A Synthesis of Construction Practices for Accelerated Loading Facilities in the United States

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ABSTRACT
As mechanistic-empirical design progresses, the need for states to calibrate and validate their findings will continue to grow. Accelerated loading facilities provide environments where these needs can be addressed and met; however, this is only the case if the facilities are constructed properly. The construction of such projects may seem fairly straightforward; however, challenges related to personnel limitations, logistical issues, funding limitations, etc. can plague the construction process. Research has been conducted by the Consortium of Accelerated Pavement Testers on the construction practices that accelerated loading facilities have utilized in the United States to make their construction efforts more efficient and productive. Using surveys and interviews, information has been received from facilities such as the National Center for Asphalt Technology's Pavement Test Track, the Kansas State Civil Infrastructures Systems Laboratory, MnROAD, the Federal Highway Administration's Accelerated Loading Facility (ALF), the Louisiana Research Technology Center's, and Florida's Heavy Vehicle Simulator. Engineers who are developing accelerated loading facilities and reconstructing previously established facilities can use this information to enhance research findings and lower overall cost. Lessons learned along with suggestions for various aspects of the construction process are provided so that future users of accelerated loading facilities will have a better understanding of what it takes to bring this kind of project to fruition. Contract mechanisms (i.e., contractor or in-house), quality construction and assurance testing, and instrumentation are addressed.

INTRODUCTION

As mechanistic-empirical (M-E) design progresses, the need for states to validate their findings will continue to grow. While some organizations consider doing full-scale testing on actual in-service roads, completing such research can be severely limited by the following factors: (1) testing could take many (15-20) years to complete, (2) it is often difficult and unsafe to close lanes on in-service roads for inspection, (3) Department of Transportations tend to be reluctant to leave roads in service until failure occurs, and (4) the public can be intolerant to traffic delays due to road closures, (5) changes in personnel and political climates can compromise long-term experiments (*1*).

Because of these difficulties, the development of a new testing system began at a time when the world was in a similar state of developing new design and analysis techniques. Much like M-E design today, these new procedures needed to be validated with performance data observed under trafficking. From this need came accelerated pavement testing (APT) facilities, also known as accelerated loading facilities. APTs were able to bridge the empirical with actual pavement performance (*2*).

For the purpose of this research, an APT will be defined as a "controlled application of a loading to pavement structures for the purpose of simulating the effect of long-term in-service loading conditions in a compressed period of time" (*3*).

APTs began modestly with the United Kingdom's "Road Machine" in 1912 (*4*). After migrating to the United States in 1919, the Arlington Test Road tested newly designed concrete pavements by simply loading them with a truck . From this simplistic beginning, came other such roads like the Bates experimental road, the Maryland Test Road, and the Western Association of State Highway Officials Road Test which tested the effects of loading on pavements using simulated or actual traffic (*5*).

APTs were brought to the forefront of the pavement research industry when the American Association of State Highway Officials (AASHO) Road Test was established to help develop a new pavement design guide. This experiment played a vital role in making road construction a "rational process" (*2*).

The 1990s brought about a surge in APT facility construction (*6*). In 1996, 28 APT programs were being run around the world (*5*). After the addition of facilities by organizations such as the Federal Aviation Administration in New Jersey, the Florida Department of Transportation, and the National Center for Asphalt Technology, 45 APT facilities were functioning world-wide by 2002. Fourteen were located within the borders of the United States of America (7).

Types of Facilities

While many people lump all APT facilities together, there are many different types of experiments within this genre of pavement testing. Running an APT facility creates experimental intricacies that add challenges and limitations to the construction and data collection processes (*2*). These experimental setups were grouped into five categories by Metcalf: test roads, circular tracks, linear tracks, free form tracks, and other configurations. No setup is perfectly free from limitations; however, by understanding the limitations and capabilities (Table 1) of APT facilities, one could appropriate choose how to set up a new APT experiment (*5*).

Table 1: Capabilities and Limitations of Full-Scale Accelerated Pavement Testing Facilities (*4*).

