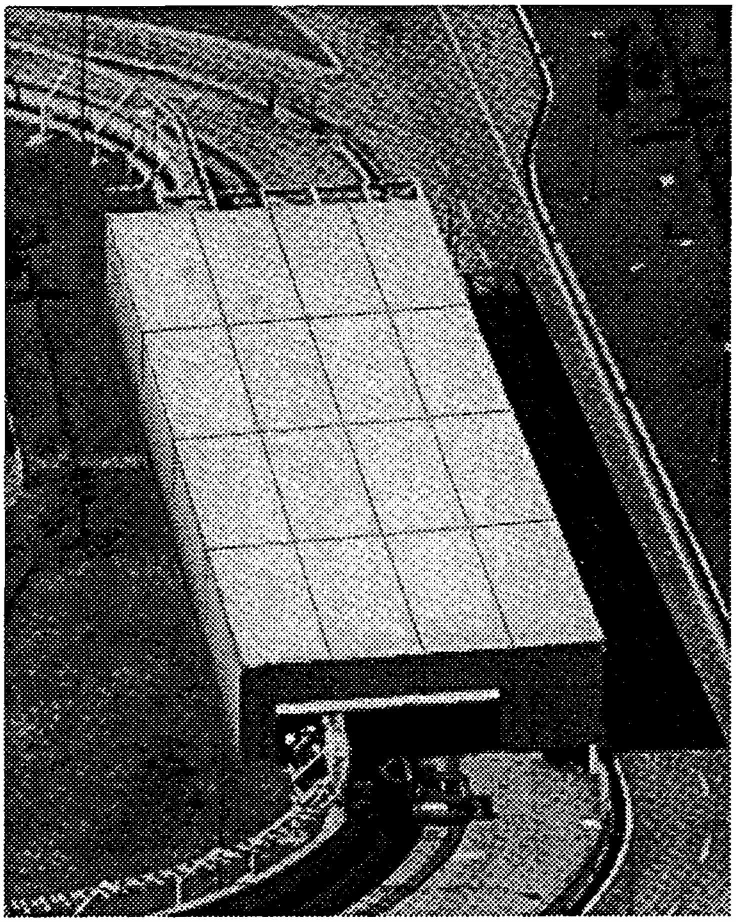


*Figure 3-9*
***Option 5 would add an environmental chamber to the CEDEX test track.***

A substantial engineering effort would be needed to design the full axle loading carriage, which would require additional electrical motor capacity. A device would be built to tow an additional loading carriage (also loaded by gravity). The unguided towed carriage would swing freely using only forward momentum to provide tracking behind the loading carriage. Superelevation in the curved sections would be required to keep the towed vehicle following correctly. There would be significant development and engineering efforts required to ensure the safety and loading characteristics of the enhanced design.

The advantages of Option 5 (Modified CEDEX Device) are the following:

1. Acceleration without overloading.
2. Potentially unattended operations.
3. Capable of using long test sections.
4. Capable of testing 6 sections at once.
5. Improved production rate.
6. Capable of full axles.
7. Capable of full environmental control.
8. Excellent simulation of truck loads.
9. Uses standard truck tires, suspension, and axles.
10. Variable load, speed, and suspension.

The disadvantages of Option 5 (Modified CEDEX Device) are the following:

1. Fixed site operations only.
2. Must stop testing for construction and maintenance of any test section.
3. Environmental control system is complex and expensive.
4. Requires two devices.
5. High initial costs.

The specifications of this option are described in Table 3-5.

*TABLE 3-5 OPTION 5*

| | |
|---|---|
| Speed | 5-30 mph |
| Load | 20,000 - 44,000 lb per tandem axle |
| Load Mechanism | Gravity load |
| Axles | Full tandem axles |
| Suspension | Air bag or 4-spring |
| Test Section Length | 6 @ 20 meters each |
| Environmental Control | Surface water spray, temperature, humidity |
| Production | 200 axles per hour per test section |
| Tires | Normal, super single, low profile |
| Total Weight | Unknown |
| Mobility | Fixed site only |

## OPTION 6: AUTOMATICALLY GUIDED VEHICLE FACILITY

This option is an attempt to reduce the cost of the Spanish racetrack-type facility by designing a totally new vehicle; operated automatically, this new vehicle would be capable of pulling additional tandem trailer axles to increase production rates. The idea behind this concept is this: Designing and constructing a custom test vehicle would be less costly than an attempt to duplicate the Spanish facility. The Spanish vehicle design has approximately 2/3 of the vehicle mass riding the monorail, with the test vehicle cantilevered out from the rail vehicle. In this system, the vehicle is constantly fighting against the monorail for guidance and propulsion. Obviously, there is a greater development cost involved in designing a custom vehicle, but the operating costs and the economics of a self-standing vehicle may be better suited to the task.

In examining several automatically guided vehicle concepts, the CTR study team has concluded that, if a race track concept is seriously considered, there may be vehicles more efficient than the Spanish vehicle. The common element in the automatically guided vehicle concept is a vehicle capable of towing additional full axle trailers around a test track. Speed should be kept to around 20 mph, since additional increases in speed would not reduce dynamic deflection enough to be significant, and also since the forces necessary to control and stop the vehicle increase with the square of velocity and linearly with mass ($F=mv^2$).

The vehicle could be either an existing truck chassis converted to remote guidance or a specially constructed chassis, as shown in Figure 3-10. The power plant could run on diesel, gas, compressed natural gas, propane, or electricity. While the fuel-powered vehicles are easier to design, the electric vehicles would probably be safer (though slightly more expensive to operate).

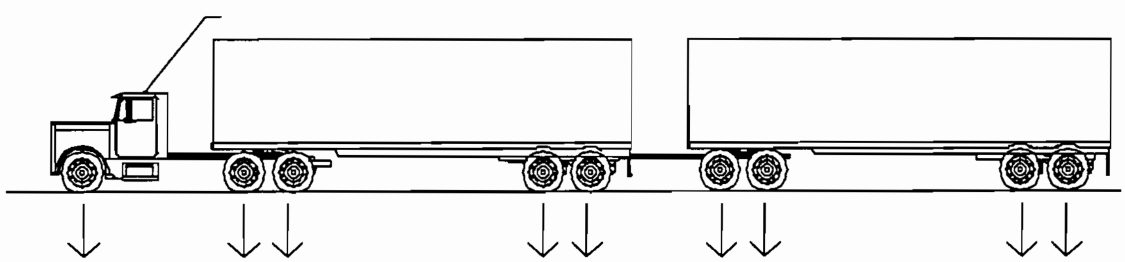


*Figure 3-10*
*Option 6 would include an automatically guided multi-axle vehicle.*

The control system could include an underground wire running through the center or through the shoulder of the test section pavement; wires could also be suspended overhead. Wires in the test pavement present special problems during and after construction and would probably add to the delay time in test-section construction. Wires suspended overhead require a supporting superstructure (such as the posts used in the Spanish facility for electrical pickup). If the power source was electricity, then a control wire could easily be incorporated into the design of an overhead electrical pickup at little additional cost.

VMW Industries has designed and built an automatically guided, propane-powered vehicle (guidance is provided by a wire running under or on top of the pavement. The vehicle, as shown in Figure 3-11, was designed to automatically drive airport baggage carts through a high powered X-ray device at a speed of 5 mph. The vehicle, which has been recently placed into service, was built for a cost of approximately $50,000.

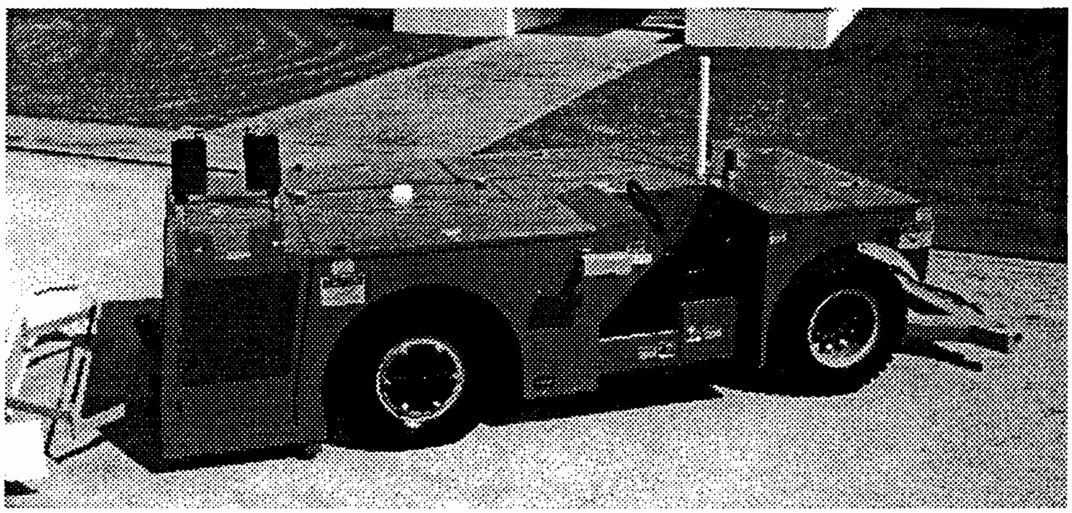


***Figure 3-11***
***Propane powered, automatically guided vehicle.***

The production rate of this automatically guided option is based on the number of vehicles, the number of towed trailer axles, the length of the track, the number of test sections in the track, and the speed of the vehicle. In order to achieve a production rate approximating that of the MLS, this option was specified using a single vehicle with a steering axle and tandem drive axle (simulating a typical truck). As shown earlier in Figure 3-10, the specified vehicle would also tow two trailers approximately 28 - 32 feet in length, with a total of three additional tandem axles. If the test vehicle was loaded to simulate current federal loading limits, the steering axle would have a 10,000-lb weight, and the four tandems would each weigh 34,000 lb, for a total vehicle weight of 146,000 lb. If the maximum loading was used, the vehicle would have a 12,000 lb steering axle and four tandems each weighing 44,000 lb, for a gross weight of 188,000 lb.

Using the 188,000-pound vehicle and 20 mph speed, the 300-meter Spanish test track can be used if a 10 percent superelevation around the curved sections of the track is included. The estimates for cost and production are based on such a configuration. Additional design costs are excluded, as are the costs for any additional safety equipment required at the track (such as concrete barriers to contain a vehicle which has left the control path).

The advantages of Option 6 (Automatically Guided Vehicle) are the following:

1. Acceleration without overloading.
2. Capable of using long test sections.
3. Capable of testing six sections at once.
4. Improved production rate.
5. Capable of full axles.
6. Capable of full environmental control.
7. Excellent simulation of truck loads.
8. Uses standard truck tires, suspension, and axles.
9. Variable load, speed, and suspension.

The disadvantages of Option 6 (Automatically Guided Vehicle) are the following:

1. Fixed site operations only.
2. Must stop testing for construction and maintenance of any test section.
3. Safety concerns of 188,000-pound automatically guided vehicle.
4. Environmental control system is complex and expensive.

The specifications of this option are described in Table 3-6.

*TABLE 3-6 OPTION 6*

| | |
|---|---|
| Speed | 20 mph |
| Load | 20,000 - 44,000 lb per tandem axle |
| Load Mechanism | Gravity load |
| Axles | Full tandem axles |
| Suspension | Air bag |
| Test Section Length | 6 @ 20 meters each |

| | |
|---|---|
| Environmental Control | Temperature, humidity, and surface and subsurface water |
| Production | 850 axles per hour |
| Tires | Normal, super single, low profile |
| Total Weight | 188,000 lb |
| Mobility | Fixed site only |

## OPTION 7: SMALL LINEAR FACILITY

This option is based on the Purdue and Indiana DOT Accelerated Pavement Tester shown in Figure 3-12. As was stated in Chapter 2, the Purdue device cannot meet all the needs of the Florida DOT. If the requirements were significantly downgraded (e.g. to just asphalt materials testing), or if the device were to serve only as a supplement to an accelerated pavement testing facility, then the Purdue APT might represent a viable option.

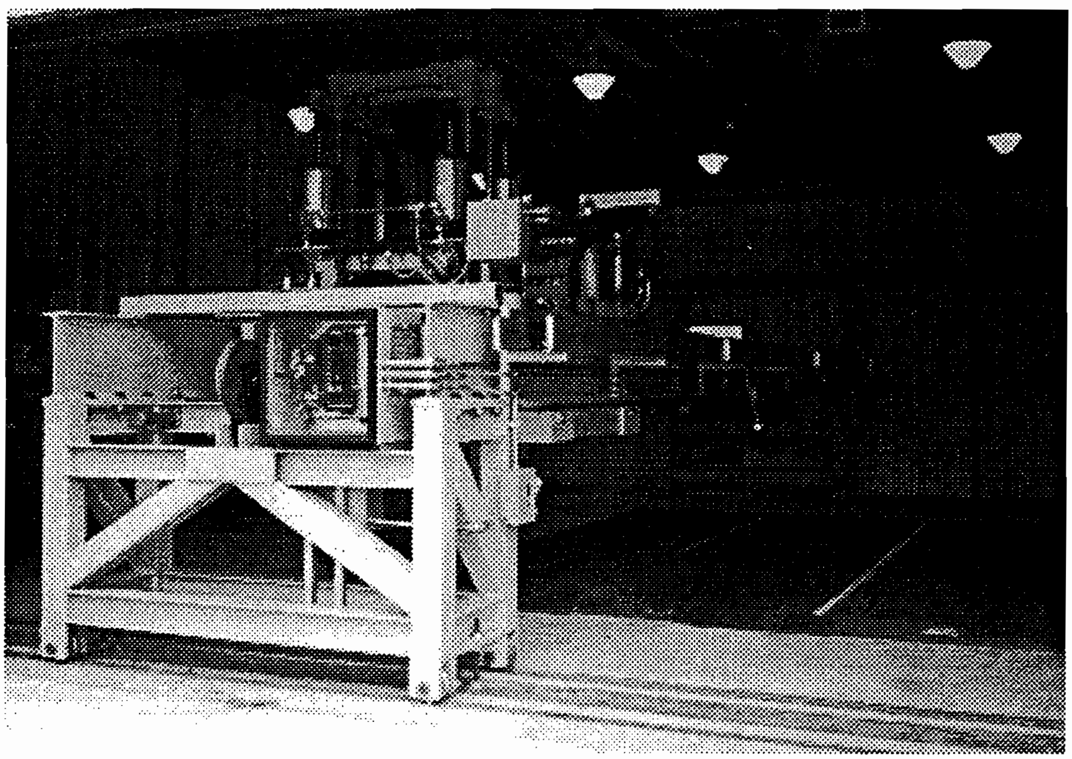


*Figure 3-12*
*The Purdue University linear testing device.*

The Purdue device was built by the University for a specific research project that tested one specific problem. It is currently being used to test the rutting performance of asphalt overlays over concrete slabs. The speed of the device is limited to 5 mph, in order to minimize the length required to start and stop inside the test facility. The Purdue device reaches 5 mph within 2 feet of travel, and stops within 2 feet of travel, which calculates approximately to a 0.45 g acceleration and deceleration, using a theoretical 9,000-lb mass.

Increasing the speed of the Purdue device to 20 mph would require either a significantly longer length or much greater acceleration and deceleration forces. Assuming the same 0.45 g loading and 9,000-lb mass, the length required to stop would be 32 feet on each end, with no increase in production rate. There are serious production rate limitations in any system which requires back and forth loading.

While the Dutch LINTRACK device operates at higher speeds and on longer test sections, its acceleration and deceleration effectively reduce the length of the test section by 2/3. Expansion of the Purdue device in reality becomes a LINTRACK device. The limitations of this device in terms of production rate, simulation fidelity, and Florida DOT needs have already been discussed in a previous report,

The costs reported for this option in the following chapter are based on commercially fabricating a Purdue-type linear device of the same size and capability. It is assumed that only asphalt materials will be tested. The building will remain the same approximate size as the Purdue facility, with the entire building being environmentally controlled. We must emphasize that although this option does not meet all of the Florida DOT requirements, it could be used as a material testing device. It would be an improvement to the test pits currently used for testing base materials at the Gainesville Materials Office.

The advantages of Option 7 (Purdue Linear Device) are the following:

1. Inexpensive.
2. Can be built indoors.
3. Simple to operate.
4. Can potentially be used for unattended operations.

The disadvantages of Option 7 (Purdue Linear Device) are the following:

1. Cannot test all pavement structures needed by Florida DOT.
2. Very low production rate.
3. Requires acceleration by environment or overloading.
4. Cannot test multiple axles.
5. Cannot simulate truck dynamics.
6. Limited speed capability.

The specifications of this option are described in Table 3-7.

*TABLE 3-7 OPTION 7*

| | |
|---|---|
| Speed | 5 mph |
| Load | 9,000 - 15,000 lb per single half axle |
| Load Mechanism | Mechanical spring |
| Axles | Single half axle |
| Suspension | None |
| Test Section Length | 20 feet |
| Environmental Control | Surface and subsurface water spray, temperature, and humidity |
| Production | 250 axles per hour |
| Tires | Normal, super single |
| Total Weight | Unknown (30,000 lb estimated) |
| Mobility | Fixed site only |

# CHAPTER 4. ECONOMIC ANALYSES OF THE OPTIONS

This chapter presents findings from the economic analyses of the seven proposed options. Several of the categories concerning costs were not applicable to every option. Other costing categories were applicable to each option equally—that is to say that items such as the test sections will be necessary, regardless of the option Florida DOT chooses, and the costs will be comparable for each option being considered. Other categories falling under this assumption are the maintenance and support facilities and the data acquisition system.

The cost categories included in the analysis are as follows: facility construction costs, data acquisition systems, environmental control systems, maintenance and support facilities, operating costs, staffing, production capability, and costs per unit production.

This chapter is organized in two parts. The first part discusses each option separately, with particular attention given to the specific device costs and how they were estimated. The second part is organized around Table 4-1, which lists the estimated complete facility and operating costs for each option. How the information in the table was used in the spreadsheet to perform the economic analysis of each APT facility is also included. The bottom line result gives the estimated annual budget and estimated cost per axle for each option.

## OPTION SPECIFIC COSTS

### *Option 1: The Texas Mobile Load Simulator*

Under Option 1, the Texas MLS device will cost approximately $2.1 million (as designed for TxDOT). This cost is based on an estimate from the current MLS designer, and on lessons learned during the design and fabrication of the device. The cost may be higher if the device were put to competitive bid. Under this option the TxMLS would have the capability of being used as either a fixed-site or mobile APT device.

The transport system is designed for the transportation of the MLS, from one testing site to another, at highway speeds. The transport system consists of two jeep trailers and two steerable dollies. The transport system has been designed and a contract has recently been awarded for approximately $240,000 for its construction. If the MLS is used as a fixed-site testing facility, the cost of transportation can be reduced; however, some transport system must be included to allow movement of the MLS between test sections. A conceptual drawing of an MLS fixed-site test facility is included in Chapter 5. This facility uses rails to locate the MLS on one of several test sections.

Table 4-1: Economic Analysis of APT Facilities

| 14-Dec<br>N/A = Not Applicable | OPTION 1<br>TxMLS | OPTION 2<br>MLS<br>44kip/Envir. | OPTION 3<br>MLS-Extended<br>Length | OPTION 4<br>Spanish<br>Facility | OPTION 5<br>Mod. Spanish<br>Facility | OPTION 6<br>Automatically<br>Guided | OPTION 7<br>Linear<br>Facility |
|---|---|---|---|---|---|---|---|
| **Facility Construction Costs:** | | | | | | | |
| A. Devices | ***$2,100,000*** | ***$2,310,000*** | ***$4,550,000*** | $2,147,000 | ***$4,794,000*** | $2,200,000 | $400,000 |
| B. Transport System (Mobile) | $240,000 | $240,000 | fixed site | fixed site | fixed site | fixed site | fixed site |
| C. Test Sections: ACP/PCC | $15,000 - $50,000 depending on materials and thickness | | | | | | |
| D. Test Track: Materials | N/A | N/A | N/A | $260,000 | $260,000 | $260,000 | N/A |
| **Data Acquisition System:** | | | | | | | |
| A. Non-consumable Hrdwr & sftwr | $75,000 | $75,000 | $75,000 | $420,000 | $420,000 | $420,000 | $75,000 |
| B. Consumable Hardware (Sensors) | $100,000 | $100,000 | $100,000 | $30,000 | $30,000 | $30,000 | $30,000 |
| **Environmental Control System:** | | | | | | | |
| A. Cost of structure | N/A | ***$60,000*** | ***$120,000*** | N/A | $400,000 | $400,000 | $20,000 |
| B. Cost of equipment | N/A | ***$60,000*** | ***$120,000*** | N/A | ***$450,000*** | ***$450,000*** | ***$125,000*** |
| C. Volume (cubic feet) | N/A | 12,400 | 19,600 | N/A | 165,000 | 165,000 | 18,375 |
| **Maint. and Support Facilities:** | | | | | | | |
| A. Buildings | Cost per square foot are approximately $110.00 per estimate from Innovation Park. | | | | | | |
| B. Aggregate Storage | Costs would be associated with each option and would consist primarily of costs of acreage. | | | | | | |
| C. Construction Equipment | Equipment necessary to construct test section. | | | | | | |
| **Operating Costs:** | | | | | | | |
| A. Electrical Power Consumption | $5,300 | $5,300 | $8,900 | $4,000 | $8,000 | $5,500 | $2,400 |
| B. Maintenance Costs | $40,000 | $45,000 | $61,700 | $45,000 | $64,400 | $45,000 | $9,000 |
| C. Staffing | $393,000 | $393,000 | $393,000 | $235,000 | $235,000 | $235,000 | $120,000 |
| **Production Capacity (axles/hr)** | 8800 | 8800 | 10500 | 200 | 850 | 850 | 250 |
| **(millions of axles/yr)** | 57.0 | 57.0 | 68.0 | 1.3 | 5.5 | 5.5 | 1.6 |
| | | | | | | | |
| **Fiscal Year Budget** | ***$1,079,600*** | ***$1,150,600*** | ***$1,634,500*** | $884,400 | ***$1,838,200*** | ***$1,270,000*** | ***$307,800*** |
| | | | | | | | |
| **Operational Budget / Fiscal Year** | $611,600 | $640,600 | $724,500 | $455,000 | $879,400 | $830,000 | $227,800 |
| | | | | | | | |
| **Costs Per Axle (cents)** | ***1.89*** | ***2.02*** | ***2.40*** | 11.37 | ***5.32*** | ***3.84*** | ***19.00*** |

* estimate includes cost for two testing devices

** items shown in bold italics are updated since previous publication

The operating cost of the MLS can only be estimated at this time, since construction of the full-scale MLS has not been completed. Items considered in the operating cost of the MLS include, but are not limited to, the following: maintenance of the diesel generator, fuel costs of the generator, maintenance and repair of the MLS device, user costs (if used in the mobile configuration), the costs of electricity to power the 200-HP motors, as well as the energy necessary to provide environmental control of the testing chamber. The staffing cost, as supplied by TxDOT, is included to give an example of the type of personnel required to operate the MLS as a mobile facility 24 hours per day in three 8-hour shifts. The production capability is once again presented in the spreadsheet for the purpose of calculating costs per unit production.

