Lessons Learned from the Operations Management of An Accelerated Pavement Testing Facility

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ABSTRACT

Thirteen full-scale pavement testing projects have been conducted at the Accelerated Pavement Testing (APT) facility at Kansas State University (KSU) over the last ten years of continuous operation. Located at the Civil Infrastructure Systems Laboratory (CISL) in Manhattan, Kansas, the facility is a part of the Department of Civil Engineering at KSU. The Midwest States Accelerated Pavement Testing Pooled Funds Program, a consortium of the Departments of Transportation of Iowa, Kansas, Missouri, and the Nebraska Department of Roads, sponsors the APT program at this facility.

The operation of an APT program in a university research environment while serving the research needs of the sponsors' presents many unique challenges. Need for uninterrupted operation of the facility and its maintenance, budget, time, staffing, and capabilities have always been big concerns. Sometimes equipment maintenance and student scheduling had been difficult at best. Technological improvements in instrumentation, data acquisition, and APT facility control systems as well as mechanical system improvements have continuously been incorporated at KSU APT. Sensors and non-destructive test equipment are being developed and evaluated. Development of the test sections with the researchers and contractors while maintaining construction quality control is a big challenge in an indoor facility. The large amount of instrumentation data collected and subsequent processing also requires a major effort. This paper describes these challenges and how they were successfully tackled over the last decade. Finally, the paper describes future goals and improvements for the next decade based on our past successes as well as mistakes.

INTRODUCTION

The year 2007 was a milestone for the Department of Civil Engineering at Kansas State University (KSU). Not only was it the 100th anniversary of the founding of the Department, it was the 10th anniversary of the Accelerated Pavement Testing (APT) program at the Civil Infrastructure Systems Lab (CISL), the Department's off campus research lab. The APT program accounts for the majority of the research performed at the lab. Thus far 13 different tests have been conducted as shown in Table 1. Tests have included design validation for Hot Mix Asphalt (HMA) and Portland Cement Concrete Pavements (PCCP), subgrade and base stabilization, and load transfer devises for concrete pavements. The average test length has been one year with some as short as 6 months or as long as three years. This paper describes the development and evolution of the program, project development considerations, and goals for the future based on the experience gained in the previous tests.

DEVELOPMENT AND EVOLUTION OF THE APT PROGRAM

In the continuing effort to improve pavement performance, transportation departments and researchers are evaluating new designs and procedures. In-service validation and assessment can be costly and time consuming. Full scale APT can be a cost effective solution that provides real world testing capability in a shorter time period. For these reasons the Department of Civil Engineering at KSU and the Kansas Department of Transportation (KDOT) developed the CISL facility. The project was supported by an industrial partner, Cardwell International, Ltd, who performed the design and construction of the testing machine. A matching grant was awarded by the Kansas Technology Enterprise Corporation (KTEC) to support the project and subsidize the construction, development, and operating costs. Private donations from KSU alumni allowed the College of Engineering to construct the building. [1]

Description of the Facility

Located in the eastern Industrial Park in Manhattan, Kansas, the 537 m^2 CISL lab houses the APT program. Three test pits, 6.1m x 4.9m x 1.8m pits and one 6.1m x 3.7m x 1.8m environmental pit, provide space to construct a variety of pavement or structural test sections. The CISL lab also houses a Falling Weight Deflectometer (FWD) calibration facility and a 2,225 kN outdoor structural testing frame. A 89 kN overhead bridge crane and an outdoor staging area for soils and aggregate enhance the lab’s functionality. Two 4.3m x 6.1m overhead doors allow access to the main testing area.

Description of the APT Machine

The APT Machine consists of a 12.8m reaction frame with single or dual axle assemblies. The dual wheel axle assemblies are belt driven using a 20 HP electric motor and a variable frequency drive (VFD) to control speed and direction. Testing speed is approximately 11.3 km/h and it is capable of 100,000 wheel load applications (bi-directional) per week. It has a 178 kN loading capacity and is capable of uni-directional or bi-directional loading. Load is applied and removed with hydraulic cylinders through an on-board pump. Up to 0.762m of wander can be applied with a user-defined interface. Operational costs of running the machine are $26/hr (USD) with the funding used to maintain the equipment and provide for technology upgrades.