Facility	Capabilities	Limitations
Test Roads	• In-service traffic • Normal construction • High credibility • Multiple sections tested	• Limited scope for acceleration of loading • No climate control • Limited control of traffic speed and loading • Fixed location
Circular Tracks	• High-speed operation • Fully controlled loading • High level of acceleration • Mechanically simple • Multiple sections tested • Partial environmental control	• Shear force at small radii • Failure of one section affects others • Pavement construction can be difficult • Fixed location
Linear Tracks	• One or two-way loading, fully controlled • Transportable • Can be used on in-service roads • Normal construction • Partial environmental control • Section failure does not affect others	• Limited speed • Mechanically less simple • Short Lengths
Free Form Tracks	• Normal construction • Partial environmental control • Fully controlled loading	• Moderate speed • Section failure may affect others • Mechanically more complex • Fixed location
Other Configurations	• Mechanically simple system • Can be climate controlled • Section failure does not affect others • Fully controlled loading	• Limited simulation • Pavement construction can be difficult • Fixed location

The test road, such as the Minnesota Test Road at MnRoad, is one APT experiment type in operation today. While pavement performance is easy to witness at such facilities, operation costs and the inability to control the environment inhibit total ease in pavement monitoring. It has been suggested that thinner pavement sections be used to facilitate early distresses (*5*).

Washington State University was one facility that operated a circular track. These experiments operate at high speeds letting appreciable numbers of loadings be applied to multiple pavement sections in a compressed period of time. The major concern with using circular tracks is what might be described as a "domino effect." If one pavement section fails, it will affect the performance of the other test sections (5).

Linear tracks, such as heavy vehicle simulators (HVS), have been in use since the 1970s. Concerns have risen about the speed of loading used at linear tracks along with the affect of dual-direction loading on pavement performance. Some linear tracks, such as the South African HVS, have the ability to be easily transported to test in-service pavements and lift the load mechanism to facilitate unidirectional traffic (*5*). Fixed facilities and circular tracks cannot always build typical pavements seen on in-service roads; therefore, testing devices that are mobile can help overcome this deficiency by testing in-service pavements (*2*).

Sources of Problems on In-service Roads

Rollings *et al.* describes four areas that plague the performance of pavements today: construction, design, materials, and maintenance (*6*). Table 2 provides a list of these potential pitfalls and examples of each. While in-service pavements were the focus of Rollings *et al.*'s research, APTs should also be aware of these four areas to provide sponsors with better, more meaningful experiments; however, since construction is the focus of this paper, design, materials, and maintenance issues will not fall within the scope of this report.

Table 2. Potential Pitfall Areas for Pavements (*6*).

Construction	Design	Materials	Maintenance
• Ignoring a known problem • Lack of incentive for quality work • Improper handling of materials	• Faulty design assumptions • Wrong design method • Ignoring environmental conditions	• Substituting poorer materials because of economics • Unnecessarily restrictive specifications • Relaxing specifications	• Little maintenance • Solving the wrong problem • Indentifying the wrong problem

Construction problems can be caused from maladies ranging from laziness to the lack of incentive for producing a quality product. Three specific construction issues include ignoring a problem, incentive for quality work, and improper handing of materials. Rollings *et al*. suggests that many contracts are set up not to reward quality work. When contractors have pay reduced due to a substandard performance, it is a reflection of the work being completed, not necessarily a penalty to the contractor. This, along with either budget or time constraints, makes some contractors believe it is easier to ignore the problem of substandard construction than to correct it (*6*).

One area where the improper handling of materials can influence pavement performance in the field of hot mix asphalt (HMA) pavements is segregation. Segregation is "a magnitude lack of homogeneity of constituents in the HMA" (*8*) and has been known to be the result of improper material handling or design flaws. If segregation occurs in HMA, the pavement could be susceptible to top-down cracking (*9*) and/or future moisture damage (*8*). While precluding segregation is important, it is also vital for contractors to make sure HMA undergoes proper compaction at adequate temperatures to precise thicknesses to ensure pavement performance.