### *Option 2: 44-Kip Mobile Load Simulator*

Under Option 2, the Texas MLS device will cost approximately $2.31 million. This is the MLS as designed for TxDOT, with the added capability of operating normally at the higher 44,000-lb tandem axle loading. However, this cost figure does not include the cost of equipping and insulating the MLS for environmental control. Incorporating environmental control into the existing MLS will cost an additional $120,000. Under this option the TxMLS would have the capability of being used as either a fixed-site or mobile APT device, as in Option 1, but with the ability to vary the environmental conditions inside the testing chamber.

The transport system under Option 2 would be the same design as the MLS under Option 1. Again, the transport system would cost approximately $240,000. Fixed-site operation would reduce transportation costs by employing the system described in Option 1.

### *Option 3: Extended Length MLS*

There was some concern expressed by the Advisory Committee that a 35-foot test section would not be long enough. Their goal was to have the ability to pave, with a paving machine, a long test section free of end effects. Also, there was a concern about the ability to perform roughness and skid resistance measurements.

The longest APT test sections are those tested at the Spanish facility. The Spanish test sections incorporate a 20-meter (66 foot) test length. To our knowledge, there is no agency that conducts skid testing on APT test sections. Also, profile measurements can be used to calculate a serviceability index on smaller test lengths. It is neither feasible nor economical, with other than a test road, to actually use a rating panel to conduct ride ratings of APT test sections. Therefore, there is little to be gained from extended-length test sections. However, since it was identified as being desired in the needs analysis, the feasibility of extending the length of the MLS for a test length of 70 feet was studied.

The MLS structure was designed to span the length of the test section. To minimize the structure, the system was designed to keep the repetitive stresses of loading as balanced as possible. The design limiting forces are the centrifugal forces generated by the motor-driven bogies as they travel around the end ramps as resisted by the entire structure. As the speed of the MLS increases above 25 mph, or as the weight on the bogies increases above 34,000 lb, there are significant increases in the forces. The increase is not linear, since force is proportional to the mass times the square of velocity.

After an analysis of the feasibility of extending the length of the MLS to incorporate a 70-foot test section, CTR concluded that it was possible-- but with limitations and with a large cost penalty. Two limitations are that, economically, it must remain a fixed-site device, and it is weight limited for highway transport. It appears that a middle support would also be necessary, unless an additional cost penalty was applied to increase frame weight. This increase in weight, in addition to the weight added by increases in the length of the MLS, would also produce significant increases in the deflections located at the four supports. However, to reduce this effect, pilings, on which the device would be placed, could be installed. The cost estimate for the device assumes that the velocity would be limited to 20 mph. After discussing options with the MLS fabricator, CTR arrived at an estimated cost of $4.55 million for the extended-length MLS, including the use of ten bogies.

There are also increased materials costs for longer test sections. However, longer sections may be constructed with Option 1 or 2, with only a smaller portion of the section being tested. The cost of the data acquisition system and sensors remains the same as that for Options 1 and 2.

There is an additional cost in converting the MLS to accommodate environmental control (the extended length option has a greater volume which must be conditioned). The extended-length MLS would require conditioning of 19,600 cubic feet (versus 12,400 cubic feet for Option 2). Thus, the cost of insulating the extended-length structure was estimated at $120,000, with the cost of environmental conditioning equipment estimated at $120,000.

The cost of electrical power consumption and maintenance was increased based on a ten bogie operating system.

### *Option 4: Spanish CEDEX Facility*

Estimating the cost of the Spanish CEDEX device was not a simple task (the information, provided in Spanish, had to be translated). CTR is confident that the estimates are close to what could be expected if the facility was to be constructed in Florida. There are several options on how a device would be built for Florida DOT. While purchasing a device from the Spanish manufacturer is an option, there are disadvantages: the motors were designed for a different power system, and there may be limited availability of replacement parts in the United States; the standards to which the device has been designed may not conform to accepted standards in the United States; and there is also the problem of the specifications to purchase the device.

If the device were built in the United States to U.S. specifications, there would be significant re-engineering required. There were significant re-engineering costs incurred in the purchase of the FHWA ALF, including over $100,000 in travel to Australia, to change the ALF to U.S. specifications. The costs are based on an estimator's review of the complete drawings of the old Spanish CEDEX device.

The CEDEX device has a very complex mechanism that rides a concrete monorail and controls the cantilevered loading portion. The old device had a single half axle and, after five years, had some fatigue problems. The new device is capable of operating two half axles with one axle driven. The cost reported by CEDEX was $3,000,000 for the two new devices, including the control system and new power rails. VMW Industries reported that, based on the old device drawings, a similar device could be built for $1,537,000 for a single axle and $2,147,000 for a tandem half axle device. This estimate excludes freight to Florida. With this information, CTR used the $2,147,000 figure supplied by VMW.

### *Option 5: Modified Spanish CEDEX Facility*

This device differs from Option 4 in two ways: more axles are needed and an environmental conditioning system would be installed. The device selected for this option is a CTR conceptual design. It retains the portion of the Spanish device that rides the monorail but has a cantilevered portion that resembles the motor-driven, full, tandem axle bogie of the MLS. It also includes a tandem axle trailer which is gravity loaded. Both the driven and trailer unit are capable of 44,000-lb tandem axle loading.

VMW estimated that the cost of designing and building such a unit, with a control system similar to the MLS, would be $2.37 million. This option was upgraded to include two units operating simultaneously to provide an adequate number of axle applications. This assumes the same track size as the Spanish CEDEX facility operating at 20 mph, applying 850 axles per hour per device. Thus, the device costs are $4.79 million for this option.

The cost of data acquisition and instrumentation remains the same as that for Option 4. The cost of staffing was also assumed to remain the same. Because there are two devices, the electrical consumption and maintenance costs are also increased.

The cost of environmental control is added to this option. Several local contractors in Austin were contacted regarding the building of an environmental control facility for the Spanish track. The major technical problem involves constructing a door, or forced air curtain, that effectively controls inside temperature. It is not certain that the operating temperatures can be kept at close enough tolerances, but several contractors were willing to give probable estimates for such a chamber.

Based upon these estimates, and assuming a chamber volume of 165,000 cubic feet, the cost would be approximately $400,000 for three test sections (one side of the Spanish facility). Equipment necessary to control temperature in that same volume would cost approximately $450,000. These are not precise estimates, but are relative to estimates for the MLS.

### *Option 6: Automatically Guided Vehicle Facility*

The design of the automatically guided vehicle option was based on the simple recognition that the ultimate goal of APT is to simulate realistic truck loads on pavements. Why not design an automatically guided truck? It could use an actual or specially designed truck and trailer chassis. The technology involved in designing an automatically guided vehicle is both available and affordable.

The device, for cost estimation purposes, is assumed to be fuel driven (propane, compressed natural gas, or diesel). The option of converting to electricity exists, but would increase the cost. This option utilizes an automatic guidance system (i.e., guided by an underground wire located to one side of the test sections). The device is gravity loaded and would use truck parts. Four tandem axle bogies, loaded up to 44,000 lb and located behind a single steering axle, were added.

This option limited the device to 20 mph and required that the curved sections of the track be superelevated to minimize the control forces and keep the trailer axles in line around the curved sections. Higher speeds would increase device costs and complexity. CTR also assumed that a significant barrier would need to be constructed around the track for safety reasons.

VMW has recently constructed an automatically guided vehicle for $50,000 which operates at 5 mph. They are comfortable with both the technology and its estimated cost of $2.2 million. This cost is based on a single vehicle control system similar in complexity to the MLS. All other costs associated with this option are similar to those of Option 5 (except for maintenance, which is on one vehicle rather than two).

### *Option 7: Small Linear Facility*

The cost of the Purdue device, if it was purchased commercially rather than built in house, was estimated at $400,000. Even with enhancements, none of the linear devices can achieve production levels that meet Florida DOT needs. This option was priced out based on the existing Purdue/Indiana DOT device.

## ECONOMIC ANALYSIS OF APT FACILITIES

The best comparisons of the devices, especially if commercialization opportunities are being considered, involve test flexibility, the time to complete a test, and the bottom-line overall cost per axle load. The actual costs of the buildings, to include office space, laboratories, maintenance, instrumentation, support and control facilities, are important in the overall budgeting and planning. However, if the level of testing effort is nearly the same for each option, then the costs are essentially device independent.

Table 4-1 compares the costs associated with each of the options. The following section summarizes the costs included in the table and explains the assumptions that generated the bottom-line cost per axle. A brief explanation of the organization of this section is also in order. The headings and subheadings in this section coincide with the headings and subheadings incorporated in Table 4-1. This explains why the letters A, B, C, and D are used numerous times throughout this section. Thus, Table 4-1 and this section allow a comparison of the economic analysis of the APT devices.

### *Facility Construction Costs*

A. Devices. The cost for the devices is based on Victoria Machine Works' (VMW) experience in designing and constructing the TxMLS, along with their estimator's inspection of the drawings of the original CEDEX device. CTR worked with VMW to achieve estimates that were considered as detailed as possible under this study. The costs of the devices were based on 1993 dollars. The estimated costs provided by VMW for the MLS and AGV devices also reflect their current workload, along with their expertise gained in constructing the TxMLS.

B. Transport System (Mobile). Gerald McLelland, of McLelland Engineering, designed the MLS transport bogies for TxDOT. The transport bogies are designed to operate the two halves of the MLS at highway speeds. Some other special features were designed into the bogies such as steerable axles, and lifting mechanisms to clear unusual obstacles such as out of specification railroad crossings. The price includes transport bogies for the upper and lower halves of the MLS. The actual bid received for the transport bogies and dollies was $240,000. The costs of the jacks, which raise and lower the MLS, are priced as part of the device. If the device were to be used in a fixed facility the cost of the transport system to move it on-site would be significantly reduced.

C. Test Sections: ACP\PCC. As shown in the spreadsheet, the cost of a typical test section is between $15,000 and $50,000. This wide range exists because of the many variables possible in the design of a test section. Of all these variables, the type of material used influences the price the most. An ACP (asphalt concrete pavement) test section can be less expensive to construct than a PCC (portland cement concrete) pavement. The cost associated is important in any APT strategy. However, it is an expense incurred regardless of the APT device selected, and does not affect the overall comparison of the different APT devices. Therefore, CTR simply determined a range of testing section costs, deeming it unnecessary to perform a detailed cost analysis.

D. Test Track: Materials. The $260,000 presented in the spreadsheet, under the heading "Fixed Site Facility," refers to the estimated costs of the material necessary to construct the test track and was based on measurements taken from the CEDEX drawings. The calculated quantities and types of material included 3175 cubic yards of portland cement concrete and 670 cubic yards of asphalt concrete pavement. This conservative estimate of materials cost is based on figures quoted by CEDEX for the cost of their test track. The estimate does not include labor or any structures constructed at the facility. The cost of the test track material (for the racetrack devices) was included because the research team viewed this as a cost particular to the device. The majority of the cost is associated with the material necessary to construct the concrete monorail, which would require a substantial effort above and beyond that required of any other fixed-site facility.

### *Data Acquisition System*

A. **Non-consumable Hardware and Software**. The figure of $75,000 used for the MLS options was based on TxDOT's budget on their request for bids. The system consists of the hardware and software for an 80-channel system (16 high speed and 64 low speed) capable of 250,000 samples per second distributed over all 80 channels. The price quoted for the Spanish facility, $420,000, was based on information supplied by CEDEX. The type or quantity of equipment, on which the price was based, was not specified.

B. **Consumable Hardware (Sensors)**. The $20,000 per test section quoted by TxDOT includes approximately 40 sensors and 33-percent sensor redundancy. The sensors can cost as much as $750 each (for a Dynatest handmade gauge). In the spreadsheet the value calculated for the MLS options was based on five tests per year (hence the $100,000 for sensors per annum). The Spanish facility, as built, tests approximately six test sections in 3 years. Using this information, CTR calculated that a per year cost of sensors for the Spanish facility would be $30,000.

### *Environmental Control System*

A. **Cost of Structure**. These estimates were based on information provided by the research team. The information included dimensions and the temperature ranges necessary for testing. Other information included the types of access necessary for the Spanish device. One advantage associated with the MLS is that no additional structure will need to be constructed in order to provide environmental control during testing. Since the MLS is an enclosed device, the enclosure may act as an environmental chamber. Therefore, by properly insulating the walls of the MLS, environmental control can be maintained within the structure. The prices for the different environmental chambers were obtained from a local Austin refrigerating and heating contractor. Estimates were made on the cost of insulation for the MLS structure and the Purdue structure, with VMW consulted regarding these cost estimates.

B. **Cost of Equipment**. The estimated costs of the environmental control equipment were obtained from the same local refrigerating and heating contractor. These estimates were based on the average high and low temperatures typical in Florida. The temperature data were obtained from members of the SHRP research team, who had compiled temperature data for each of the fifty states during their research. If Florida decides to commercialize the use of their Accelerated Pavement Testing (APT) facility, then the possibility of other extremes of the temperature range must be explored. The temperature range used for Florida was 30 degrees Fahrenheit on the low side and 110 degrees Fahrenheit on the high side.

C. **Volume (cubic feet).** Estimates of the equipment costs were also based on the volume of air requiring conditioning. It was for this reason that the volume of each of the proposed environmental chambers was included in the table.

### *Maintenance and Support Facilities*

A. **Buildings.** The cost per square foot, as acquired from Innovation Park, was estimated at $110.00 per square foot. This estimate was based on a bid for a facility similar to that required by FDOT for its lab facilities. Estimates were also solicited from other developers to verify the value given above. The amount of square footage necessary to conduct testing is dependent on the level of testing determined by Florida DOT.

B. **Aggregate Storage.** This cost, which is associated with all of the proposed options, would consist primarily of the cost of the land on which the aggregate was stored. This cost was included because of the considerable amount of land necessary to spread out the aggregate for the drying processes necessary to obtain the proper moisture content.

C. **Construction Equipment.** This is another cost category which is associated with each of the proposed options and is only included in the spread sheet as a reminder that it is a cost associated with APT.

### *Operating Costs*

A. **Electrical Power Consumption.** In estimating the operating costs, CTR concentrated primarily on power consumption and estimated yearly maintenance costs. The figure for the MLS power consumption was based on CTR calculations. Electrical energy costs for the TxMLS were based upon a price of $0.10 per kilowatt-hour (kW-h). The estimated energy costs will vary according to the number of hours the device is operated daily. The figures presented in the spreadsheet for the MLS options were based on an 18-hour per day and on a 30-day per month operating schedule. An additional cost associated with a mobile device, if no commercial utilities are available, is the purchase/lease and operation of a mobile generating unit. The figures for the Spanish facility, supplied by CEDEX, were average values for operating the device for one year.

B. **Maintenance Costs.** The maintenance costs were given by CEDEX as a yearly average expenditure. The value of $45,000 was equal to approximately 3 percent of the device cost. Since no other basis for the calculation of maintenance cost for the other devices was available, the same 3 percent of the device price was used to estimate the yearly maintenance costs for the other devices.

**C. Staffing Costs.** The staffing costs of an APT facility are based primarily on two factors: the level of testing planned for the facility, and whether the device has been designed for unattended operations. The Spanish facility was designed for unattended operations and operates on a 24- hour day. The MLS was not designed for unattended operations partly because of the rapid accumulation of axles. Because of this rapid accumulation of axles, the test section must be watched and inspected on a regular basis. The Purdue facility was not designed for unattended operations.

TxDOT has completed a staffing plan to justify all new positions for MLS testing. The concept of operations is based on a mobile device. Four two-man crews will operate the device 24 hours per day, seven days a week. The operators being hired to operate the device will have various specialties and will normally work four 12-hour shifts and have four days off. Figure 4-1 charts the TxDOT MLS organization.

For the MLS options, the $393,000 for staffing consists of the following annual salaries (without fringe benefits)

| | |
|---|---|
| Engineering Staff | $ 117,000 |
| Engineer Specialist (1) | 32,000 |
| Tech V's (4) | 144,000 |
| Tech II's (4) | 100,000 |
| Total | $ 393,000 |

For Options 4-6, the staffing cost of $235,000 was provided from the operation of the CEDEX facility. The CEDEX organization chart is shown in Figure 4-2. Notice that the costs include only one engineer, with two personnel included specifically for analysis of testing. In the case of the Spanish track, the CEDEX research facility supports the test track; laboratory testing, the instrumentation, and a small machine shop are not included in those costs.

In determining the level of staffing required to support an APT test facility, several functional areas and specific tasks must be addressed. Some of the functions can be contracted out or supported by other organizations.

### *Costs Per Axle*

The costs per axle was calculated by first adding the cost of the device, the transport system (if applicable), and the non-consumable hardware and software, and then by dividing that total by the 5-year expected life of the device. Next, all the annual costs associated with operating the device were added. These included electrical power consumption, maintenance costs, staffing, and consumable hardware (sensors).