Evolution of the APT Machine

The APT Machine has gone through many changes over ten years of operation. Originally the axle assembly was an actual trailer bogie from a tractor-trailer. Load was applied with air bags from the bogie’s air suspension system. It was felt that this would provide a “softer” suspension than a hydraulic system. The original design provided a 77.8 kN loading capacity, which was the load rating of the axles. An on-board air compressor applied the load. The desire to increase the loading capacity required a larger air compressor to be remotely installed and a system was developed to transport the air to the moving bogie. As the system used hydraulic cylinders to lift the axles in uni-directional loading, larger cylinders were installed to lift against the increased load. The cylinder attachments started to break and were strengthened. Then the axles broke. This required a redesign to apply the load and lift the axles using hydraulics exclusively. Dennis Pauls of Daptech, Ltd. who originally designed the machine while at Cardwell International, performed the hydraulic system changes.

In an effort to accelerate the number of load repetitions applied, the next upgrade was developed. The original analog control system using relay logic had few safety systems and required personnel to be present to monitor the equipment**.** Student employees worked evenings until 10:00 pm when we would stop testing and restart the next day. It was decided that we needed to perform testing 24 hours a day, 7 days a week in order to increase the number of load repetitions. It was also decided to incorporate the ability to provide wheel wander at that time. Dennis Pauls designed the mechanical system improvements. These consisted of incorporation of screw jacks to move the frame for lateral wander, installation of load cells, transducers, and safety systems. Tim Arnot of Advanced Control Systems developed the programmable logic control system as a subcontractor to Daptech, Ltd. The installation went well and after correcting a few problems we now have the capability to operate 24/7 unattended.

There was still a desire to increase the loading capacity of the machine. In order to apply single axle loads, one of the dual axles had to be disabled and chained in the “up” position. This resulted in a difference in load in one direction while testing in bi-directional mode. As the reaction frame was rated for fatigue at 178kN, to apply an axle load above 89 kN, a single axle was needed. Daptech, Ltd. designed a custom axle capable of higher loads and incorporated improvements to the hydraulic and suspension systems. As the costs of these improvements exceeded our budget, it was decided to incorporate as many parts of the existing axle system as possible, including the existing wheels and hubs.

Instrumentation and Data Acquisition

The need for accurate instrumentation has always been a concern. Researchers need the ability to determine how the pavement is performing and why the pavement fails. Readily available instrumentation usually comes with a higher price tag. Sometimes equipment that meets our needs is simply not available. Developing instrumentation has been a priority at CISL.

In order to monitor the development of rutting on flexible pavements, a transverse profiler was constructed. It consists of 4.27 m of aluminum tubing with a 5.08 cm square cross section. Stands on each end allow for height adjustment and individually adjustable feet allow for level correction. A Chicago Dial Indicator digital gage with a resolution of 0.025 mm is attached with a movable mount on to the beam. The indicator has a digital output and software to output data to a spreadsheet format. Fixed reference points are mounted at each end of the pavement to be profiled and measurements are taken at 1.27 cm intervals.

We have also developed the asphalt strain gages that we use. While asphalt strain gages are available, the lack of selection and high cost led us to develop a low cost version. We start with a TML type PML-60-2L concrete embedment strain gage. Two aluminum "H" bars are machined and attached using epoxy. These bars help bond the gage to the base of the asphalt layer. High temperature TFE insulated wires are attached to the gage. While we experience a high failure rate (at or above 15%) during construction, the lower cost of these gages allows for redundancy and we realize a significant cost saving. Geokon model 3500 soil pressure transducers are used to measure soil stress. We have found these transducers to be very reliable. We have been able to salvage and reuse these from one test to another. We have built a pressure chamber to calibrate the soil pressure transducers, which saves time and money. Thermocouples are constructed from the Omega thermocouple extension wire. Campbell Scientific Time Domain Reflectometer (TDR) probes are used to measure soil moisture. We are currently developing Linear Variable Differential Transformer (LVDT)-based multi-depth deflectometers to measure deflections of pavement, base, and subgrade layers under load.