APT Construction

APTs can stand alone; however, the results from APT are better when they are supplemented with laboratory data (*3*). In order for this type of comparison to occur, proper care is paramount in the construction process of the experiment. Nunn emphasized the importance of pavements being constructed well and maintained, using quality asphalt and foundation materials to ensure the distresses are due to loading and not from construction or material defects (*10*). While it is important to understand how construction affects pavement performance, this is not typically the focus of most APT experiments.

The previously mentioned construction issues plague most APT facilities today, but APTs also have unique construction dilemmas. When studying the construction management in the Indiana APT, it was noticed that "determining the construction cost estimates and keeping the actual costs under budget without compromising quality were key issues" (*11*) for project success. As construction costs rise, APT facilities have to turn to new methods to accomplish the same tasks. For example, the NCAT Pavement Test Track used its fleet drivers as equipment operators to complete the foundation work for the 2006 research cycle.

Another area of construction where much care must be taken is HMA placement. Most contractors have experience paving long stretches of roadway. Many APT facilities use shortened test sections for their experiments. Test sections can range from 200 feet at the NCAT Pavement Test Track to 500 feet at MnRoad. Getting consistency in such a short distance can prove problematic. For example, handwork at either end of short test sections can significantly effect surface texture, localized segregation, etc.

The use of embedded instrumentation in roadways provides another unique problem to APT experiments. Instrument installation can cause delays in projects that contractors are not used to encountering. Gauges must also be placed precisely and protected well to ensure survivability. On top of this difficulty, they add to the complexity of the quality control process (*11*). If care is not taken to make sure proper compaction takes place near embedded instrumentation, premature failure can occur (*3*).

Scope

The Consortium of Accelerated Pavement Testers (CAPT) is a pooled-fund organization in the United States of America designed to bring together leaders from APT facilities or states interested in APT research to share knowledge and experiences so APT research can become more profitable to the pavement community.

Using web-based surveys and interviews, CAPT has collected data on specific construction practices and the lessons learned from the following APT facilities in the

United States: Federal Highways Administration Accelerated Loading Facility (ALF), the National Center for Asphalt Technology Pavement Test Track, the Ohio Research Institute's Accelerated Pavement Loading Facility, Florida Department of Transportations HVS, Louisiana Transportation Research Center's ALF, MnRoad, the Kansas State Civil Infrastructure Laboratory APT, CalTrans' HVS, and the Indiana Department of Transportation's Accelerated Pavement Testing Facility.

While there are many aspects to constructing an APT experiment, this report will only focus on construction mechanisms used to build the APTs and quality control procedures to help ensure experimental success.

Objectives

Very little published research has been conducted on the construction processes used at APT facilities. The objectives of this paper are two-fold.

1. To synthesize construction mechanisms and quality control processes at nine United States APT facilities
2. To display successes and failures at APT facilities in the United States to improve future APT construction

FACILITIES

The following data are the results of web surveys completed by nine different APT experiments. It should be noted that each APT experiment comes with its own unique set of challenges, and there is no "one size fits all" pattern for the construction of APT facilities. Table 3 provides basic information about the nine facilities that were willing to share construction experiences. This information includes the following: facility name, type, and what governs the research design (sponsor, industry, etc . . .).

Table 3. APT Facility Information.

Facility	**Type**	**Needs-Based**
Federal Highways Administration (FHWA)	ALF	Research, Sponsor, Industry, Nationwide
NCAT Pavement Test Track	Closed Loop	Sponsor (mostly DOTs, but also FHWA and private industry)
Ohio Research Institute	HVS	Sponsor
Florida DOT	HVS	Research
Louisiana Transportation Research Center (LTRC)	ALF	Research
MnRoad	Test Road	Research (main goal), sponsor, industry (depending on project/scope)
Kansas State	HVS	Research
CalTrans	HVS	Sponsor
Purdue/Indiana DOT	HVS	Research

Some experiments may have their construction practices controlled by governing or sponsoring agencies. This, along with the type of facility, should be considered before implementing any construction practice.