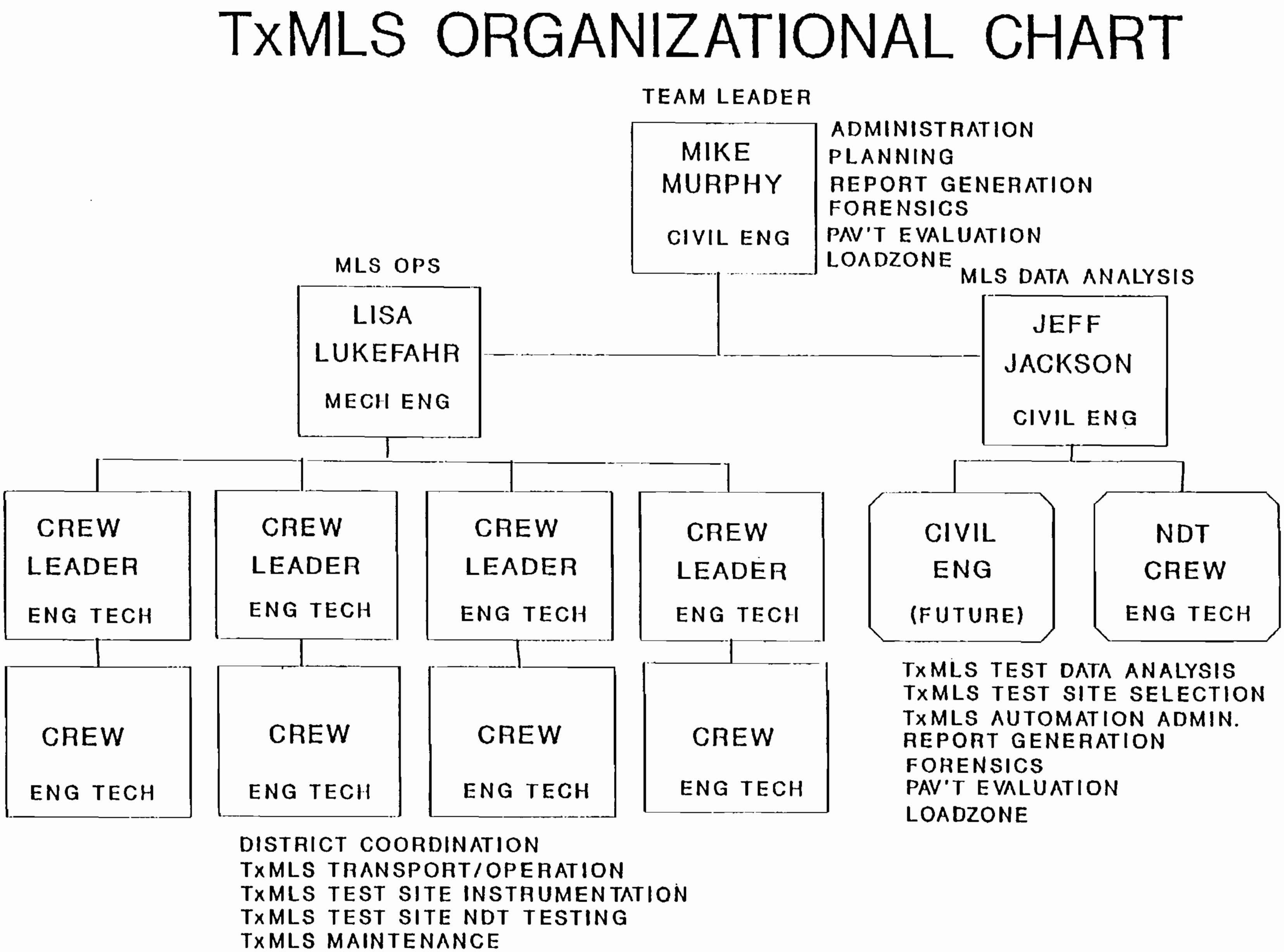
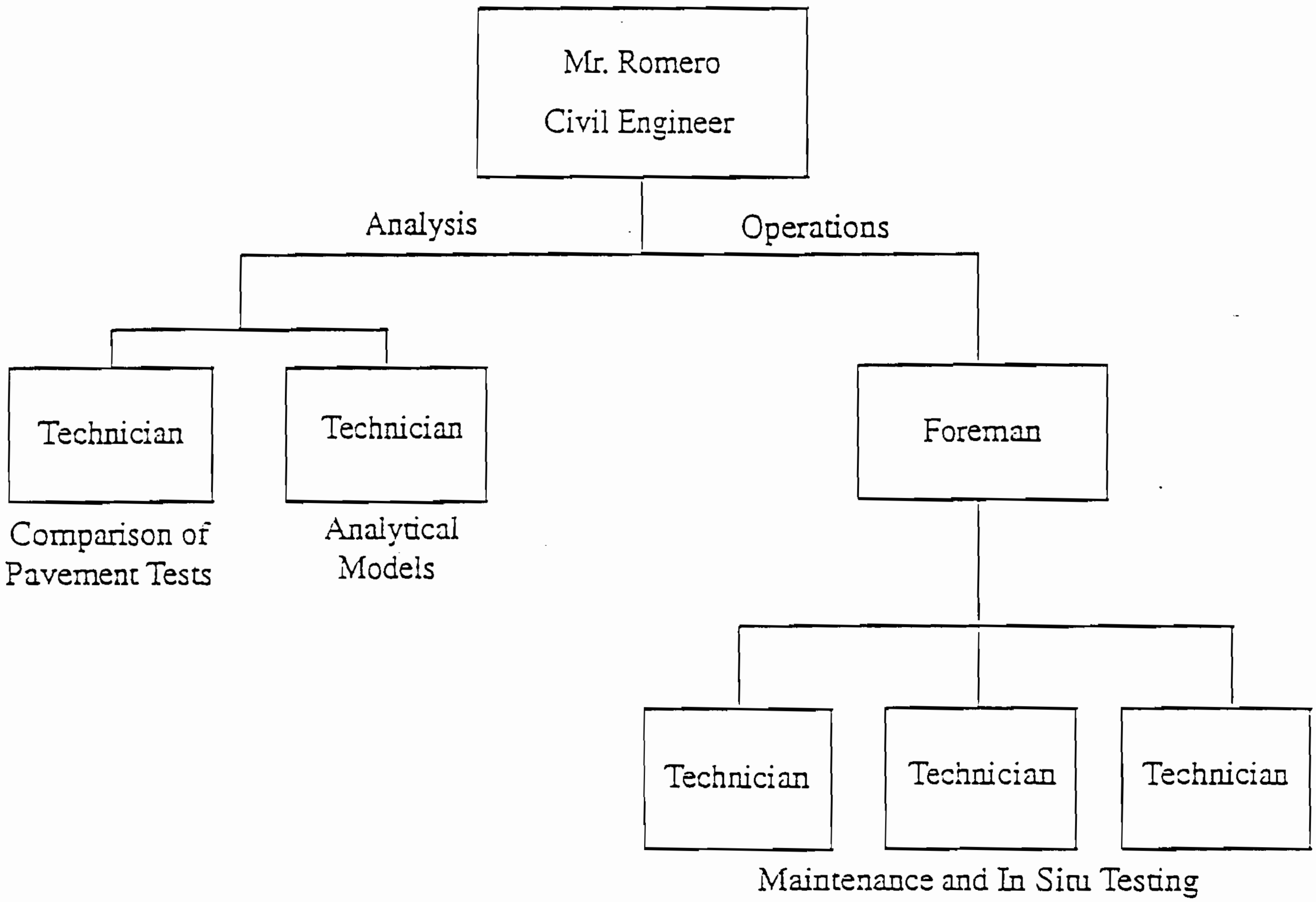



Figure 4-1

*TxDOT MLS Staffing Chart*

## CEDEX Test Track Staffing




Other Direct Support: Materials Laboratory Testing
Instrumentation Shop
Machine Shop

**Figure 4-2**

***CEDEX APT Staffing Chart***

This total was then divided by the number of hourly axles, multiplied by 18 hours per day, and multiplied by 360 days per year. This total was then multiplied by 100 to achieve the units of cents. In the case of the MLS device with environmental control, the cost of environmental equipment was added and amortized over a 5-year period. In the case of the Spanish type facilities, the costs associated with environmental control and the cost of the test track were added and amortized over a 20-year period.

The costs associated with buildings, aggregate storage, construction equipment, and test sections were not included in the calculation of the costs per axle for the devices. They were not used in the calculation because the costs would be approximately equal for each device, assuming equal amount of testing, and would not enter into the decision-making process for selecting a device. However, the cost associated with these items is quite significant and should be considered in the overall APT decision-making process. The range of costs of the facilities could vary depending on the budget available. The control facility could range from a used trailer to a brick and glass building, as seen in the Spanish facility. The range of support facilities also could vary (independent of the device selected). Laboratory space, instrumentation shops, and equipment vehicle maintenance space would be needed regardless of which device was selected.

# CHAPTER 5. IMPACTS ON IMPLEMENTATION

After Phase I, the Advisory Committee informed CTR that only two of the potential sites, studied in Phase I, should be considered: Tallahassee and Gainesville. The additional instruction passed along to CTR was that the Advisory Committee would not be making the decision as to which site would be more suitable, and that CTR should discontinue their analysis of the two potential sites.

In Phase I, an analysis of the two potential sites was conducted, with the results presented in the Phase I report. The summary of the Phase I site analysis is still valid, with one notable exception. It was reported in Phase I that the Gainesville site, adjacent to the State Materials Office, was too small to implement some of the options. Since that report was written, the State Materials Office has gained control of the entire adjacent maintenance yard; therefore the site probably has adequate space for Options 1-3 and 7. There may still be some difficulty with the space requirements for Options 4-6 (the racetrack options).

In this chapter, the potential impacts of implementing an accelerated pavement testing facility on a generic site will be presented. The facility requirements will be presented as a group, in generic terms for Options 1-6. The facility requirements for Option 7 are basically those of Purdue University. The facility space requirements for Options 1-6 are very similar in terms of support facilities, instrumentation, and laboratories (if the same level of testing and staffing is assumed).

Thus, the facilities required by each option do not indicate which option is better for Florida DOT, with one exception: the racetrack options represent more complex facilities that will probably take more time and money to construct.

## FACILITY REQUIREMENTS

The amount of space required for each of the functions varies according to the staffing, number of test sections per year, the complexity of the tests and materials tested, and by the budget available. The purpose of this contract is not to design this facility, but to help identify the requirements of such a facility, so that they are considered in the actual design. From our testing experience, we know that there is always a need for more space than initially estimated for research testing, just as most research test plans are altered after testing begins.

Space should be allocated for the following areas during the design of the accelerated pavement testing facility:

- Administrative/office space
- Laboratory space and specimen storage
- Instrumentation shop
- Machine shop
- Vehicle/equipment repair and storage space
- Spare parts space
- Test section repair/maintenance space
- Aggregate storage space
- Soils preparation areas

## POTENTIAL FACILITY LAYOUTS

As Shown in Figure 5-1, the Spanish CEDEX facility is well suited for a racetrack-type testing facility. While the tunnels under the concrete monorail allow for monitoring of the test section instrumentation during testing, they may not be feasible in a Florida facility (because of high water tables and sandy soil). This may necessitate the use of a bridge or overpass in order to access the space inside the test track during testing.

In considering the space used by CEDEX for their functional areas, one should bear in mind that their testing schedule is not demanding by most standards. They normally take over one year to complete a test of the six test sections. With higher production rates, more space may be needed for aggregates, materials, laboratories, and specimen storage space.

The Turner-Fairbanks Accelerated Loading Facility can serve as a guide for the MLS options. The site is currently under reconstruction to the twelve-test-section configuration shown in Figure 5-2. The Turner-Fairbanks facility relies completely on contracted construction of test sections and contracted testing support to operate the device, record data, and perform maintenance on the test sections. Thus, the Turner-Fairbanks site does not require space for these support functions on site. However, the down-side is that, as of this writing, no testing has been accomplished since the ALF completed refurbishment in February 1993, as a result of contractual problems in getting the test sections constructed. Testing stopped in September 1992 to allow the ALF refurbishment to begin. The result is almost one year of down-time required to complete the site enhancements and test section construction.

Another test facility model to consider when constructing an accelerated pavement testing facility is one located at Tyndall AFB, Florida. Mr. McNerney had the opportunity and privilege to design and construct part of that test facility, and to conduct over 30 tests of 20 by 20-foot repairs with aircraft load simulators. One of the key features of that facility was the large amount of paved space required for preparing a clay subgrade to

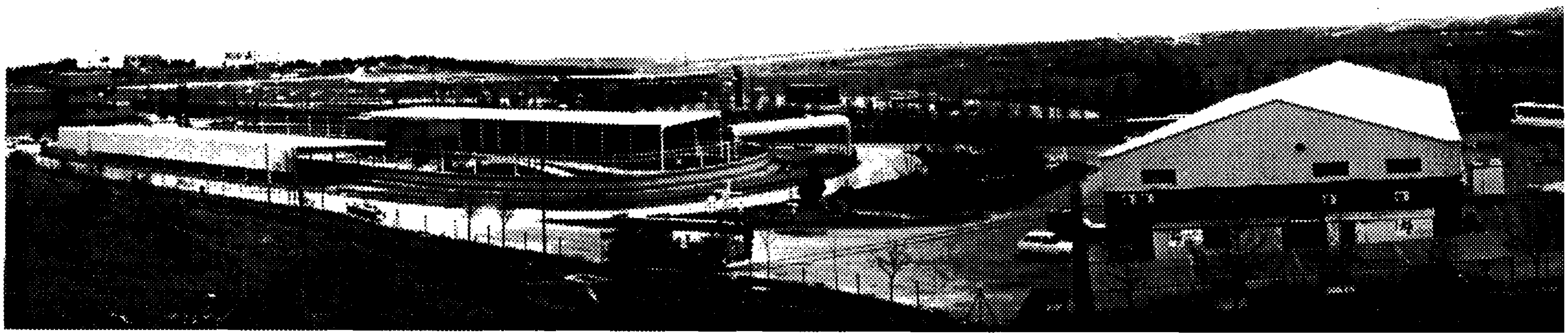


Figure 5-1

*The CEDEX facility layout*

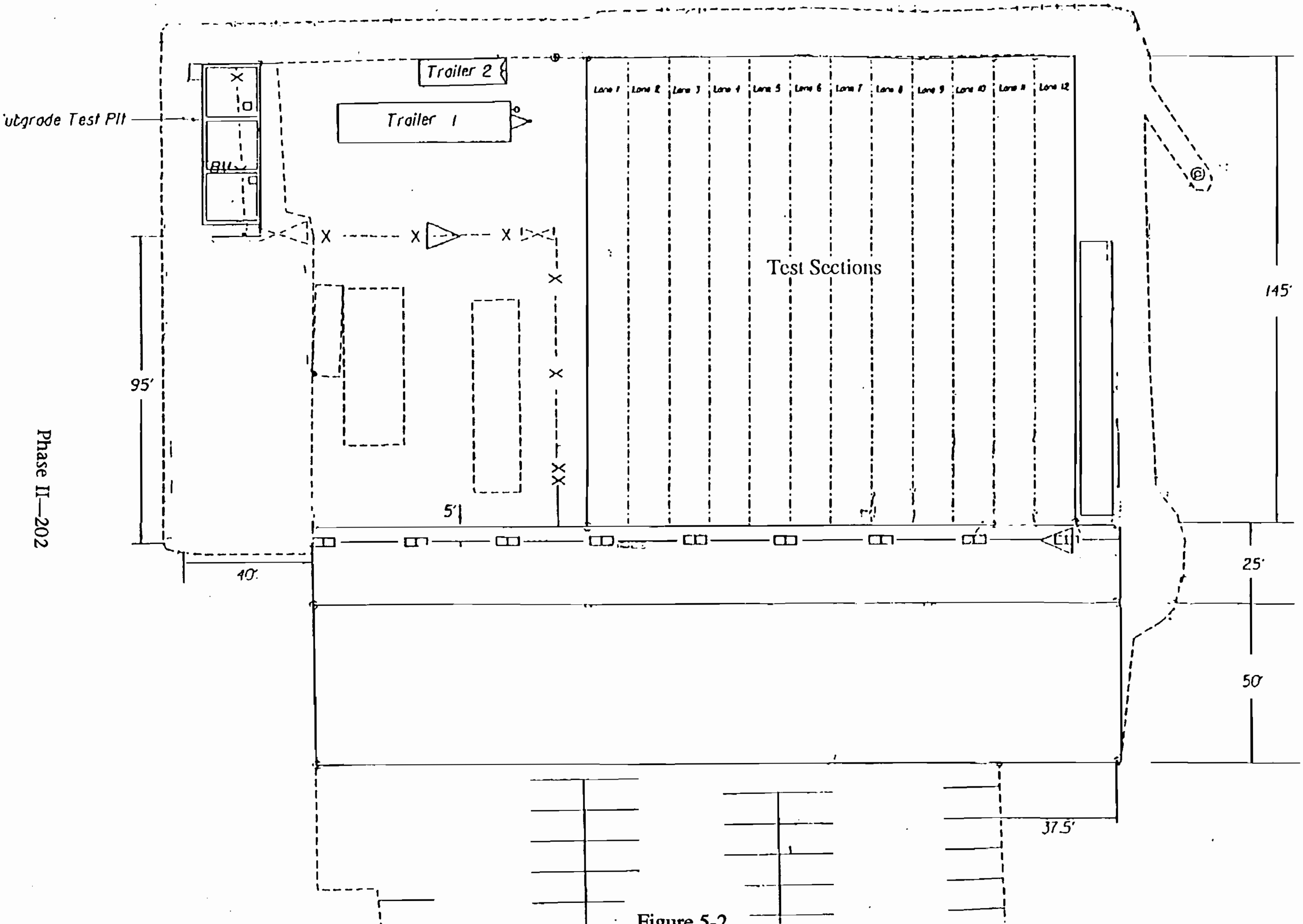



Figure 5-2

*Turner-Fairbanks Accelerated Loading Facility site plan* optimum water content, and the large amount of space required for storing the clay material (which was not native to Bay County). CTR recommends that this site be visited before the design of an accelerated pavement testing facility for Florida DOT gets underway.

Any site layout for Options 1-3, which use the MLS, must include a method to move the device laterally at the site. One option, which was considered by the research team, is to mount the MLS on temporary or permanent rails. The device could then be moved laterally, much like the device at the Purdue facility, only on a much larger scale (such as the LINTRACK device). Figure 5-3 shows a potential site layout for Options 1-3, where the MLS would move laterally on rails and could pivot at one end to allow access to a second row of test sections.

## POTENTIAL IMPACTS OF SCHEDULE

In case time is a factor in the selection of a device, a comparison has been made as to the estimated times required for design and construction. The times are, however, only rough estimates and should be used for comparison purposes only. The actual times required to design and build a device or facility are highly variable. The time necessary to design and build facilities at the Innovation Park location in Tallahassee are probably very much shorter than the time required for the Gainesville site (since a mechanism exists to speed the process there).

The time estimates presented below are based on the assumption that VMW Industries is the designer and fabricator. The use of any other designer or fabricator would increase the estimated times reported in the following figure. The times are somewhat optimistic estimates; that is, they assume that no major problems will be encountered, and that a good communication system exists between the designer/fabricator and Florida DOT.

Figure 5-4 shows the estimated times (in months) that each of the options could be completed. Options 1 and 2 are estimated to be the shortest, at ten months, with Options 3 and 7 the next shortest, at 11 months. Notice that the controlling constraint in several options appears to be the completion of the facility (rather than the completion of the device). Notice also that Option 4 has the longest amount of time required to complete the device. Option 4 takes longer to complete than Option 5 because the Spanish design is used for both the trafficking half and the monorail half, whereas the Spanish design is used for only the monorail half of the device in Option 5. In Option 5, the trafficking half is self-supporting and similar in design to the MLS bogies; thus, VMW could design and build it in a shorter amount of time.

## BENEFIT-COST RATIO

Our economic comparison of the different APT devices considered specific benefits and costs.

# Possible Facility Layout for Options 1-3

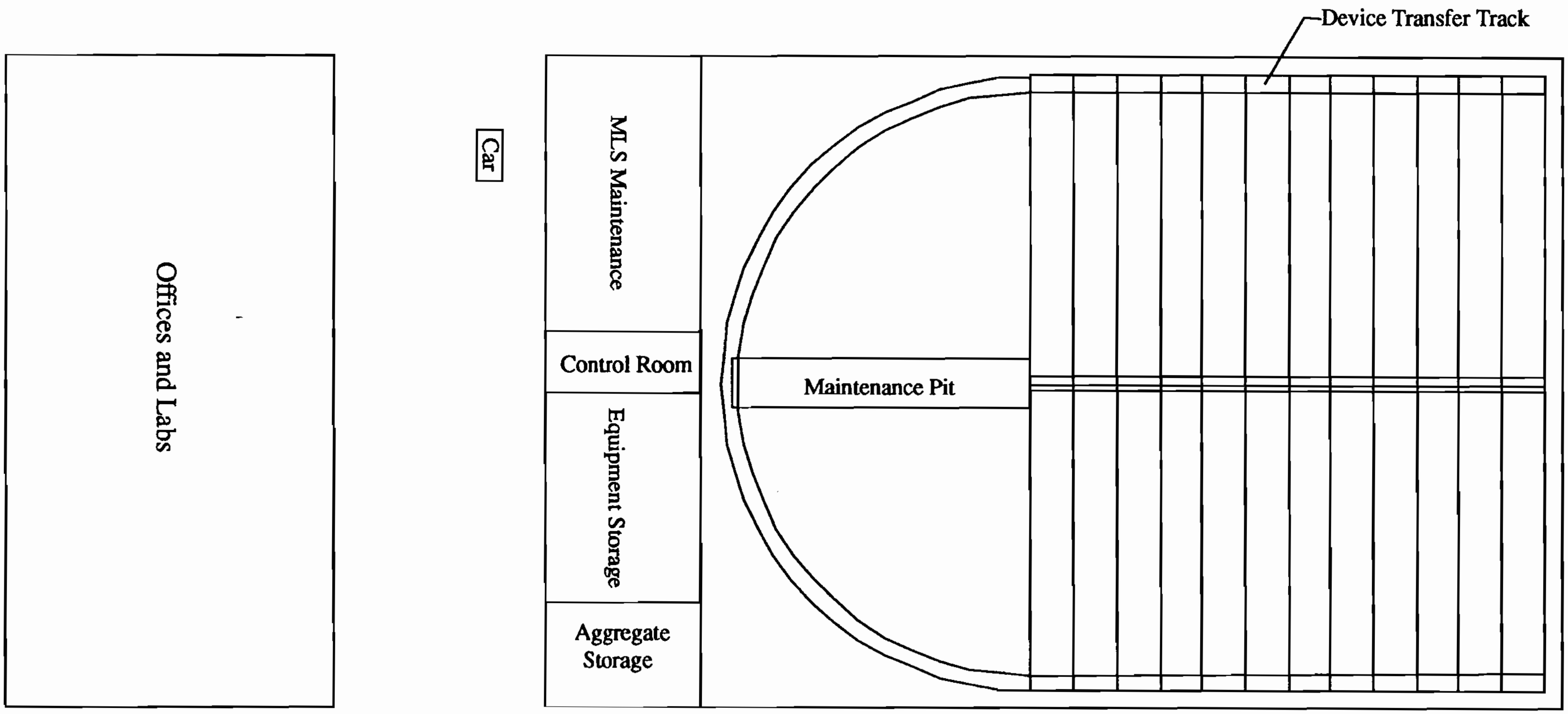



Figure 5-3

*Possible facility layout for fixed-site MLS operations*

Potential Schedules for APT Construction

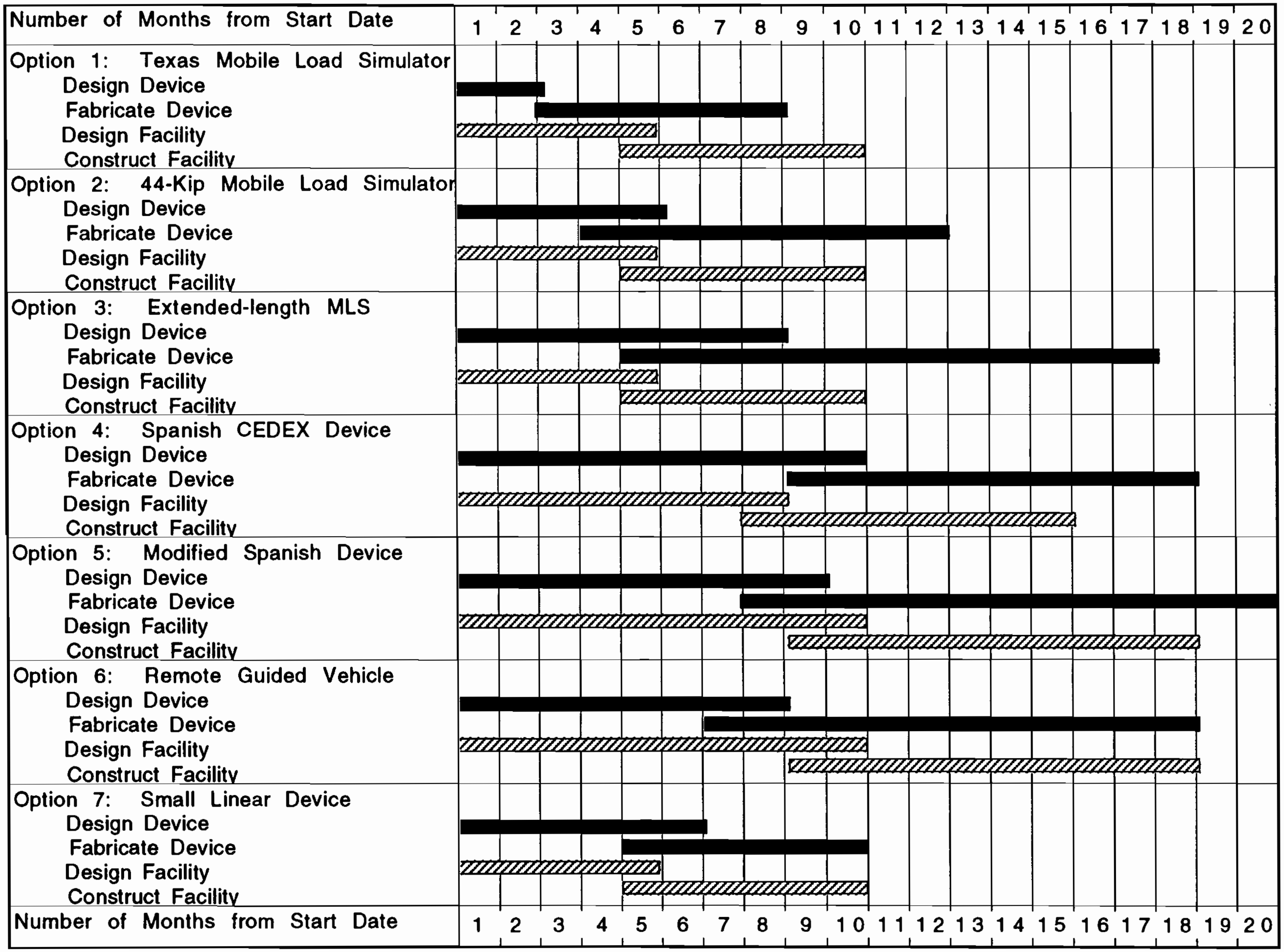



**Figure 5-4**

*Potential APT facility construction time requirements*

The first step was to compare the ability of the different options to meet the Florida DOT's prioritized needs (together with their respective costs). This is shown in Figure 5-5. The diagram clearly depicts the difference between the devices.