A National Instruments SCXI data acquisition system is used to collect data. We have developed software and built signal-conditioning hardware so that we can acquire data from in-situ sensors, load cells, and position transducers all within the same acquisition system and time base. As our capabilities have increased so has the amount of collected data. What once needed floppy disks now requires DVD's to store. Processing and analysis of this large amount of data requires major effort. Attention to detail and accurate record keeping is mandatory to ensure satisfactory results.

Non-destructive test equipment is being used and evaluated to ensure quality control and measure pavement performance. A Troxler moisture density gage, a Geogage, and a light Falling Weight Deflectometer (FWD) are used to evaluate subgrade condition (density and moisture). KDOT provides us with data from their Dynatest FWD to measure pavement deflections. We are currently evaluating a Portable Seismic Property Analyzer for Pavements (PSPA-P). This along with the capabilities of the Civil Engineering Department's asphalt laboratories provides researchers with many resources to evaluate pavement performance.

Environmental Capabilities

An indoor facility has advantages and disadvantages. The ability to control environmental conditions is an advantage. The difficulty of duplicating natural conditions, such as freeze-thaw cycling and rapidly changing temperature conditions is a disadvantage. To this end we have incorporated several systems. Refrigerant compressors and a boiler give us the ability to heat or cool a glycol and water mixture -31.7^{o} C to 60^{o} C. The mixture is circulated through surface heat exchangers and u-tubes in the subgrade soil of the environmental pit.

The fact that pavement materials and soil are not good conductors of heat makes achieving set point temperatures or changing them a time consuming process. Infrared radiant electric heaters have been employed with some success in creating differential temperatures between the pavement surface and the subgrade. Maintaining uniformity throughout the test section has been difficult at best. The ambient temperatures within the building vary with the seasons as the building has heating but not cooling. The evaluation of flexible pavements, where performance varies with the temperature, has led us to develop an environmental chamber around the APT Machine. Walls of lightweight aluminum and insulating foam now enclose the machine. Heating/cooling units on both ends provide us with the capability to maintain temperatures between 37.8^{o} C and 15.5^{o} C. This system has been successful in maintaining temperatures throughout the test section.

PROJECT CONSTRUCTION CONSIDERATIONS

Construction of test sections that meet the needs of our sponsors and researchers can be a difficult process. Maintaining quality control during construction is very important. The fact that our test sections are constructed in pits requires the use of specialized equipment. Compaction and grading of the subgrade and base must be done with smaller sized equipment than in the field. We use a rammer style compactor to achieve compaction specifications. We have developed a method to grade the soil in the pits using a heavy beam fitted with a grader blade edge, pulled by chains and pulleys, and powered by our overhead crane. The small size of our test sections and the need to stop often for measurements has required us to do most of the subgrade construction in-house using student employees. Training and scheduling, as well as safety concerns, requires flexibility and attention to the details. Working with pavement contractors to provide timely project completion can be a challenge. The small size of our pavements makes these projects a low priority for the contractor. It is difficult to find contractors willing to do this type of work even with inflated prices. A good working relationship with the local companies is necessary. It is very important that all parties involved in the project realize these challenges and provide adequate time and flexibility to ensure successful project completion. Many unexpected problems can occur in maintenance, scheduling, personnel, and budget. Parts for the APT Machine can be difficult to find and require significant lead-time to acquire. Students require flexible schedules and may not be available when needed. Class schedules, breaks, and holidays must be incorporated into the testing plan. Fixed budgets do not necessarily allow for unanticipated expenses such as equipment failure and replacement parts. All these factors are difficult to anticipate but must be considered while developing a project that may not start until a future date. Occasionally project time and cost extensions have been required but every effort has been made to stay on schedule and within budget.

FUTURE GOALS AND IMPROVMENTS

To maintain the success we have enjoyed the past ten years we need to increase and improve our capabilities. We need to maintain and upgrade the testing equipment. We should incorporate improvements in technology as time and budget permit. A flexible improvement plan is an important part of our program.