CONSTRUCTION MECHANISMS

One of the first decisions that must be made before construction can begin is the mechanism under which construction will take place. By this, the authors mean the following: who will be performing the majority of the tasks required to successfully complete the construction of the pavements used for the experiment? As can be seen, there is no one way to complete pavement construction.

Table 4. Construction Mechanisms used at APT Facilities.

Facility	Sole Source	Bid	In-House	Multiple Sources	Varies
FHWA	X				
NCAT		X	X	X	
Ohio		X			
Florida	X	X	X		
LRTC		X			
MnRoad	X	X	X		
Kansas State		X	X		
CalTrans					X
Purdue/Indiana DOT	X	X	X		

The most common construction mechanism used at these nine facilities was bidding for project construction. This mechanism was followed by facilities performing work in-house and then sole sourcing. In the analyses, CalTrans was not considered. The mechanisms used by CalTrans vary due to some experiments being conducted on in-service pavements.

Sole Sourcing

Sole sourcing occurs when a contract stipulates that only one company is able to deliver a product or render a service in the manner needed to successfully complete the project. According to the survey, 50% of the APT experiments had used a sole source contract successfully for vastly different purposes in construction. Some facilities, such as the Indiana DOT experiment, use sole source contracts for rather small parts of the project like materials purchasing (*11*). On the other hand, the FHWA ALF experiment was built almost entirely using a sole source contract. MnRoad and Florida have both completed parts of their HMA and Portland cement concrete (PCC) projects using this contract mechanism.

The ability to sole source seems directly related to available capital for the experiment. While FHWA used a sole source contract on its last project, the change in the contracting climate is encouraging it to look at alternatives to this contract type. Another consideration is relationships with local contractors. Some facilities have developed partnerships with local contractors that allow for successful sole sources to be completed without escalating costs to extremes.

In-House Work

In-house work was completed in 62.5% of the APT facilities surveyed. Like sole sourcing, in-house tasks vary by facility. Table 5 provides this information.

Table 5. In-House Work Completed.

Facility	Subgrade/Base Placement	Milling	Test Pits	Aggregate Hauling	PCC Placement	Did Not Specify
NCAT	X	X		X		
Florida			X			
MnRoad						X
Kansas State		X			X	
Purdue/Indiana						X

The NCAT Pavement Test Track and the Kansas State Civil Infrastructures Systems Laboratory are the two facilities with the most experience completing construction in-house. While Kansas State uses contractors for asphalt placement and removal, it completes all its other work in-house. This includes buying PCC, placing and testing granular bases, and placing PCC.

The NCAT Pavement Test Track completed its first two construction phases using a comprehensive contract administered by the Alabama Department of Transportation (ALDOT). However, due to increasing construction costs, a series of subcontracts were let by Auburn University for the 2006 construction cycle. Since NCAT uses live traffic, the facility was able to use its fleet drivers to save cost on short-hauling the aggregates. Most of the drivers were also able to operate construction equipment; therefore, NCAT also took responsibility for contract administration, milling, and subgrade/base placement.

This situation was less than ideal for NCAT. It placed an extra burden on the Track personnel in administering tests and preparing foundations and bases. MnRoad had similar experiences working with untrained staff. The project was able to achieve a lower overall cost, but the quality of the project may have suffered due to worker inexperience.

Low Bid

One of, if not, the most common construction mechanism used in engineering today is to take the low bid. Since it is prevalent in most typical construction projects, it was no surprise that 87.5% of the APT experiments had bidding incorporated into the project construction process due to the ease it added to the facility workload.

The LTRC has used the standard procedures for bidding and construction in Louisiana for its embankment and test pits over the past four research cycles with much success. The Indiana DOT has experienced advantages such as less activity in mobilization and preparation for construction due to its use of contractors in aggregate hauling and asphalt placement (*11*).