If the degree to which the respective options meet the FDOT needs is taken to represent benefits, the diagram shows that the respective benefit-cost ratios could vary over a wide range. The diagram therefore illustrates that the user of APT devices must select its device very carefully, taking into account its needs and its human and financial resources.

In order to help FDOT with its selection and to refine the information necessary for considering commercial applications of the APT device, *benefits* and *costs* were further explored.

### *Benefits from Research*

Benefits from research or operational application of research tools are primarily related to the worth of implementable end products. In turn, this is related to the quality of the research team and the tools used. Examples of implementable products are:

- Changes in procedure
- Ability to design new pavement types
- Evaluation of new materials
- Determination of rehabilitation strategies where it is difficult to determine structural integrity, shrinkage cracks, D-cracking
- Evaluation of drainage systems
- Evaluation of joint behavior
- Enhancement of technology

Because of the short history of APT usage in the United States, very little information is available on the worth of such implementable products relative to the use of APT devices. In South Africa, where the HVS's have a long history, records have shown considerable savings from APT as a result of design input or comparative studies of rehabilitation alternatives, etc. Benefit-cost ratios of 20 to 1 have been found.

In the present study, the actual goal is not the determination of benefit-cost ratios, but rather a comparative evaluation of APT devices. In Chapter 2, it was shown that the MLS and the Spanish-type devices are both capable of meeting many of the FDOT needs. In view of this, CTR decided to concentrate on the relative costs of the two devices, which are easier to establish. Once this had been established, the relative benefit-cost ratios could be deduced.

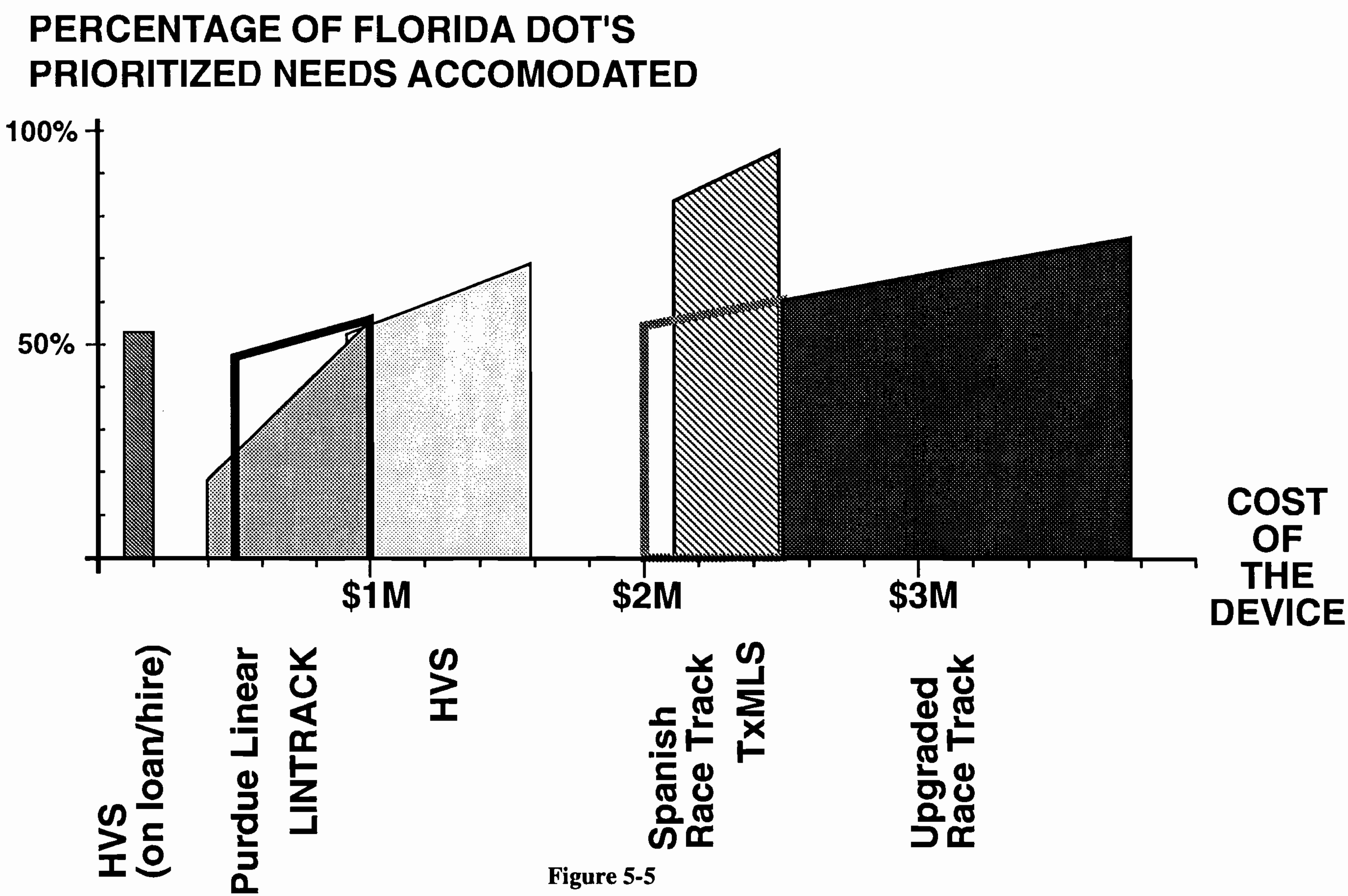



Figure 5-5

*Cost effectiveness of APT devices*

### *Costs of APT Usage*

Since the determination of implementable end products is, in most instances, related to the number of load applications, CTR concluded that the cost per load application carried per test section would be a feasible measure of comparison of APT devices. Indeed, assuming *"equal benefits"* from all devices means that cost per load application, per test section, can be used as a measure of benefit-cost ratio.

### *Cost Comparison of Selected APT Devices*

From the analysis of the relative cost of the various options (see Table 4-1), it can be seen that the costs vary from as little as 1.89¢ per axle application to as much as 19.0¢ per load application. The large discrepancies between the comparative costs of the devices considered in the analysis is apparent. This further underscores the fact that there are large differences between the relative benefit-cost ratios of the different devices. The final selection of an APT device will therefore have to take *all* factors into account.

## POTENTIAL FOR COMMERCIALIZATION

CTR considered it important to determine what the French were doing with their APT device from a commercial point of view, and to compare the costs of load applications. In an interview with G. Carroffe from SCETAUROUTE (a toll road authority), CTR was told that the cost of their APT device amounted to 15¢ (U.S.) per load application. The significant cost differential speaks for itself. He indicated that the French APT was operated under the auspices of the Laboratoire Central des Ponts et Chaussees (LCPC), and that its commercial use was successful. Because of the support they receive from the toll authority, they actually received a rebate. LCPC also received support from the government.

Since the number of available APT devices is limited both nationally and internationally, the possibility of niche markets is self-evident. CTR suggests that it would be appropriate to consider forensic and diagnostic studies. Clients could include other states, toll authorities, consultants, and product developers. It would, of course, require careful planning to ensure that FDOT's own needs are met. It would be prudent to balance commercial and FDOT operations on an equal basis if sufficient capacity existed.

Commercial operations are expected to be mostly of an urgent nature and of a short term. If operations are managed as set out above, tests should be a blend of short term (< 2 million axles) and long term (> 10 million axles) per test.

Typical niche markets might include:

- Testing of new materials and processes
- Evaluation of aging
- Evaluation of multiple axles

- Evaluation of the effect of surface condition
- Evaluation of varying geology and climate
- Testing of in-situ roads
- Testing of aspects of concrete pavements
- Evaluation of truck suspension components.

In conclusion, there is sufficient evidence to suggest that commercialization might be successful; accordingly, it should be considered in FDOT planning.

# CHAPTER 6. SUMMARY

CTR has presented seven options for accelerated pavement testing facilities. Options 1, 2, and 3 are based on the MLS design as constructed for the Texas Department of Transportation. The device, which will undergo acceptance testing in June 1994, represents a new generation of load simulation capability, both in terms of rate of application and in terms of high-fidelity simulation of truck traffic. Environmental control has been added to Options 2 and 3. Completion of a facility based on an MLS option would require less time than an option based on the racetrack concept. The devices described in Options 1 and 2 have the added flexibility of being either mobile or fixed in operation. These two options fulfill one of the needs expressed by the Advisory Committee, that the device be used in varying geographic locations. The cost of devices and facilities for the MLS Options are generally less than the cost of the racetrack options, and the MLS options provide the least cost per axle to build and operate.

Options 4, 5, and 6 are based on a racetrack concept derived from the Spanish CEDEX facility. The facility, which has been in operation for 5 years, has recently been enhanced to double its rate of production (considered rather slow). Options 5 and 6 have emphasized methods of increasing the production rate of the racetrack concept. Options 5 and 6 are new, innovative concepts that will require additional research and development to design and construct, but the improvements in productivity and load simulation capability are worth the added costs. Environmental Control is an option available with the racetrack concept, as described in Options 5 and 6, but will require a design that has a greater degree of risk in meeting economic feasibility in operation.

Option 7 may not meet all of the accelerated pavement testing needs of Florida DOT, but may still be useful for accelerated testing of asphalt materials. It could be useful as a screening tool to supplement testing of a facility built from Options 1-6. In its enhanced form, it could be equivalent to the HVS or the Dutch LINTRACK devices.

This report has presented an economic evaluation of the needs analysis conducted in Phase I. The economic evaluation recommends that the requirement for braking be deleted, that speed need not be greater than 20 mph for testing, and that test sections longer than 35 feet are unnecessary, unless skid testing is required. A test section longer than 35 feet is desired for testing construction methods.

This report also gives estimated costs for staffing and operation. However, for equal amount of testing it is not a discriminator in choosing options. Likewise, the amount of support facilities needed is nearly equal for all of the options, given an equal amount of testing.

It is CTR's view that Florida DOT will benefit from any of the options discussed. Accelerated pavement testing is very cost effective if properly used, providing the possibility of successful commercialization of the facility.

The next step in implementing this research would be to select one or more options and assign the responsibility within Florida DOT for implementation. It is also necessary that a site be selected (or a procedure be established for site selection). The FDOT office selected must have the determination and desire to build and use the accelerated pavement testing facility. It should also have the authority to make technical decisions during the design and construction of the device and facility. Administrative delays in making technical decisions could add 3 to 5 months to the fabrication time.

Since this study has begun, there has been a significant increase in interest in accelerated pavement testing throughout the United States. A national interest group,the Accelerated Pavement Testing Users Group, was formed in October 1993, to promote, educate, and coordinate accelerated pavement testing in the United States. Florida DOT would benefit greatly from participating in this national effort.

Several other states have expressed interest in accelerated pavement testing. CalTrans has expressed interest in refurbishing two HVS devices and leasing them in California. WAASHTO has expressed a clear desire to purchase one or more accelerated pavement testing devices. The U.S. Army Cold Regions Research Laboratory plans on acquiring an accelerated pavement testing device in fiscal year 1994. FHWA plans on acquiring a second ALF to increase their production rate and add environmental control. Interest in accelerated pavement testing has been shown by inquiries from the states of Alabama, Washington, Montana, and Oklahoma.