APT Machine

Currently a compensator on the hydraulic pump controls the wheel load. As the axle assembly moves over irregularities in the pavement the load will increase or decrease. The installation of an additional hydraulic accumulator has helped. The best solution is to have a closed loop control system. Feedback from the load cells on the axle would allow a controller to adjust the load using servo valves in the hydraulic circuit. In order to reach the rated frame load with the single axle assembly, stronger wheels and hubs would need to be installed. Tires with a higher load capacity would also be needed. Interest has been expressed in the ability to use a “super single” tire and wheel combination.

Instrumentation and Data Acquisition

As technology is constantly improving, the data acquisition system should improve as well. Faster sampling rates with higher resolution and additional channel capacity are constant goals. Upgrading software and applications should be done as new versions are released. New sensors should be developed and/or evaluated to improve our ability to monitor pavement performance. Better processing and analysis methods need to be developed to handle the increasingly large amounts of data.

Environmental System

Improvements in the environmental system can be made. Separating the heating and cooling loops will reduce the time required to do the freeze thaw cycles. Improving flow through the heat exchangers and adding a bypass loop will improve our ability to achieve temperature extremes. Better control of the ambient temperature within the facility would help better regulating the testing temperature.

CONCLUSION

APT continues to be a cost-effective method of evaluating pavement performance. This is evidenced by our sponsors’ commitment to fund the program for the next five years. The lessons learned over the past ten years have helped to insure our continued success. Interaction between the sponsors, researchers, students, staff, and contractors is needed to develop successful research projects. Careful attention to detail when preparing a project is essential. Time and budget commitments must be carefully made to account for unexpected delays and costs. Technology upgrades must be continuously incorporated.

Visiting other APT facilities, attending conferences, and reviewing the body of work in pavement testing are essential to success. We are privileged to work in an environment of cooperation rather than competition. Everyone is encouraged to provide input. Building on our successes and learning from our mistakes will ultimately help develop the program, and insure our continued success for the next decade.

REFERENCES

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List of Tables and Figures

Table 1. APT Testing and Research Activity at CISL

• Rutting of cold in-place recycled, fly ash stabilized, asphalt pavement with a thin asphalt overlay. [1]
• Comparing three different types of shear transfer devices in jointed Portland Cement Concrete Pavements (PCCP). [2]
• Comparison of KDOT Superpave (SM-2C) with Marshall (BM-2C) overlay mixes over existing/previously tested PCCP under radiant heat conditions. [2]
• Comparing fiber reinforced (FRP) dowels versus epoxy coated steel dowels in PCCP under adverse cooling/heating conditions. [2]
• Testing 8 inches of an asphalt concrete mix on grade compared to 5 inches of the same mix placed on 5 inches of reclaimed asphalt milling. [2]
• Milling a 2-inch layer from the surface and replacing it with a new HMA overlay.
• Rutting performance of Superpave mixtures with different ratios of river sand.
• Pilot instrumentation of a Superpave test section at the Kansas Accelerated Testing Laboratory. [3]
• Effectiveness of thin non-doweled non-reinforced PCCP overlays on highly distressed PCCP.
• Performance of non-doweled, non-reinforced PCCP on drainable and semi-permeable bases.
• Effectiveness of epoxy-coated steel and fiber reinforced polymer (FRP) dowels as PCCP joint repair.
• Performance of foamed asphalt Stabilized base in full depth reclaimed asphalt pavement. [4]
• Thin bonded rigid overlay on PCC and HMA pavements.