While some projects take comprehensive bids, other experiments have bid using multiple sources to try to reduce costs even more. While it preferred the use of a competitively bid comprehensive contract administered by ALDOT, the NCAT Pavement Test Track divided its construction into a series of subcontracts for asphalt supply, aggregate long-hauling, plant production, and mix placement. This forced the Track personnel to handle and administer contract issues. A comprehensive contract allows a rigorous qualification process to be in-place by highly experienced personnel.

While using contractors might ease some areas of the construction process, APTs have felt that contractors also provide some disadvantages that should be realized by future APT users. These are as follows:

- Less control in the construction process in terms of time and tolerances
- Results are based on field construction specifications which have large variability compared to lab-grade construction
- Contractors can be pricey for small projects
- Low bid can prove problematic in terms of project quality.

Lessons Learned

There are advantages and disadvantages to each construction mechanism. Most disadvantages can be alleviated through proper and open communication. During the construction of the Indiana DOT facility, the contractor and facility were noted as having a "business as usual" (*11*) attitude. The facility also failed to have a meeting to discuss the required specifications for the project. When the time came for construction to commence, the contractor failed to apply a tack coat between HMA since it had not applied tack coats on previous Indiana DOT projects. This failure in communication led to a premature pavement failure and prevented completion of the project (*11*).

Clear communication between contractors and researchers allow for clear scope definitions for the project and a specific construction supervision plan. Sometimes this lack of communication comes from a researcher's lack of practical experience. APTs need to be specific up-front about their needs to the individuals or contractors performing their work. If the facility fails to tell the contractor what it needs or expects, the experiment may not produce the desired results.

It is also important for contractors to understand the difficulties that can come with embedding instrumentation in HMA. These difficulties can include correctness of placement, compaction around instruments, and damaging the instruments.

QUALITY CONTROL

Ensuring that materials are within project specifications is the goal of quality control and quality assurance. If APT facilities are going to run practical and useful experiments, it is paramount that the test pavements are constructed free of errors that would jeopardize the integrity of the project. While this may seem easy, material variability has plagued APTs since their inception.

An element of the OECD DIVINE Project that was undertaken in New Zealand, studied and saw the affects of variability on pavement structures. When variability was reduced in the material properties, the service life of the pavement increased (*12*). Failure to achieve proper compaction has been the root of other premature APT failures. At times, it has even caused the facility to remove and retrofit gauges back into the pavement (*13*).

When Texas was running its MLS, three specific problems were noted in causing premature failure, and all three were related to quality materials being constructed at the test site. First, variability within the pavement foundation caused performance differences in the test sections. Second, pockets of poorly constructed material influenced the surrounding areas negatively. Third, poor compaction led to an increase in field air voids. This resulted in early fatigue cracking (*14*).

Base and Subgrade Construction

In April 2007, the CAPT group met in Gainesville, Florida, for its spring meeting. During the meeting, several areas of concern were brought before the group about APT construction. The problem that seemed to resound through the most users was how to construct quality base and subgrades. Table 6 lists the tests conducted on subgrades and bases at the nine surveyed APT facilities.

Subgrade Construction

As can be seen in Table 6, there are a wide range of tests used to run quality control on subgrade materials. The four most common tests conducted are gradation (GSD), density, water content, and elevation. After those four tests, the other tests are measurements of stiffness of the unbound materials.

Table 6. Subgrade and Base Tests Performed at APT Facilities.