# PHASE II — APPENDIX A

# TASK SCHEDULES

Aug 3, 1993

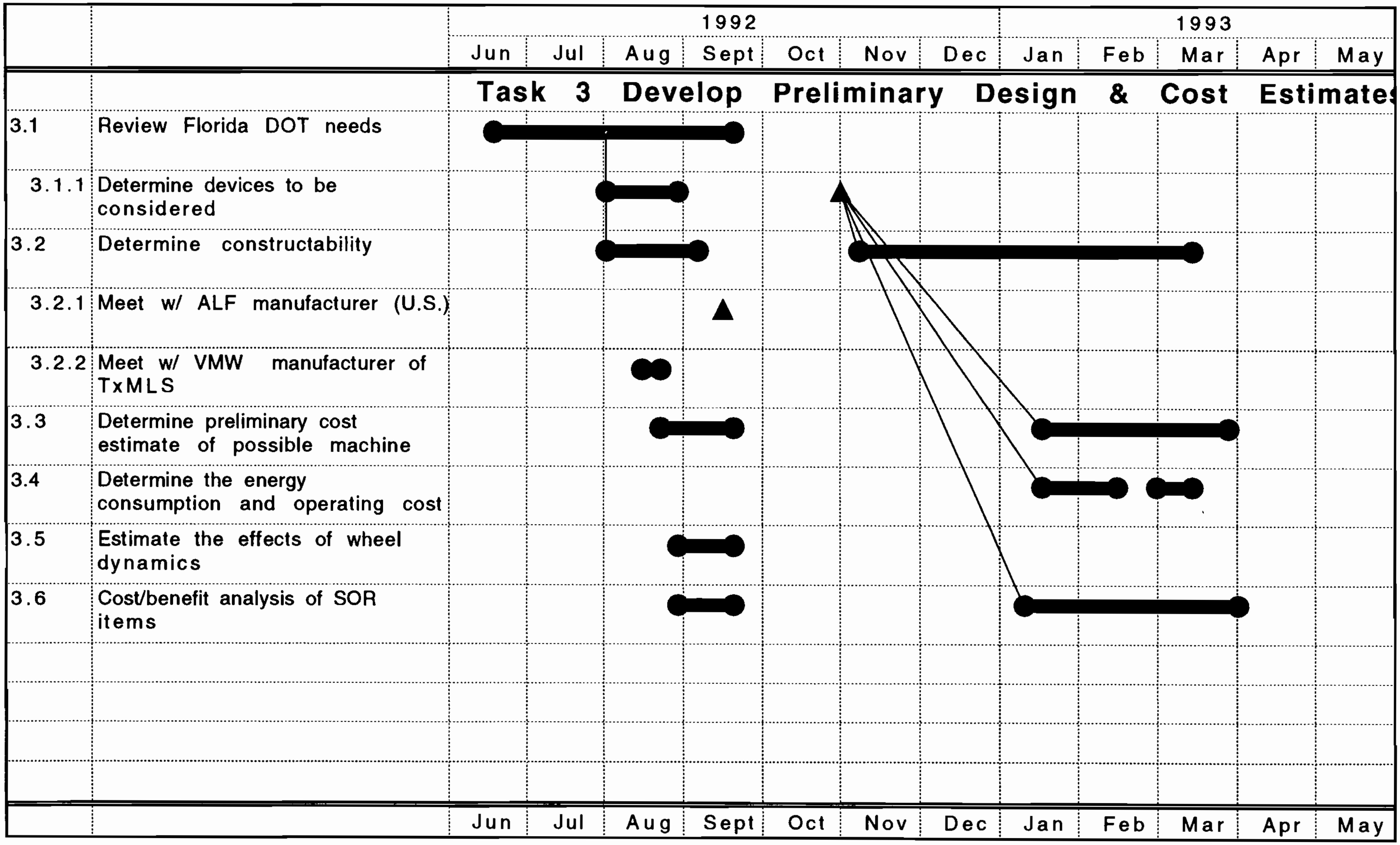



Figure A-1

*Task Three Schedule*

Aug 3, 1993

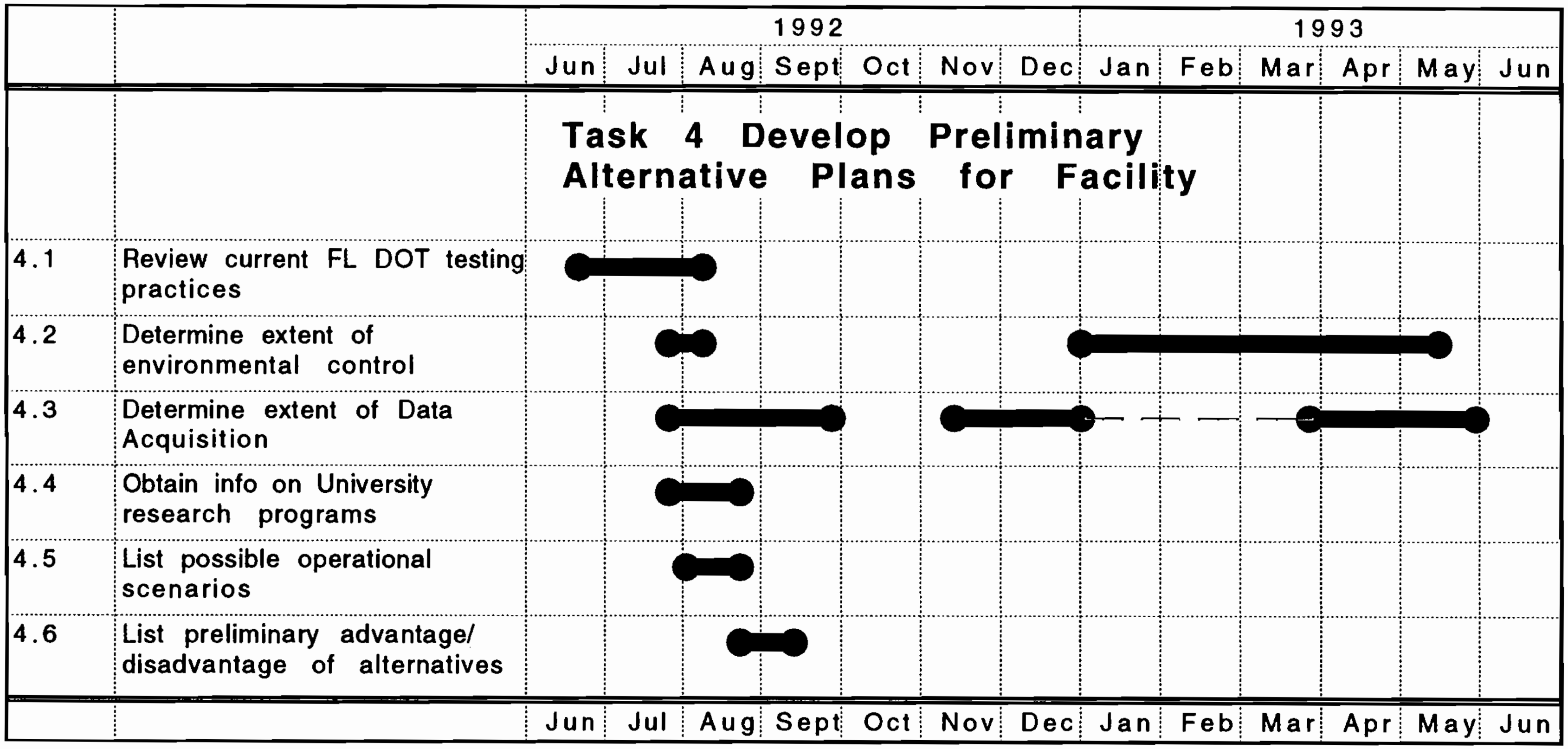



Figure A-2

*Task Four Schedule*

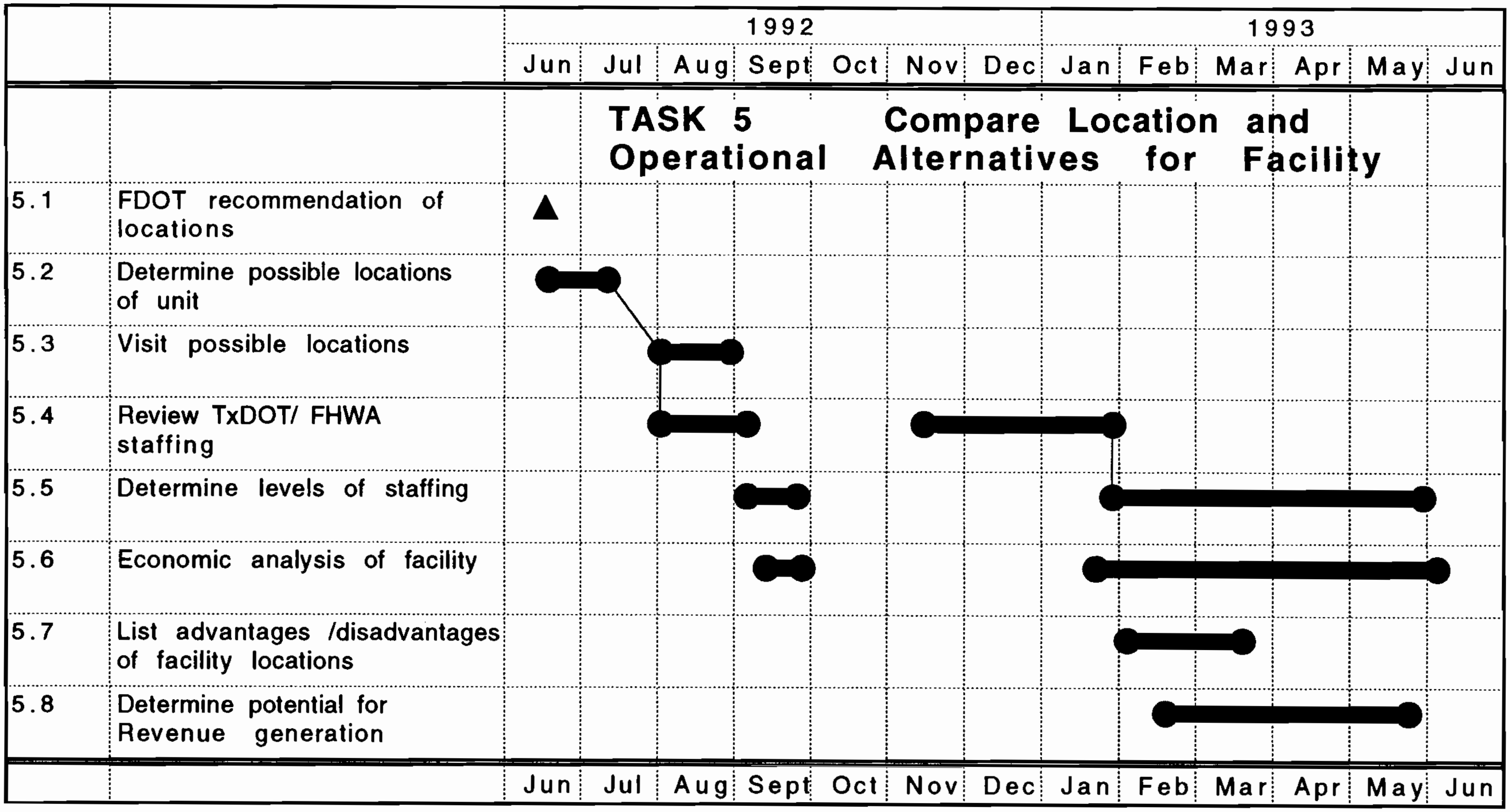



Figure A-3

*Task Five Schedule*

May 26, 1994

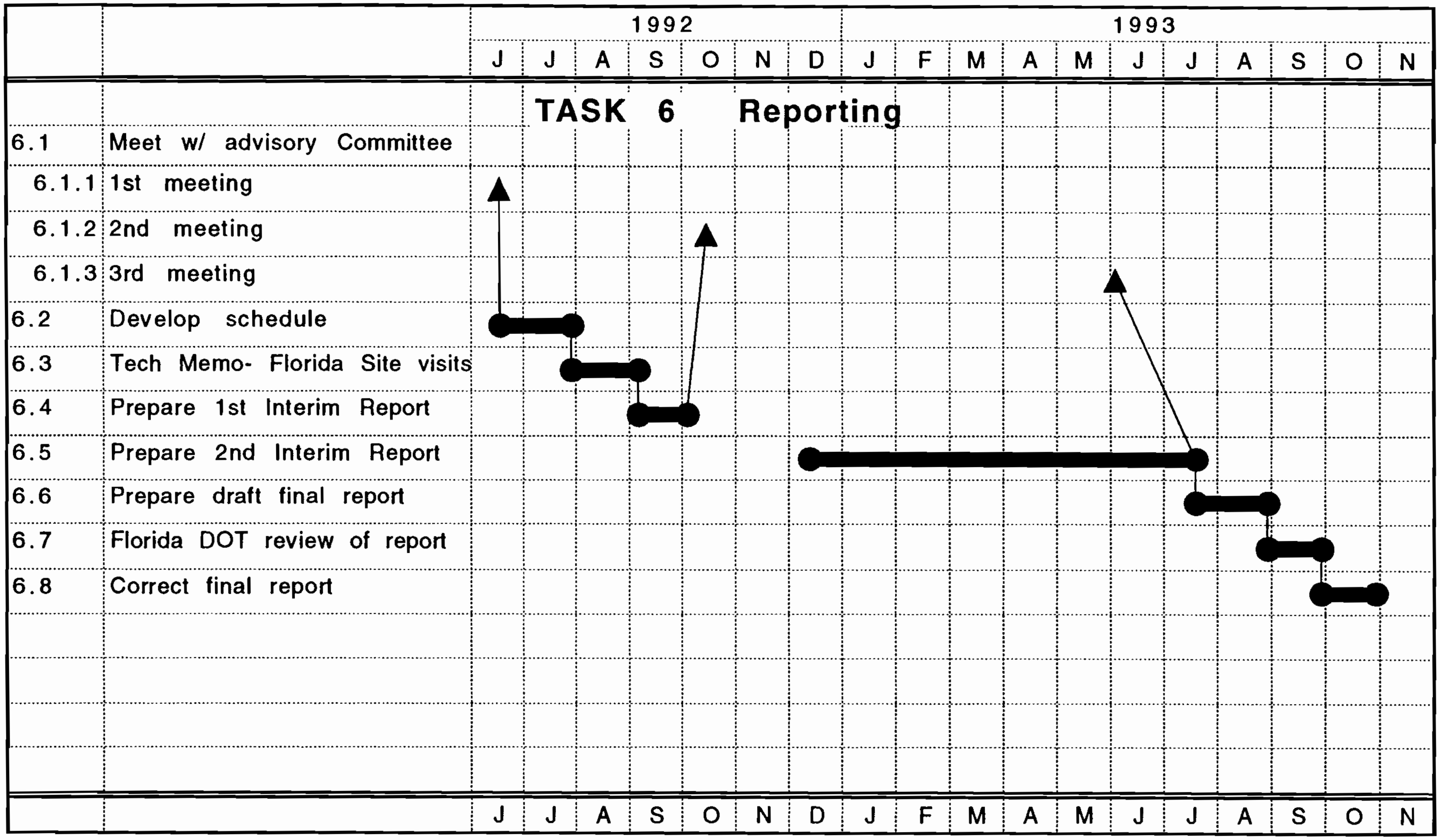
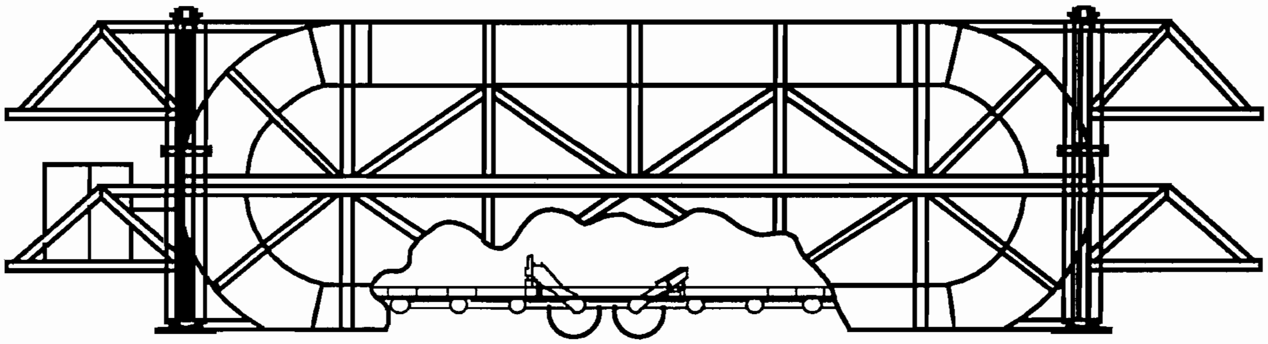



**Figure A-4**

*Task Six Schedule*

# PHASE II — APPENDIX B

# THE TEXAS MOBILE LOAD SIMULATOR



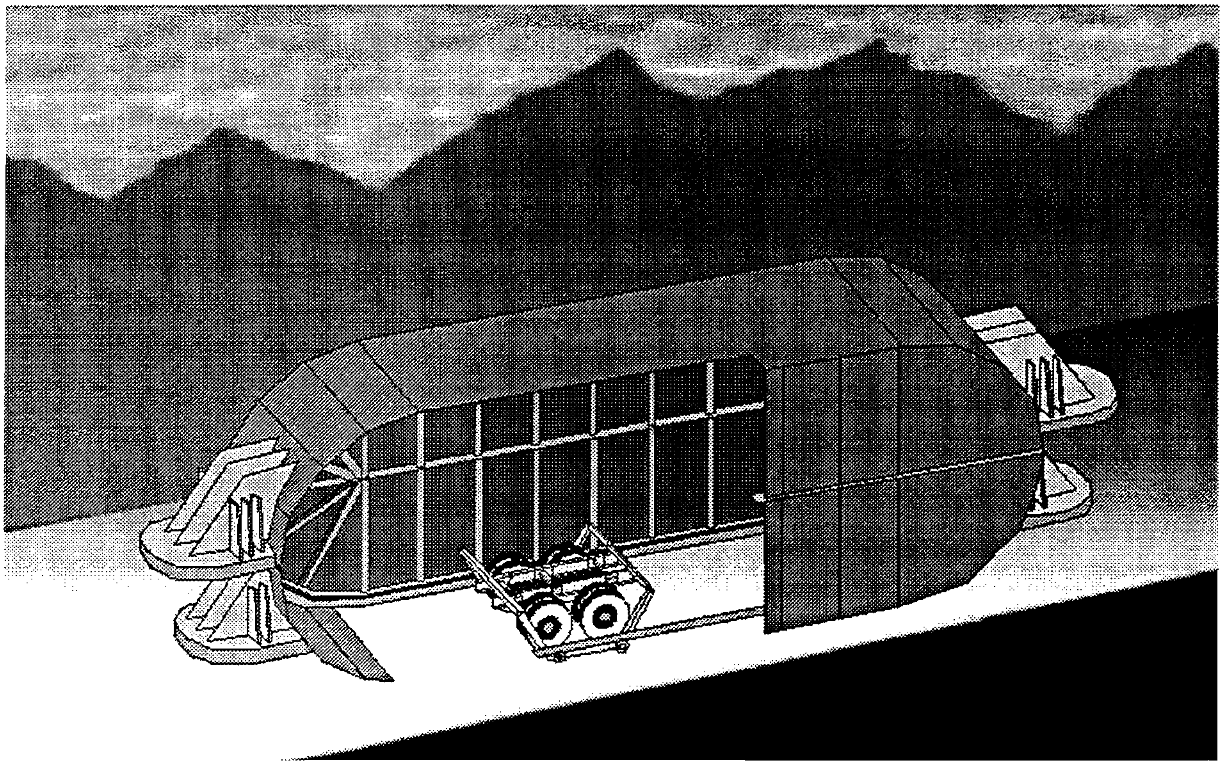
# ACCELERATED PAVEMENT TESTING (APT) USING THE TEXAS MLS

*A new testing machine named the Texas Mobile Load Simulator (TxMLS), which was based on a provisional patent owned by Dr. Frederick Hugo*

Based on a proposal submitted by the Center for Transportation Research (CTR) at The University of Texas at Austin, a research program was initiated by the Texas Department of Transportation (TxDOT) through which CTR was to develop a device for carrying out full-scale tests on pavements using APT. After the first phase of the study, TxDOT decided to develop a new testing machine named the Texas Mobile Load Simulator (TxMLS), which was based on a provisional patent owned by Dr. Frederick Hugo. The purpose of this progress report is to relay technical information on the TxMLS to other transportation departments and interested parties.

The TxMLS is a mobile testing device capable of accelerated simulation of real traffic loading on any selected pavement section. Accelerated testing is principally achieved by increasing the number of axles and/or the rate of application. It is also capable of accelerated testing by overloading. The pavement sections to be tested can be either existing in-service roads or specially constructed test sections.

The TxMLS is a unique system featuring the energy-saving, closed-loop concept. Rotation of truck bogies linked by a chain-type mechanism around the stationary frame is achieved using electric motors on two drive axles transforming rotation of the wheels in contact with the pavement to translation of the chain around the frame.



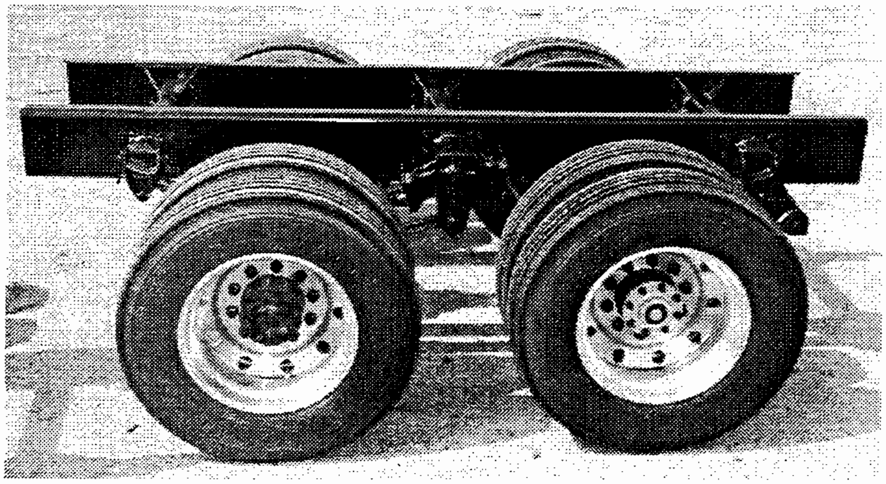
# TxMLS PROTOTYPE

*The MLS consists of many off-the-shelf components as well as several specially designed and engineered components*

Though the detailed design of prototype components fell outside the scope of the 1988 TxDOT study, conceptual designs and calculations were made to evaluate the feasibility of the machine and its operational components. The conceptual study was followed with a design contract with an engineering services company. This contract was terminated in the general design phase to proceed with a detailed design and building contract with VMW Industries, Victoria, Texas. The MLS consists of many off-the-shelf components as well as several specially designed and engineered components.

The main components of the MLS are:

- Six tandem truck bogies with suspension and frame rails;
- Two electric motors with drive axles;
- Six load frames called "bogie carriages" that force the bogies into place;
- A chain that connects the bogie carriages;
- A control system to run the motors and monitor the bogies;
- A load rail and load wheels to apply force to the bogie carriages;
- A closed-loop ramp on which the bogies roll when not in contact with the pavement;
- The superstructure that holds the system together; and
- Four jackscrews that raise and lower the structure.



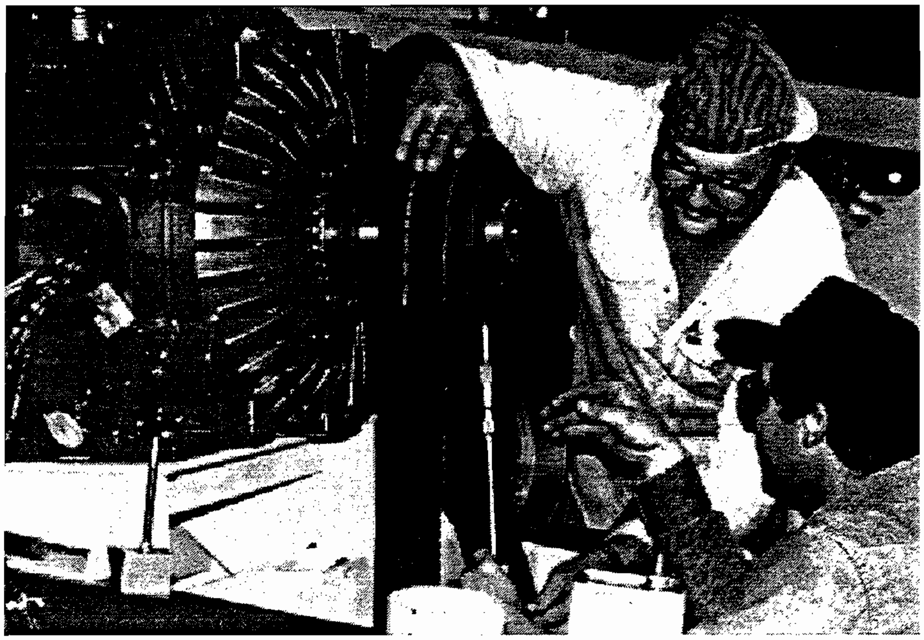
# TRUCK BOGIES

*There are at least four basic suspension types available for dual axles on trucks*

The TxMLS will use actual off-the-shelf truck bogies consisting of chassis frame rail elements, suspension systems, axles, wheels, and tires. The term "bogie" is used by some truckers when referring to these truck tandem axle units. The basic configuration of the TxMLS typically calls for 6 bogies (12 axles) symmetrically placed around the loop.

There are at least four basic suspension types available for dual axles on trucks, namely the four-spring, air-bag, Mack Camelback, and walking-beam. Although the four-spring is currently the most prevalent suspension type used for over-the-road trucking, the air-bag is gaining popularity in the trucking industry. The walking-beam bogie has different dynamic response characteristics than the four-spring system. The four-spring bogie allows a great number of spring systems to be incorporated, including air springs. The first TxMLS prototype will use the four-spring suspension.

Two bogies will be powered while the other four will be trailing. In addition to the standard items listed above, the powered bogies will also incorporate an off-the-shelf gear set and electric motor. Only minor modifications will be made to the bogie for attachment to the load transfer frame, sometimes referred to as the bogie carriage or saddle.

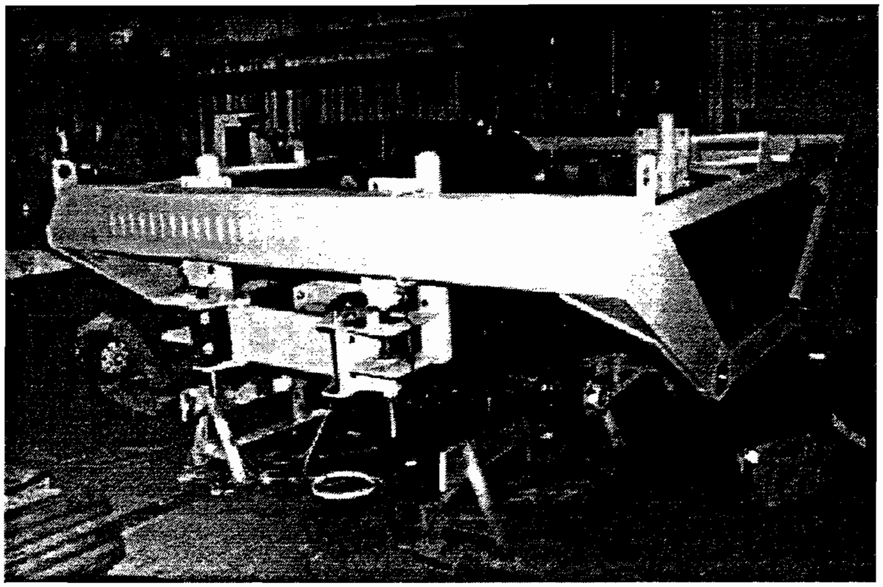


# ELECTRIC MOTORS

*The implication of a perfectly symmetrical or balanced system is that power can be reduced to only that necessary to overcome frictional resistance*

The figure illustrates the mounting position of the electric motors. The motors will draw their power from a power rail built into the main structure. The speed (or torque) of the motor will be controlled by variable frequency drives (VFD). The VFD will allow control of speed (or torque) of the bogies. The electric motors will engage the bogie gear unit via a belt drive system. Thus, the drive axles will simulate exactly the drive mechanism of trucks on the road.