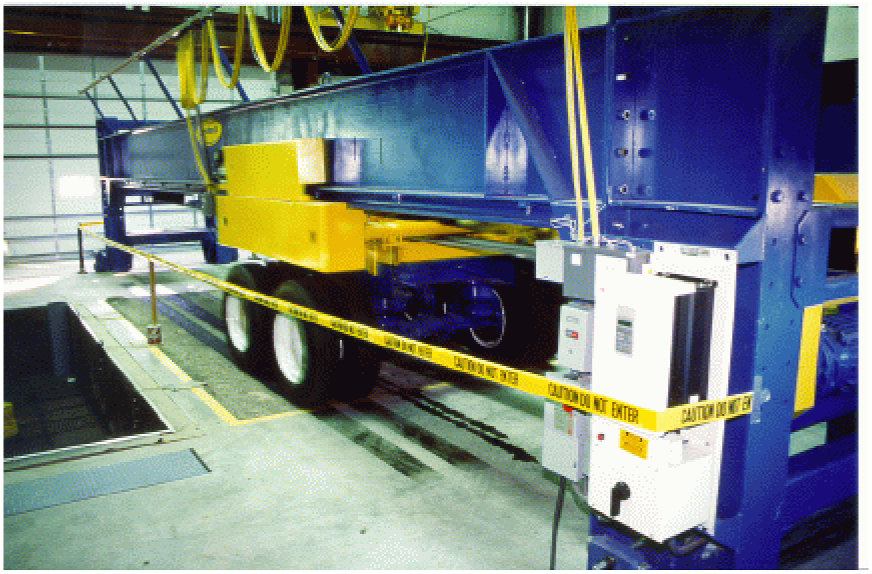
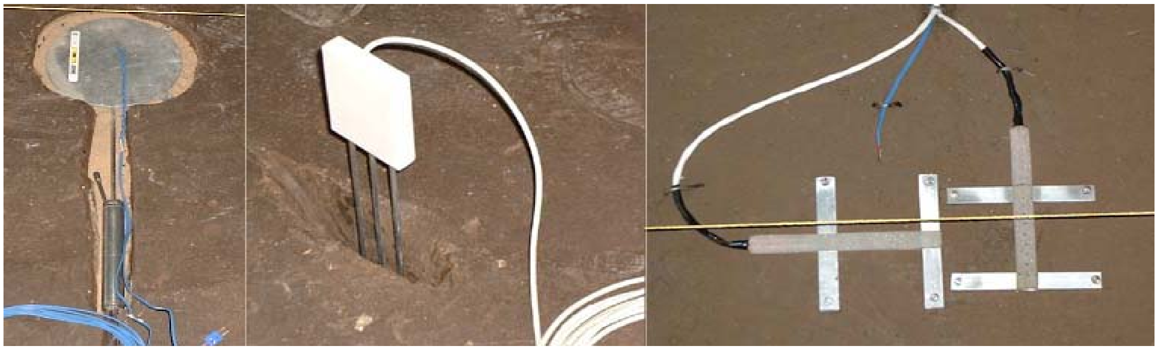


Figure 1. Original APT Machine Configuration

Figure 2. Single axle configuration

Figure 3. Transverse Profiler



(a) Soil Pressure Cell **(b) TDR Probes** **(c) Asphalt Strain Gages**

Figure 4. Instrumentation

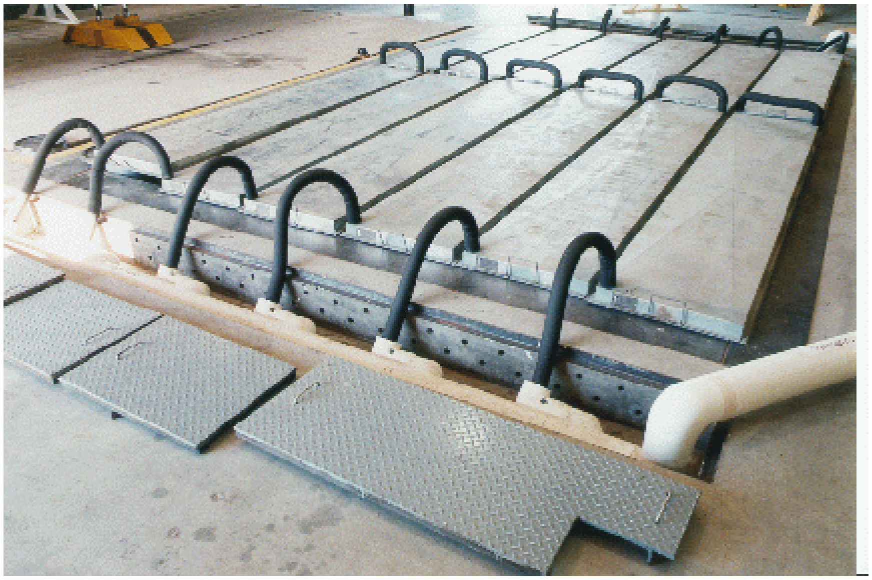


Figure 5. Surface Heat Exchangers

Figure 6. Environmental Chamber