Soils	**Atterburg Limits**	**GSD**	**Density**	**Water Content**	**Elevation**	**DCP**	**M_r**	**Other***
FHWA								X
NCAT		X	X	X	X	X	X	
Ohio			X	X	X			
Florida		X	X	X	X			
LTRC			X					
MnRoad		X	X	X		X	X	X
Kansas State	X	X	X		X		X	
CalTrans	X	X	X	X	X			
Indiana			X		X			
Base Material	**FWD**	**GSD**	**Density**	**Water Content**	**Elevation**	**DCP**	**M_r**	**Other****
FHWA	X	X	X	X				
NCAT		X	X	X	X	X	X	
Ohio			X	X	X			
Florida		X	X	X	X			
LTRC		X	X	X				
MnRoad	X	X	X	X		X	X	X
Kansas State		X	X	X	X			X
CalTrans		X	X	X	X			
Indiana			X		X			

**Include: Intelligent Compaction, Light-Weight Deflectometer, Humbolt Stiffness gauge, strength, x-ray, stabilization, and Falling-Weight Deflectometer (FWD)*

***Include: Intelligent compaction, LWD, Humbolt Stiffness gauge, L.A. Abrasion, strength, plasticity, x-ray, and stabilization*

Some facilities, such as Kansas State University, have had much success in achieving stiff subgrades close to their target values while others have found that achieving proper and consistent density and stiffness can be challenging. While some engineers would see this as only a temporary problem, facilities such as MnRoad have dealt with rutting in the subgrade material due to improper densities. When reconstruction occurs, how can this rutting effectively be removed without having to reconstruct the entire subgrade?

The simplest, yet most challenging, answer to that question is to achieve proper compaction at the onset of the project. Two suggestions can be made besides proper testing to ensure a quality subgrade material. The first is use a contractor with experience running the tests and constructing test sections. A second suggestion is to be flexible. If the subgrade is not compacting, researchers must be willing to try something different. In Indiana, it was difficult to achieve subgrade compaction in the small-scale environment, and it was impossible to use a standard-sized roller. Therefore, a backhoe had to be adapted with a vibratory compactor driver, and when the backhoe could not compact the corners of the test section, vibratory soil plates were used to complete the task (*11*).

Base Construction

Similar results are seen for the tests run for base and subgrade quality control. Density, grain-size distribution, water content, and elevation are the typical tests run at facilities. A fifth test is typically, as was the case for subgrades, some sort of stiffness check for the unbound granular material.

Facilities such as the LTRC and NCAT Pavement Test Track have had success in their base construction efforts; however, while finding the subgrade simple to compact, Kansas State has had difficulties in achieving target densities that may heave been attained through typical compaction methods. Much like with subgrades, CalTrans emphasizes the importance of strict quality control in terms of layer thickness, moisture content, and compaction. Some materials, such as recycled building rubble recently used for a base coarse, have led to uniformity issues, and this should be taken into consideration when analyzing the results of the project.

Many constructability issues could be solved during the design of the physical facility and test sections. A facility can be designed to provide a larger test pit than needed so a more uniform granular layer could be placed which can prevent the size of the test pit from negatively impacting the outcome of the research.

HMA CONSTRUCTION

All nine experiments surveyed perform accelerated loading tests on HMA pavements. Table 7 provides information on the spectrum of HMA testing completed at these facilities.

Table 7. HMA mix and binder tests.

Facility	AC%	GSD	Air Voids	VMA	VFA	G_{mm}	G_{sb}	G_{mb}	PG	Other
FHWA	X	X		X		X			X	X
NCAT	X	X	X	X	X	X	X	X	X	X
Ohio	X		X							X
Florida	X	X	X	X		X	X	X	X	X
LTRC	X		X	X		X			X	X
MnRoad	X	X	X	X	X				X	
Kansas State	X	X	X			X			X	
Caltrans	X		X	X	X	X	X	X		
Indiana			X	X	X					

Other includes: G, Brookfield viscosity,*
G_{mm} *= Theoretical Maximum Specific Gravity;* G_{mb} *= HMA Mix Specific Gravity;* G_{sb} *= Aggregate Specific Gravity*

The three most commonly used tests on the HMA mix are binder content, air voids, and VMA. These are three properties that have been linked to pavement performance, and they are common among state DOT specifications for projects (*15*). Most facilities have been pleased with the construction of their HMA layers noting little to no problem in this process.