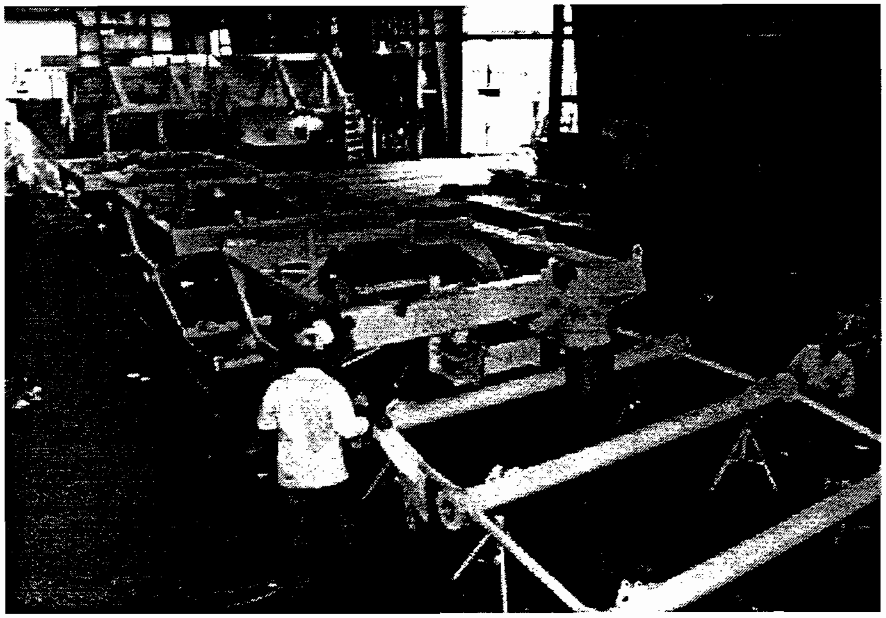
The implication of a perfectly symmetrical or balanced system is that power can be reduced to only that necessary to overcome frictional resistance, once the intended rotation speed has been reached. Motor sizes are governed by the inertia of the total chain system, the amount of friction that will be generated, gear ratios, the time required for the necessary velocity to be achieved (start-up acceleration), and by the amount of grade simulation desired. Friction will consist of chain friction, steel-wheel-on-steel-rail friction, and rubber-tire rolling resistance on pavement surface.



# LOAD TRANSFER FRAME ("BOGIE CARRIAGE")

*The main purpose of the "Bogie Carriage" is to provide load transfer from the main structure through the load rail*

This figure shows the layout of the "bogie carriage" for the TxMLS prototype. The design featured here is comparable to the construction of the moving load frame of the TxMLS model. The main purpose of the bogie carriage is to provide load transfer from the main structure through the load rail. The bogie is attached to the bogie carriage with an adjustable attachment device. The bogie carriage adjustment is used to vary the load on the bogie against the load rail (since the load rail does not move).



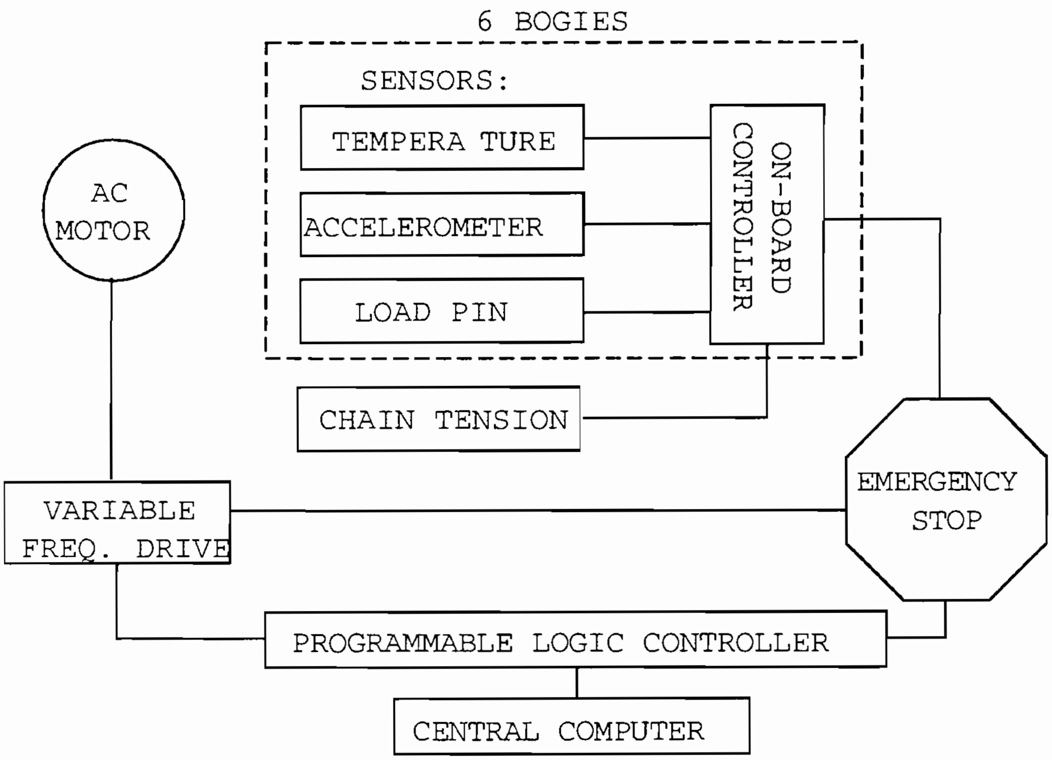
# CHAIN MECHANISM

*Balance will result in the exertion of minimal longitudinal and vertical forces on the supports of the structure*

The "bogie carriages" are connected to each other by a chain mechanism and thus each bogie carriage is also a link in the chain. The chain is designed with the load wheels and bogie carriage as principal members. Each link is 48 inches center to center of load wheels. The chain has cross members at each link to resist torque. The design of the chain length was dependent upon the placement of the load wheels in relation to the center of gravity of the combined bogie and bogie carriage.

The rotating masses of the MLS generate significant centrifugal force. These forces are a limiting factor in the design based upon speed and mass of the bogie and bogie carriage. These centrifugal forces are carried by the continuous closed ramp. The MLS is designed to withstand 20 mph normal speeds, with a capability to increase to 25 mph maximum speed. The speed is infinitely controllable and programmable within the minimum and maximum limits. Minimum speeds are dependent upon the geometry of the bogie center of gravity (CG) and the load on the bogie. Significant changes in the bogie CG could be a limiting factor on both minimum and maximum allowable speeds.

The bogie layout was designed symmetrically in that the forces on the ramp on one end are balanced by an approximately equal force on the ramp on the opposite end, and as one motor is going up the ramp the other is coming down the other end with a balance of vertical forces. This balance will result in the exertion of minimal longitudinal and vertical forces on the supports of the structure, a condition that maximizes stability and decreases the possibility of resonance during testing.



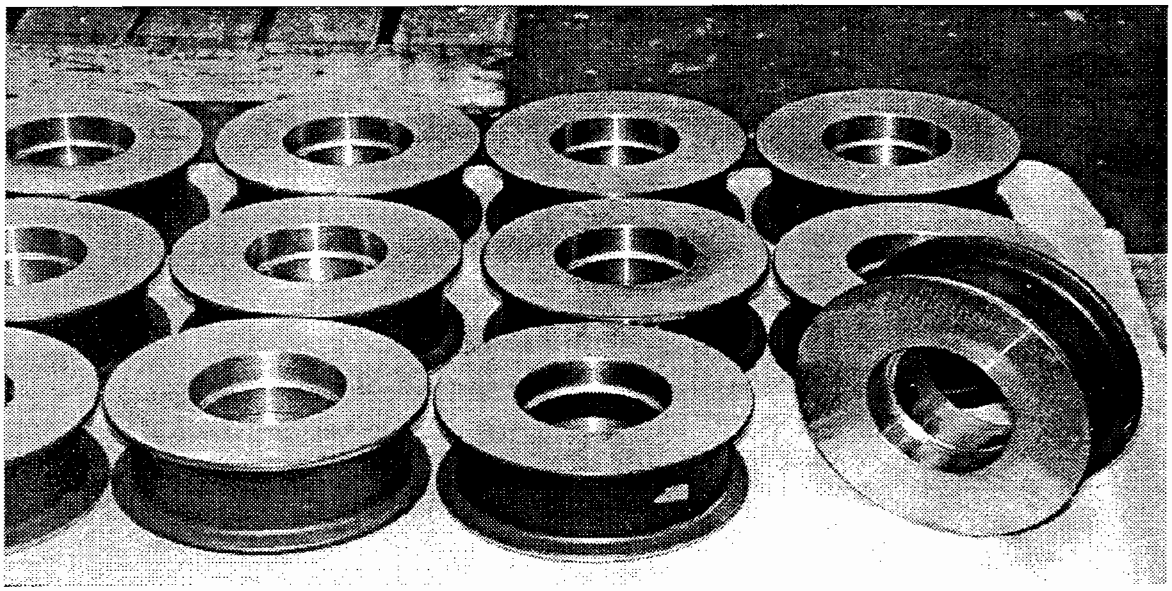

# COMPUTER CONTROL SYSTEM

*The control system is designed to integrate completely with the data acquisition system*

A computer control system was designed to control the speed and torque of the motors. Automatic shut-off was designed with a system that monitors each bogie continuously. Sensors are located on each bogie to measure accelerations, temperature, acoustical signature, and the load applied at each of the four corners of the bogie.

Any impending failure that triggers the limits programmed on any one of the sensors will result in immediate shut down. The system allows for trouble shooting by individual sensor; reprogramming or recalibration is possible for each individual sensor as well.

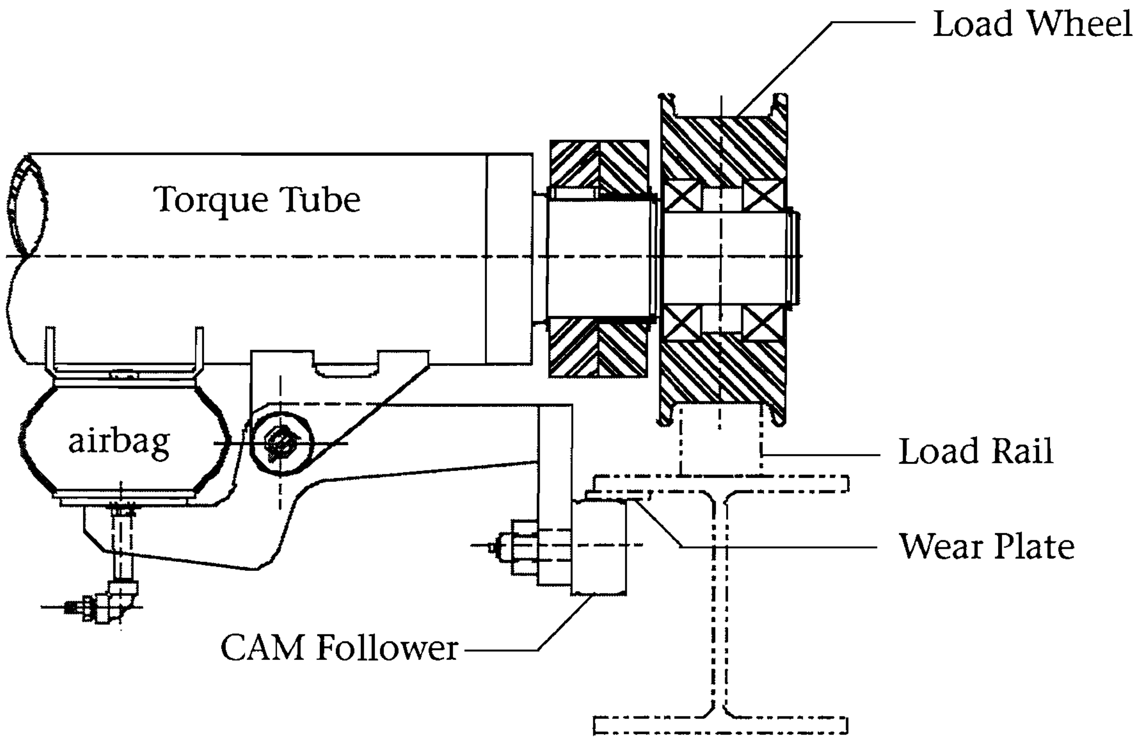
The entire MLS can be controlled from an onboard touch console or from an identical touch screen located in the control trailer. The control system is designed to integrate completely with the data acquisition system.



# LOAD WHEELS

*Specially designed load wheels were needed for required specifications*

The load will be transferred from the rigid load rail to the "bogie carriage" through the steel load wheels. The load wheel connection points also serve as hinges in the chain mechanism. The use of off-the-shelf crane wheels was analyzed, but specially designed load wheels were needed to meet the required specifications.

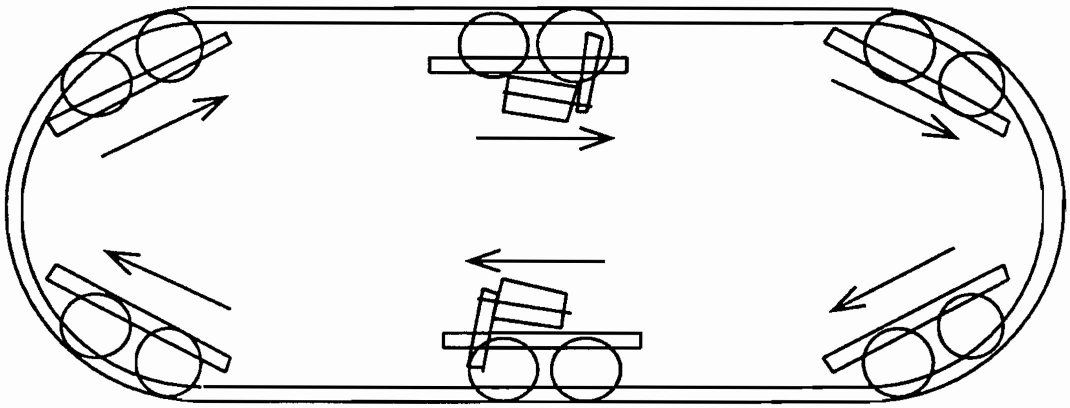



# LOAD RAIL

*The deflection requirements for the rail are such that upward forces caused by moving loads on the pavement should not generate deflection variations greater than a predetermined tolerance*

The load rail, shown above, indicates the loading mechanism that exists in the TxMLS. It is a rigid element spanning the length of the straight section. The deflection requirements for the rail are such that upward forces caused by moving loads on the pavement should not generate deflection variations greater than a predetermined tolerance, as the number and positions of wheels between the load rail and the pavement vary. Spacing of supports from the main structure to the load rail must be governed by this deflection criteria. A limit of 5% or less change in deflection of the load rail subjected to 126% of normal axle loads is envisioned.

The load rail poses a challenge in fabrication because of the significance of the dimensional accuracy required, the geometry of the two half-circle curves, and the great strength and rigidity required of the load rail. Initial investigation looked into the feasibility of using conventional rails and having members rolled or bent into shape. However, the final solution required that the load rail be fabricated and milled into shape.



# CLOSED-LOOP RAMP

*The ramp system permits the simulation of vehicle resistant forces such as steep grades and wind*

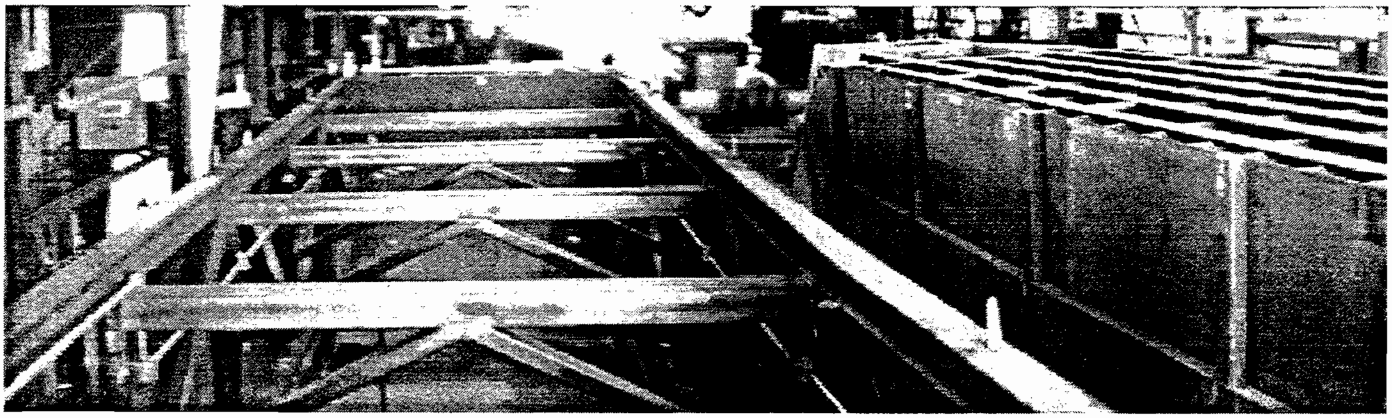
A closed-loop ramp concept was selected for its many advantages. The most notable advantage from the TxDOT and CTR viewpoint is safety. The second most notable advantage is dynamic effects. The bogie is continuously under load throughout the loop; therefore the fatigue loading is reduced and the dynamic loads imparted by the device to the pavement are minimized. Other advantages are: (1) reduction of centrifugal forces on the chain, (2) increased life of the bogies, (3) longer effective length of the test section, (4) containment of noise, and (5) ability to simulate accelerated environmental cycles.

The safety advantages of the fully enclosed loop design were sufficient to warrant the use of this concept. This enclosure will prevent potential flying debris from striking passing vehicles and pedestrians. It will also prevent curious onlookers from accidentally injuring themselves by getting too close to the machinery during operation.

The ability of the ramp to handle the large centrifugal forces reduces the forces on the chain, thereby allowing for a more reasonably sized chain mechanism. The ramp will increase the life of the bogies by preventing them from suffering a sudden impact when entering under the load rail. This impact is eliminated by keeping the bogies under load at all times By eliminating the impact to the bogie when entering under the load rail, the ramp also increases the effective length of the test section for measurement and data collection purposes by providing a longer section without artificially introduced dynamic loads.

The closed-loop system provides for the containment of noise. Although not planned for the first prototype, this enclosure also allows the TxMLS to simulate environmental conditions such as seasonal temperature and rainfall cycles within the contained structure. A certain degree of environmental control can be achieved with the addition of heating and cooling equipment. Built-in water sprays can provide rainfall simulation.

The ramp system permits the simulation of vehicle resistant forces such as steep grades and wind. On future prototypes, changing degrees o: friction may be imposed on bogies by various means when they are in contact with the closed metal ramp, allowing foı an increased simulation of longitudinal shoving. The shoving action can also be increased by having fewer drivε axles, which will increase the amount of friction to be overcome per drive axle at the samε speed. This ability to resist alsc has the potential (on future prototypes) to allow for some power regeneration thereby reducing operating costs.



# SUPERSTRUCTURE

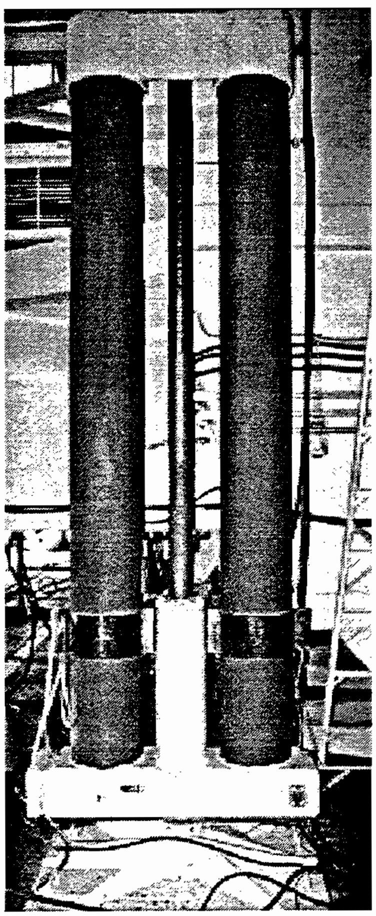
*The superstructure is composed of two pseudo-plate girders connected by lateral cross members*

The primary function of the superstructure is to transfer the deadweight of the TxMLS to the bogies while maintaining rigidity and shape. It must be capable of surviving millions of cycles of vibration without failure. It must also maintain its rigidity during transport.

The superstructure is composed of two pseudo-plate-girders connected by lateral cross members. The two large pseudo-plate-girders on each side also serve as containment for safety, noise, and environmental simulation as discussed.