Other facilities expressed they rely on contractors too much for data generation, and more testing should be done in-house. For example, Kansas State gets gradations and binder contents from the contractor. Both CalTrans and Indiana receive their binder data from the contractor. Some experiments feel they should do more in-house testing to assure pavement quality and fully understand the materials being placed.

One of the most important properties for an asphalt pavement is in-place density. This parameter has been linked to distresses such as fatigue cracking and rutting (*15*). Knowing this, it should be no surprise that all nine facilities measure density as one of their in-place HMA tests. Table 8 expands on the type of density testing and the other in-place HMA properties tested. Eight of the nine facilities use the nuclear gauge as their choice of density measurement; however, facilities, such as NCAT, use core densities to correlate nuclear gauge responses.

Table 8. In-Place Properties Tested.

Facility	Nuclear Gauge	Non-Nuclear Gauge	Cores	Air %	Smoothness	Thickness
FHWA	X		X	X		X
NCAT	X	X*	X	X	X	X
Ohio	X			X	X	X
Florida	X	X	X	X		X
LTRC	X	X	X	X	X	X
MnRoad			X	X	X	X
Kansas State	X		X**			X
CalTrans	X		X	X	X	X
Indiana	X					

**for research purposes only*
***from untrafficked areas postmortem*

Thickness is another important component for stress and strain dissipation. With the exception of Indiana, pavements are checked to ensure they have the proper structural thickness. If these structures are not built to their specified design thickness, it will be difficult to determine if the prototype design performed as desired. The LTRC has had difficulty obtaining accurate thickness data for each lift. Due to the difficulty of reproducing pavement thicknesses in laboratory, contractors have to be held very closely to the specified design thickness to help ensure structural integrity.

PCC CONSTRUCTION

Very little data were collected on the construction of PCC at APT facilities. Six of the nine CAPT partners have used PCC in previous experiments: Ohio, Florida, MnRoad, Kansas State, CalTrans, and Indiana. Currently, PCC does not undergo as rigorous testing as HMA does to ensure quality. The quality control/quality assurance tests performed by each experiment show the 28-day compressive strength to the be only consistent test performed on PCC. Other tests included air content, smoothness, beam testing, cylinder testing, plastic properties, maturity meter, slump, and water-cement ratio. MnRoad and CalTrans have the most extensive concrete testing parameters.

Very little difficulty has been reported when using PCC in APT experiments. Kansas State University buys its PCC from contractors; however, it believes that sometimes the contactor puts more cement into the mix than required by the design to ensure high strengths. This can be problematic if different designs or new innovations are being tested. Indirect tensile tests and compressive strength tests are performed on this concrete; however, once tests confirm the extra cement, little can be done to resolve the design flaw.

CONCLUSIONS

No two APT experiments are designed to obtain the exact same results using identical loading scenarios; therefore, it is impossible to create a "one-size fits all" construction scenario for all APT facilities. Based on the survey results and previous literature review, the following conclusions can be made.

- Using experienced contractors under a comprehensive contract will improve quality of the experiment and free facility staff to perform other duties.
- Base and subgrade densities are the most difficult material properties to achieve due to the unique construction requirements of test sections/pits.
- Binder content, air voids, and VMA are the three most tested mix properties at APT facilities in the United States.
- Nuclear gauges are the most prolific form of density testing used at APT facilities in the United States.
- 28-day compressive strength is the only consistent property tested among APT facilities using PCC.

Recommendations

The following recommendations can be given for construction practices based upon experiences seen at APTs in the United States.

- Communicate specifically and openly with contractors to ensure the project specifications are clear pre-construction.
- Be flexible with compaction efforts. Try something new if traditional efforts are not working.
- Ensure uniform materials are placed before trafficking commences to inhibit early failure through proper monitoring and testing procedures.
- Continue research into construction practices of APT facilities. The more these facilities learn from each other's successes and failures, the better the results will be for the pavement community.

The majority of this work was based upon questionnaires. These surveys did not provide adequate information to convey information about proper PCC construction. More research should be conducted on successes in PCC construction at APT facilities.

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