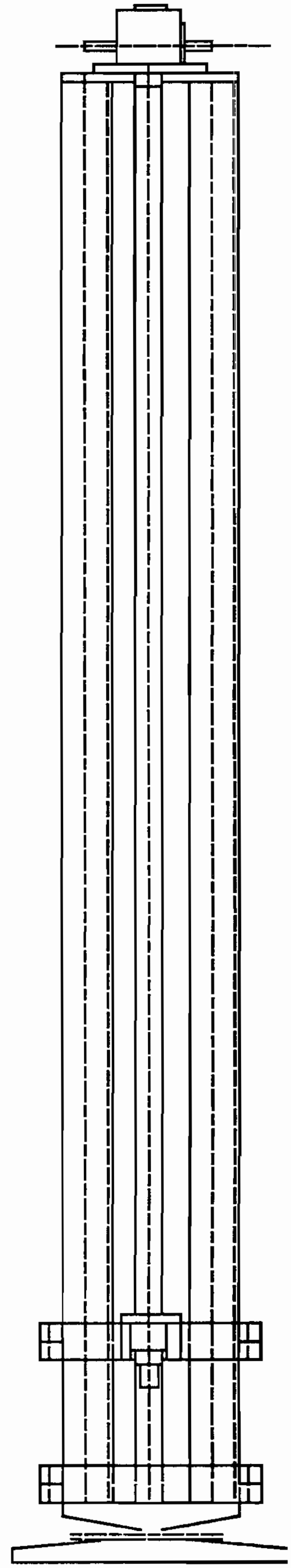
# JACKSCREWS

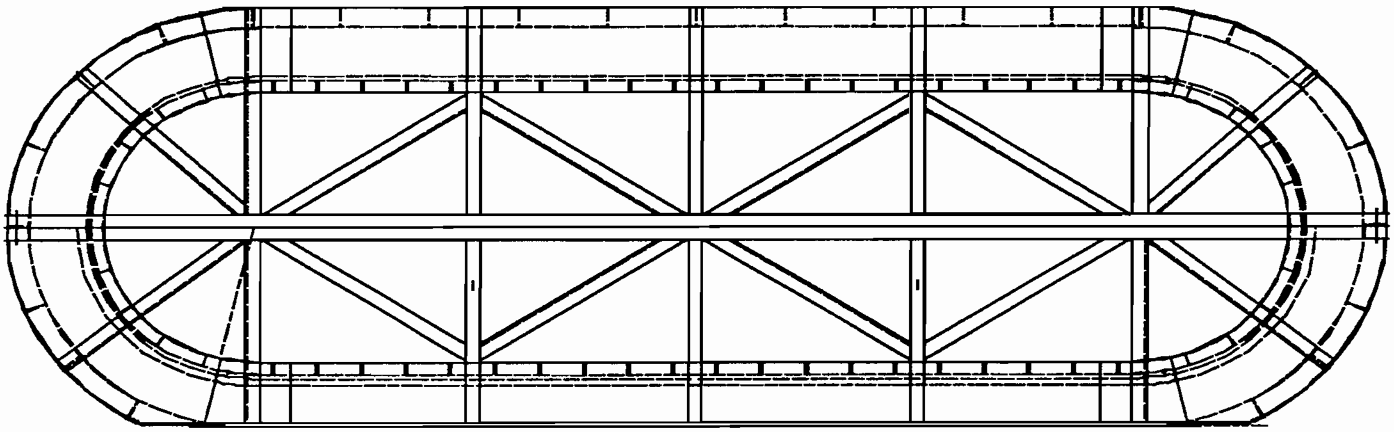
*The jacks are used to raise each of the halves of the MLS and lower them to the testing position or onto the specially constructed travel trailer and dolly*



Four 20 foot jackscrews connected to the upper half of the MLS are used to raise and lower the structure. To change the load on the pavement, the load rail, which is rigidly attached to the structure, can be forced lower or higher, resulting in higher or lower forces transmitted from the suspension to the pavement surface. An automated jacking system with a two-speed motor is used to make these adjustments. As illustrated, the jackscrews consist of two 20 foot lengths of 12-inch tubing connected to a screw actuator.

For transport, the MLS is too tall to travel unrestricted on the Texas highway system. The jacks are used to raise each of the halves of the MLS, separate the top and bottom halves, and lower them to the testing position or onto the specially constructed travel trailer and dolly. The jackscrews must also be removed for highway travel to meet height restrictions.






# OVERALL DIMENSIONS OF THE TxMLS

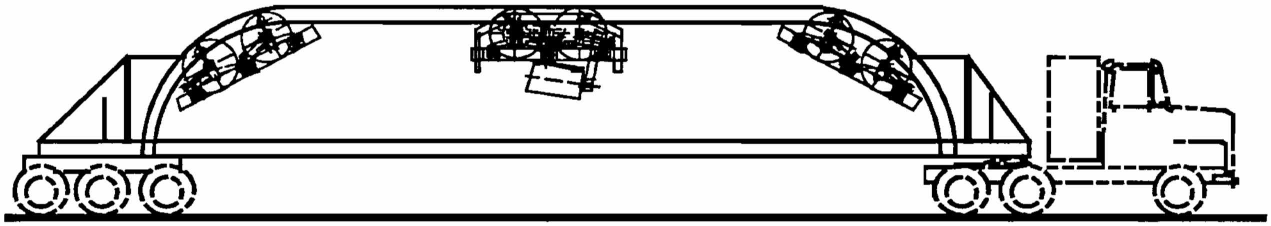
*The length is primarily dictated by the design test section*

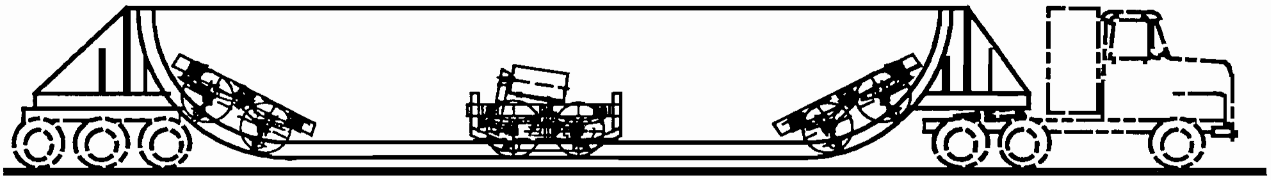
Overall Width (W), 12 ft. 6 inches (150 in.): The normal width of a heavy vehicle traveling without a permit on Texas highways is 102 inches. In order to provide the necessary lateral wheel distribution, additional width will have to be built into the permanent width of the machine. The width increase (to 144 inches) is expected to provide increased stability for the machine, both in transportation and in testing.

A standard truck has a width of approximately 8 ft. (96 in.). Based on comparisons of lateral load distributions of 31.5 inches for the Australian Accelerated Loading Facility (ALF) and 60 inches for the South African Heavy Vehicle Simulator (HVS), the TxMLS has been designed to distribute the load over a width of 24 inches. Because failure to provide adequately for lateral load distribution may result in erroneous pavement response measurements, the TxMLS designers recommended that the overall width be set between 132 inches and 168 inches depending on other structural components.

Overall Length (L), 86 ft. 5 inches (1038 in.): The length is primarily dictated by the design test section length plus twice the protrusion of one of the semi-circular end ramps plus the end sections which are needed to transport the TxMLS on the highway.

Overall Height (H) 22 ft. 6 inches (270 in.): The overall height of the machine during testing is dictated by the geometry of the parabolic end ramps. For transport, the height will be equal to or less than 13.5 ft. This is accomplished by dividing the machine into sections as described in the next section.



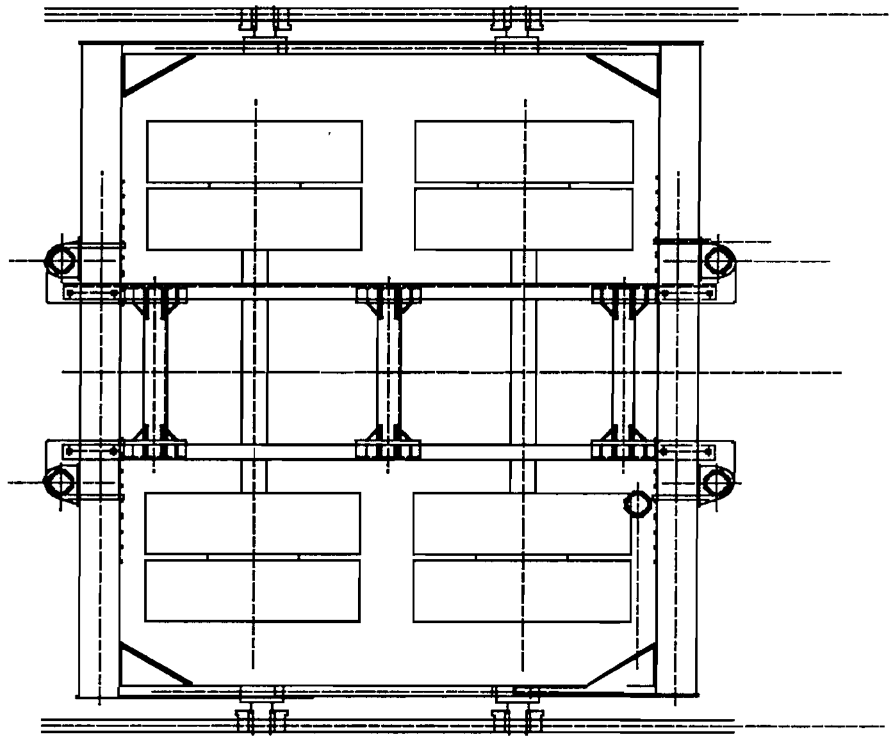


# TRANSPORTATION METHOD

*The lower half is backed into position and mated with the upper half*

The design of the TxMLS has specifically addressed the time-consuming task of site establishment. Because the assembled TxMLS exceeds legal heights, the transportation configuration for long-haul transport will include not only the reduction in height for transport, but also the safety and ease of assembly and disassembly. The length, width, and weight parameters will exceed legal unpermitted limits; however, each parameter will be within permitting limits. Four 20-foot jackscrews attached to the upper half of the MLS will be used to raise and lower the MLS.

Operational setup includes placement of the upper half of the MLS in position and raising it to full height. The lower half is then backed into position and mated with the upper half. When both halves are bolted together the MLS is raised off the transport trailers and set into testing position with the jackscrews. During testing, if the MLS needs to be moved for FWD testing of the test section, the MLS can be moved short distances on the transport trailers all in one piece.

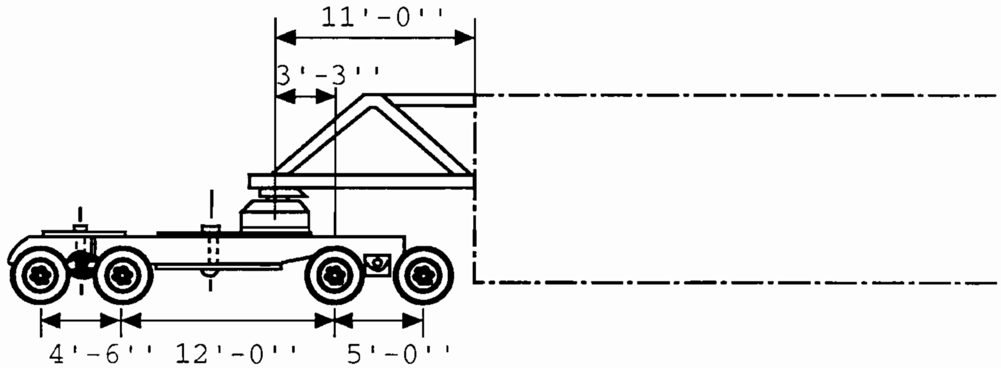


# TOTAL MASS OF BOGIE CARRIAGE AND TRUCK BOGIE

*The total mass of the powered bogie is 8,800 pounds*

The total mass of the moving frame is important in the calculation of the forces that will be exerted on the chain through rotation. Dynamic effects can be minimized by placing the frames in a symmetrical configuration. Nevertheless, shear forces on the main frame will have to be considered as well as the repetitive fatigue loads.

The total mass of the powered bogie is 8,800 pounds and the trailer bogies are approximately 4,400 pounds each. The mass of the bogie carriage is approximately 3,000 pounds each. The brake shoes, brake drums, and idler arms have been removed from the comercially purchased bogies in order to save weight. This has resulted in an approximate additional weight savings of 800 pounds per bogie.

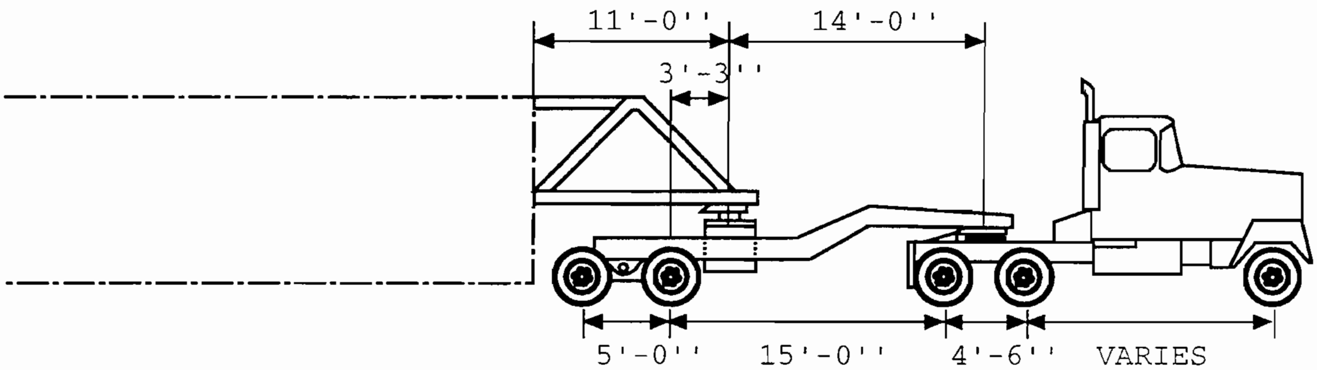



# EVALUATION AND DATA COLLECTION OF TEST SECTION

*The data acquisition computers will interface with the MLS controller*

A computerized data acquisition system has been designed to accompany the MLS. The data acquisition computers will interface with the MLS controller. The system will be state of the art, with numerous instrumentation channels and both low and high sampling rates. In addition to reading strain gauges in the pavement, several other measurements will be made automatically as well. On this first prototype, testing of the pavement section will require moving the machine off the test pavement. Surface profiling, falling weight deflectometer, and crack mapping will be performed.

The instrumentation and data acquisition package is being designed such that data can be transmitted from the site to the TxDOT home office. The office will also be able to access the operation of the MLS and transmit changes to the field. Much of the data will be reduced at the site to minimize analysis time.

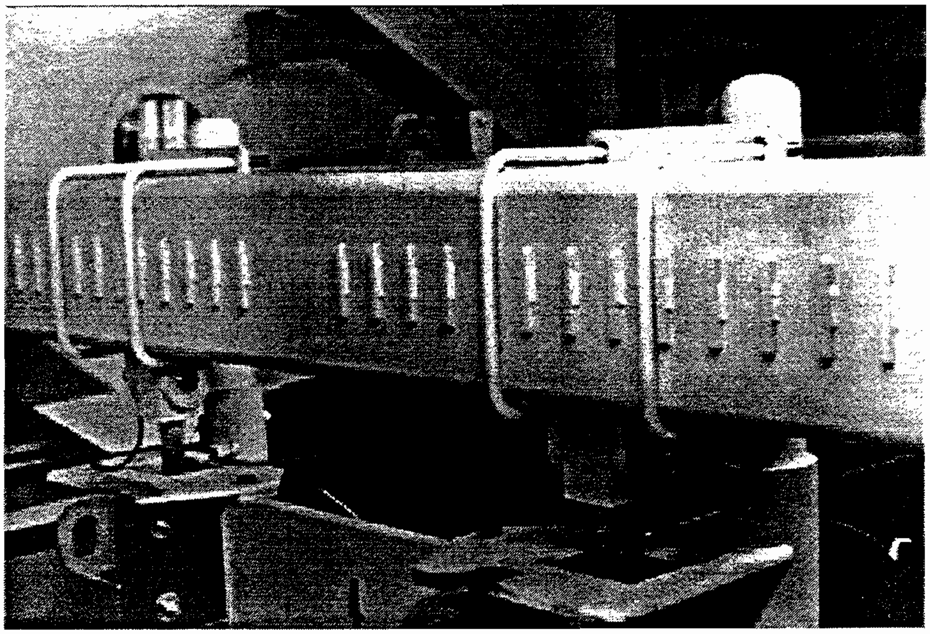



# PROVISIONS FOR REAL TRAFFIC AND ENVIRONMENTAL SIMULATION

*The utilization of real truck suspensions and axles make the TxMLS an excellent pavement evaluation tool*

The TxMLS is capable of simulating actual traffic conditions to a degree unattainable by other linear load simulators. And such additional features as the utilization of real truck suspensions and axles make the TxMLS an excellent pavement evaluation tool.

As discussed earlier, environmental simulation can be achieved by utilizing the box-like structure of the TxMLS. By closing the sides, ends, and top, the designers have provided an environmental chamber. The uniqueness of this environmental chamber is its mobility (that is, it goes everywhere the TxMLS goes).

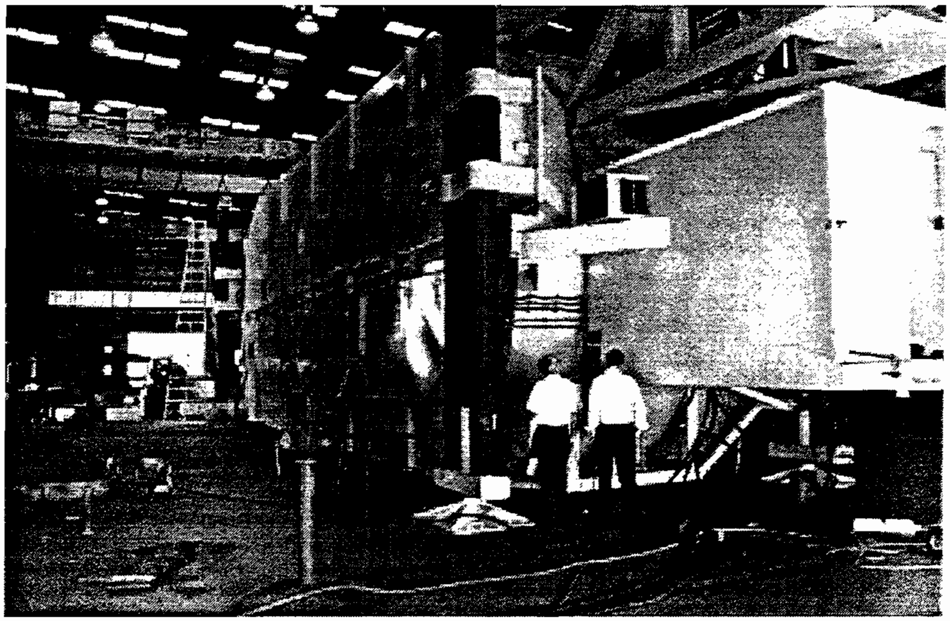


# TxMLS OPERATION

*The MLS is designed such that the six bogies can be placed in the same alignment and distributed in a pattern up to 12 inches either side of center*

The primary objective of accelerated traffic simulation is to apply as many equivalent single axle loads (ESAL) as possible in a given time. The MLS primarily uses legally loaded 34,000-pound tandem axles using a six-bogie configuration for a total of twelve axles. This configuration is based on such factors as deflection basin influences, following distances for adequate pavement recovery time, and degree of overloading. Other axle configurations may be selected, provided some symmetry is maintained (if possible). Provisionally, a maximum of 16 axles is possible. Use of either single axles or tandem axles will require a different bogie design (one that would fit the current bogie carriage).

The MLS is designed such that the six bogies can be placed in the same alignment and distributed in a pattern up to 12 inches either side of center. This adjustment is done manually to simulate the wander or distribution of normal truck traffic on highways.



# TxMLS JUSTIFICATION

*The most significant benefit to be gained through application of the TxMLS is the high rate of real load application*

Mobile load simulation has become an essential operation for progressive pavement agencies. Other mobile accelerated loading devices are in existence, and a comparison of the specifications of these devices is shown in *Table 1*. In *Tables 2a and 2b* the applicability of the respective machines for many pavement test variables is indicated.

The most significant benefit to be gained through application of the TxMLS is the high rate of real load application in contrast to other systems requiring overloading to accelerate the loading process. Combined with the vast amount of expertise available from the other two programs (the HVS and the ALF), the implementation of the Texas Mobile Load Simulator program should contribute tremendously to pavement engineering knowledge.

# APPENDIX C

# THE NEW SPANISH CEDEX ACCELERATED PAVEMENT TESTING DEVICE AND FACILITY

CTR recently visited the CEDEX facility in Madrid, Spain. At the time of the visit the new CEDEX devices were under construction and the test track was idle, as the track was being configured with new power rails to accommodate the two new testing devices. Figure C-1 shows one of the new CEDEX devices under construction.

In the left side of the figure, the portion of the device that contains the control system, the electric motor, and a very large frame that rides the concrete monorail is visible. Also visible are the sixteen truck tires mounted horizontally to counteract the forces on the cantilevered section. There are four truck tires mounted vertically which carry the load of the devices on the concrete monorail.

The loaded section of the device is also visible on the right side of the figure. One can see the dual tires on a half axle. The new model provides reinforcement in this portion of the device. The large horizontal silver cylinders visible in the photo are used to control the movement of the loaded section to account for truck wander.

Figure C-2 is a photograph taken from the rear of the cantilevered portion of the device, which shows the air-bag suspension. A very large compressor is installed on the device, which is capable of providing additional air continuously to the air spring suspension, to the tires (to overcome a small leak), and to the braking system, with enough capacity to stop the device quickly. In Figure C-3, the on-board air compressor and air lines required on the device are shown (the air system is a very important part of the CEDEX device). Nearly all the tires on the device are monitored with limit switches that can shut down the device in case of tire failure.

In Figure C-4, a close-up is shown of the connection between the cantilevered loading portion and the portion that rides the concrete monorail. The connection is hinged to allow vertical movement in the loading portion. Also, in the lower right portion of the photograph, there are two circular openings in the loading carriage. One is used to provide a drive axle to the dual wheels for the device, and the other is used to access a second half axle if deemed necessary. Although the device is capable of two half axles, current plans are to continue testing with a single half axle.

While the maximum legal axle load in Spain is 13 tonnes, the typical maximum load in Europe is 10 tonnes; the compromise legal load decided by the European Economic Community will be 11.5 tonnes. The load on the CEDEX device is applied by gravity. To vary the load on the loading device, ballast is used to add more weight above the minimum weight of the device. Figure C-5 shows the steel plates that are used for additional ballast to control loading.

Figure C-6 shows a layout of the CEDEX test track. The track is 300 meters in total length. Three 20-meter test sections are located in each of the 75 meter straight sections of the track. The test sections are covered from the elements on both sides of the track.

The actual track is two paving lanes wide, such that the outside lane is not trafficked and acts as a control comparison to the loaded lane.

The building in the center of the track houses the control facility and the data acquisition computers. The building is accessed by tunnels at both ends of the track. The control building has windows to observe the device as it travels around the track. The control building also contains a full basement and connects to instrumentation tunnels underneath the straight sections of the monorail.

The offices of administrative staff occupy a portion of the main CEDEX building. The CEDEX organization at that site includes two other branches besides the test track: a traffic branch, which operates weigh-in-motion equipment, and a rehabilitation branch, which is responsible for developing rehabilitation strategies.

The laboratory occupies the basement level of the main building and definitely contains the state of the art in equipment. A significant amount of space has been provided to store samples of test pavement cores and beams.

The building at the opposite end of the track houses the support equipment for the test track and the traffic branch. Several garage spaces house the falling weight deflectometer (FWD), a truck-mounted Benkleman Beam deflection measuring device, a coring rig, and several other pieces of equipment. The building also has a small machine shop and a large instrumentation laboratory. Space is provided to maintain the test sections with patching materials and to mark cracks in the pavement with paint.

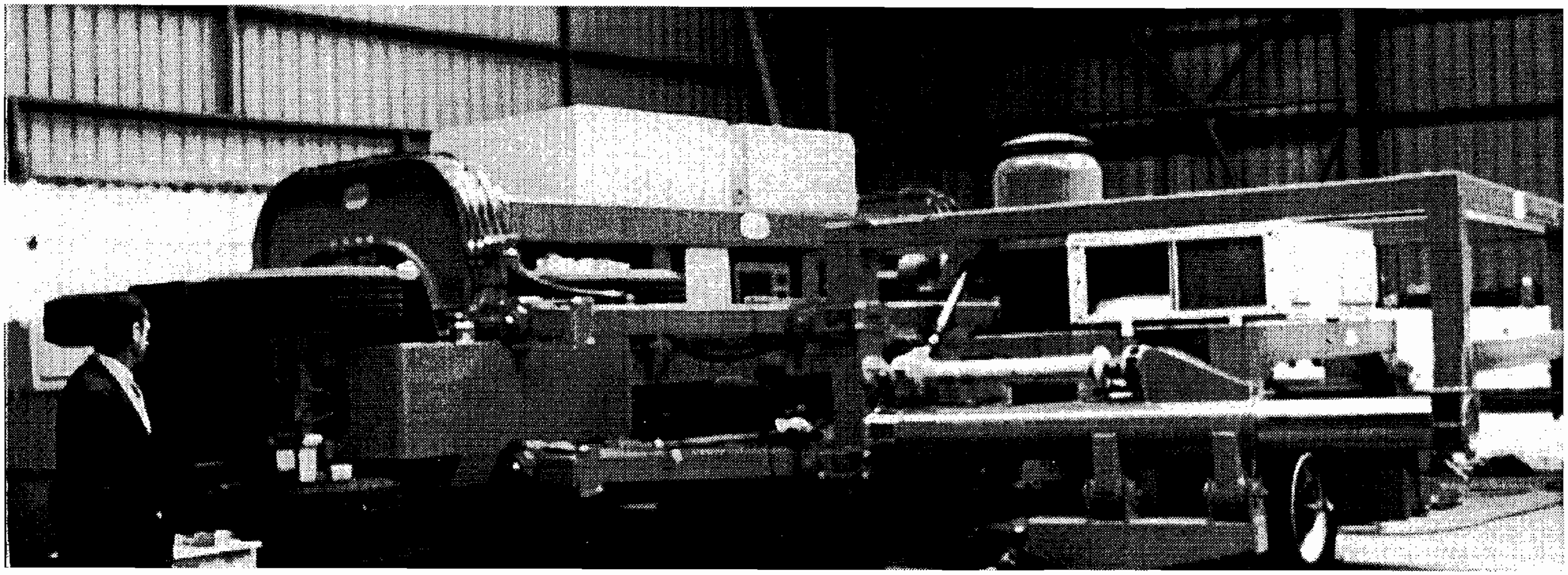


Figure C-1

*The newCEDEX testing device*

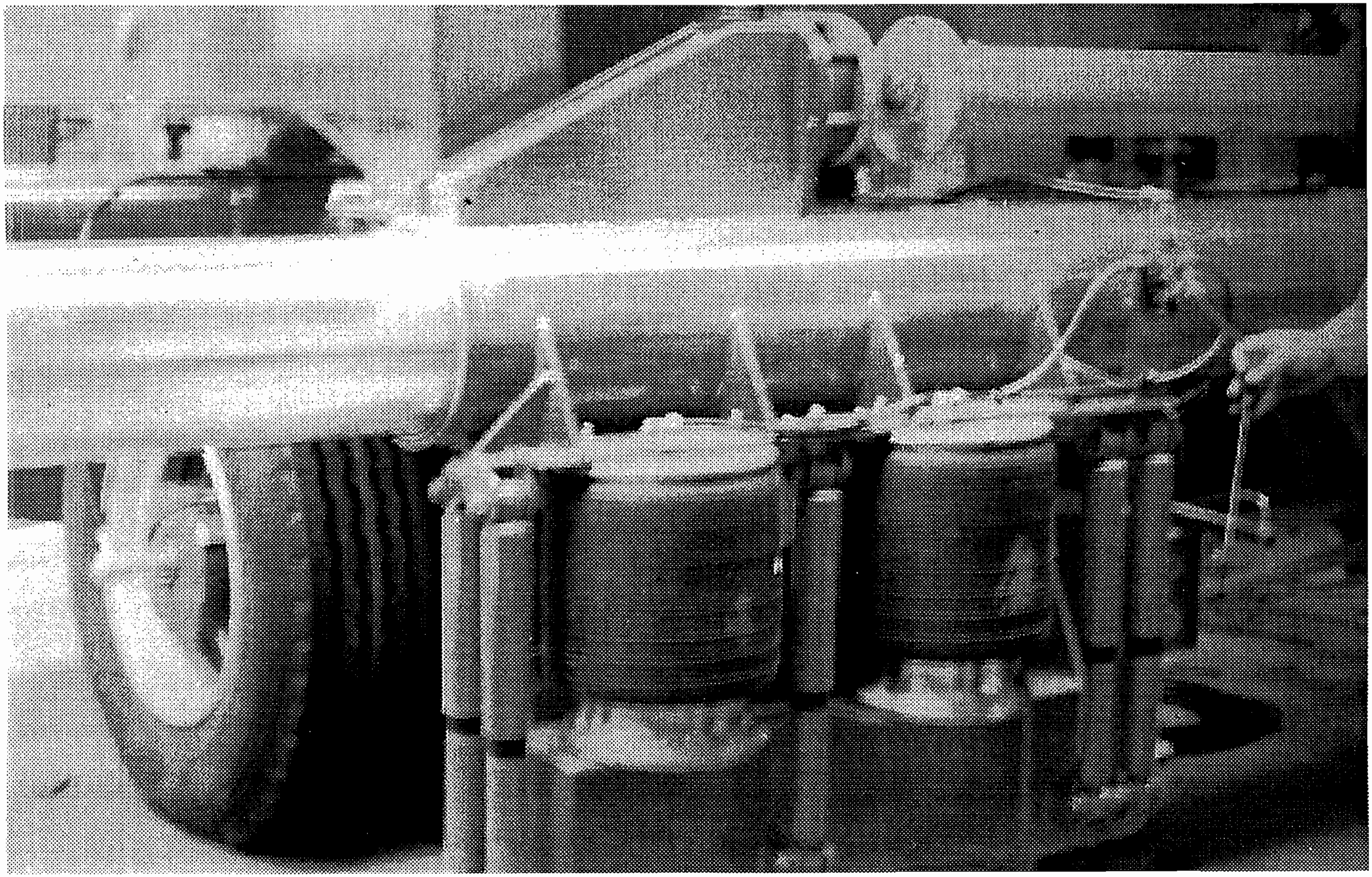


Figure C-2

*The air-bag suspension of the new CEDEX device*

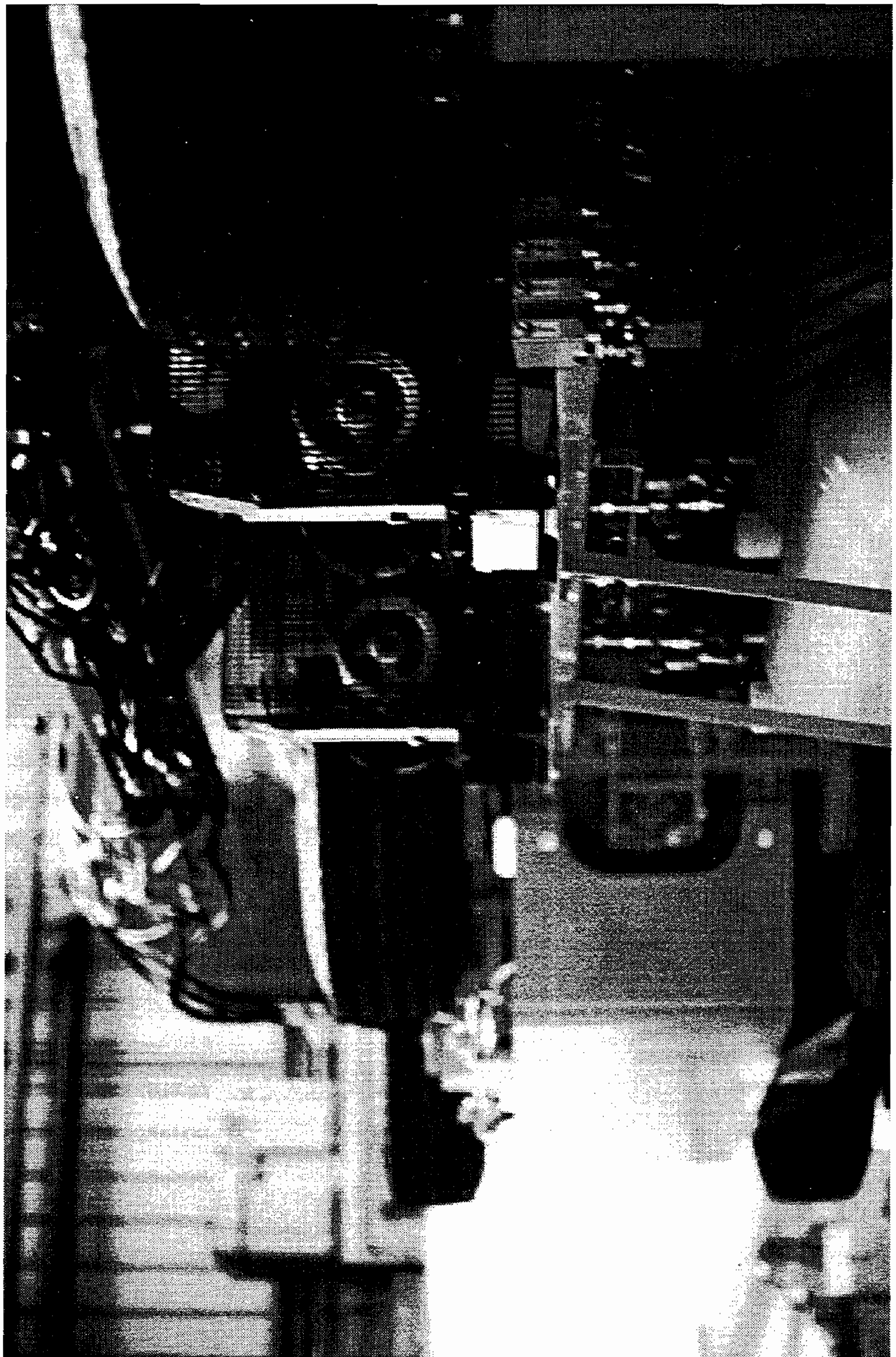


Figure C-3

*The air supply system of the new CEDEX device*

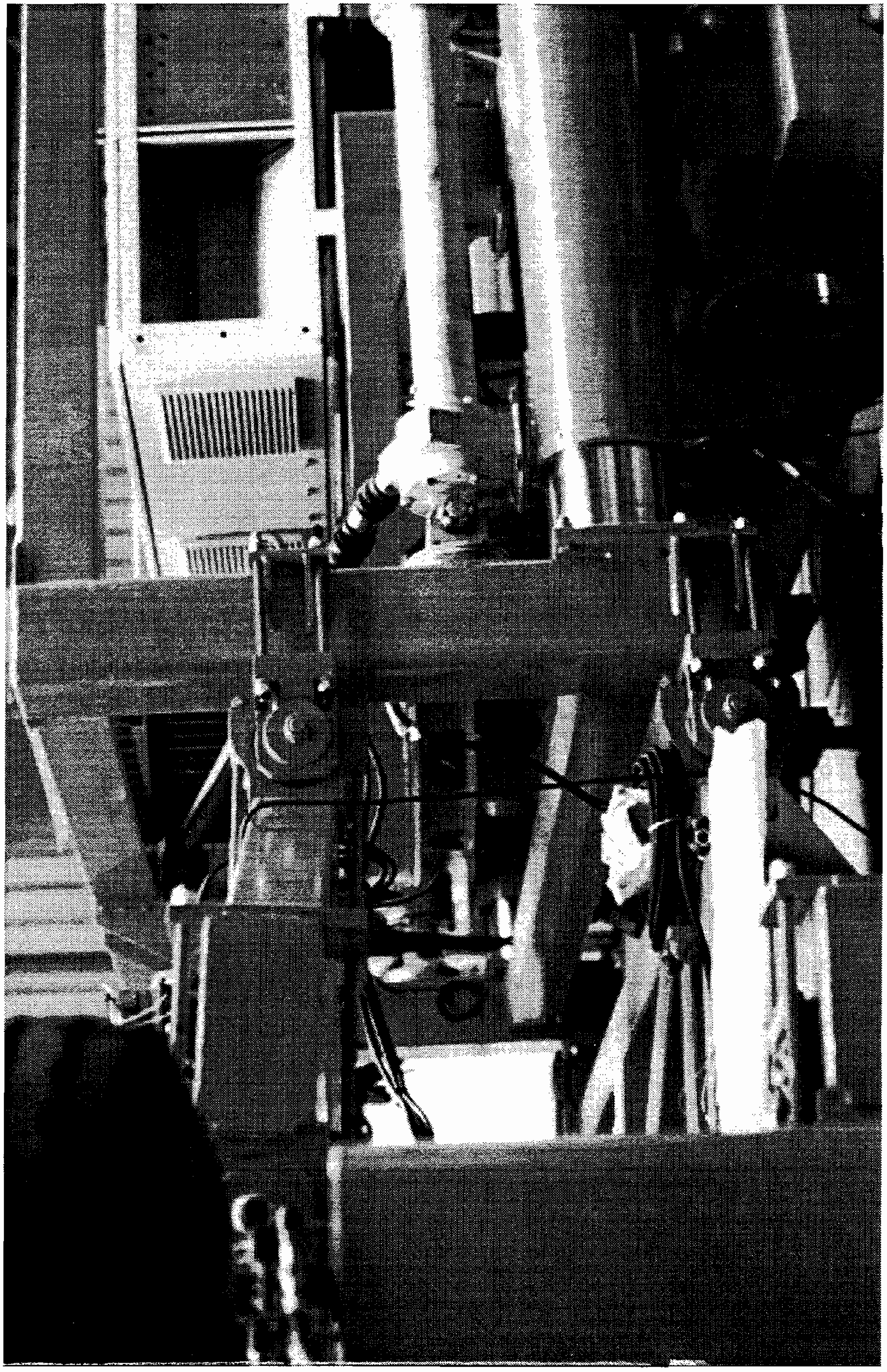


Figure C-4

*The cantilevered portion of the new CEDEX device*

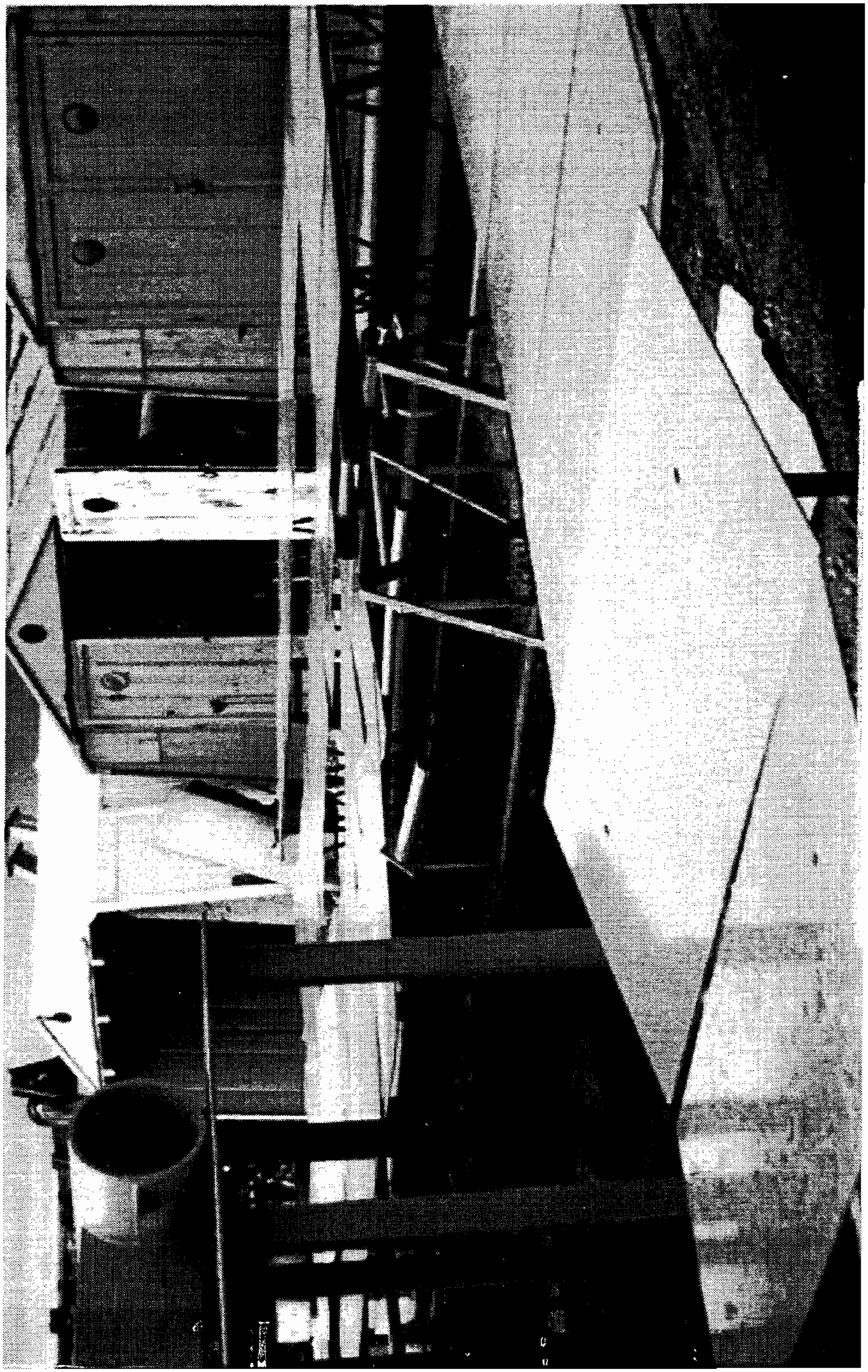


Figure C-5

*Steel plates used for ballast on the new CFDFX device*

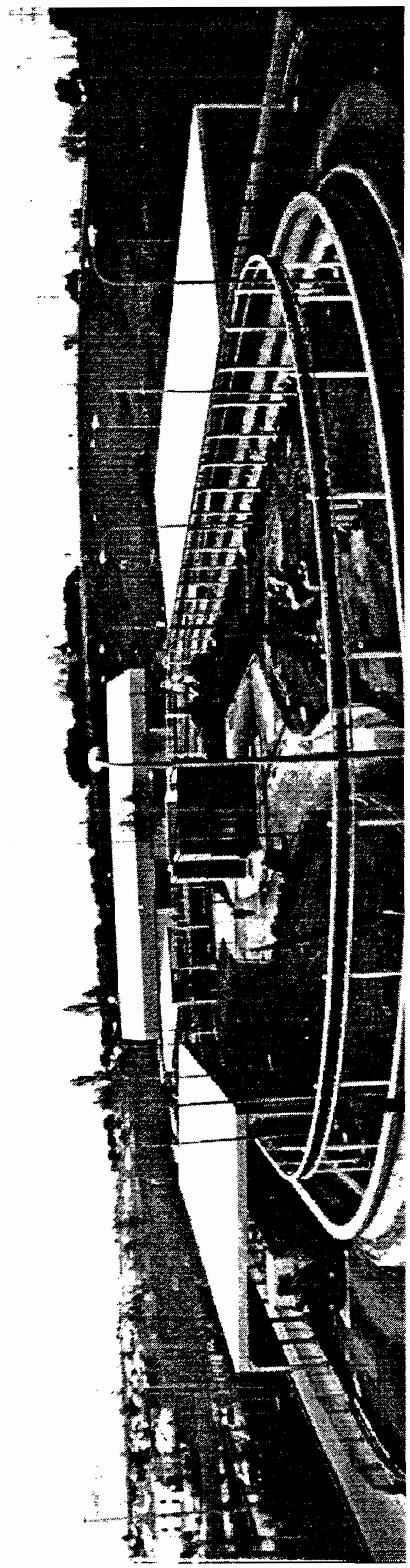


Figure C-6

*The CEDEX test track layout*

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