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The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center deals with the development of basic ideas, concepts, and technologies for the applications of Robotics and Automation to Highway Maintenance and Construction Operations. This report discusses the activities related to testing pothole repair technology and in particular, the evaluation of the Python Pothole Patcher (PHP). The PHP automates the traditional hot asphalt patch process as follows: 1) it air jet blasts the pothole clean, 2) sprays tack oil, 3) fills the pothole with hot asphalt fill, and 4) employs a high pressure roller for compaction of the patch. While a commercially available machine, the PHP procured for this project has a number of unique features allowing it to best meet Caltrans' needs. As such, its deployment in Caltrans' operations has required close cooperation with the manufacturer to overcome numerous development issues. This document reports on the efforts of AHMCT Research Center staff to facilitate the use of the PHP in Caltrans' operations. AHMCT staff has also provided a combination of classroom instruction and equipment operation training for Caltrans' operators.

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Evaluation of Pothole Patching Equipment and Processes

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Professor Steven A. Velinsky: Principal Investigator

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Division of Research and Innovation

Abstract

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center deals with the development of basic ideas, concepts, and technologies for the applications of Robotics and Automation to Highway Maintenance and Construction Operations. This report discusses the activities related to testing pothole repair technology and in particular, the evaluation of the Python Pothole Patcher (PHP). The PHP automates the traditional hot asphalt patch process as follows: 1) it air jet blasts the pothole clean, 2) sprays tack oil, 3) fills the pothole with hot asphalt fill, and 4) employs a high pressure roller for compaction of the patch. While a commercially available machine, the PHP procured for this project has a number of unique features allowing it to meet Caltrans' needs. Specifically, it has the unique ability to fill potholes in a moving highway lane closure. As such, its deployment in Caltrans' operations has required close cooperation with the manufacturer to overcome numerous development and technical issues. This document reports on the efforts of AHMCT Research Center staff to facilitate the use of the PHP in Caltrans' operations. AHMCT staff has also provided equipment upgrades and repair along with a combination of classroom instruction, and equipment operation training for Caltrans' operators.

Executive Summary

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center deals with the development of basic ideas, concepts, and technologies for the applications of Robotics and Automation to Highway Maintenance and Construction Operations. This report discusses the activities related to testing of pothole repair technology, and in particular the evaluation of the Python Pothole Patcher (PHP). The Python Pothole Patcher (PHP) automates the traditional hot asphalt patch process as follows: 1) it air jet blasts the pothole clean, 2) sprays tack oil, 3) fills the pothole with hot asphalt fill, and 4) employs a high pressure roller for compaction of the patch. The quality of the resulting patch can range from long-term to permanent, depending primarily on pothole preparation and cleaning.

Pothole patching has proved to be a very hazardous task on working highways. Two Caltrans maintenance workers have recently lost their lives in separate events while attempting to patch potholes. By utilizing automated equipment like the PHP, the worker's direct traffic exposure hazard is eliminated. The PHP is a commercially available machine, but it had never been used on Interstate type highways. The machine procured for this project had to be modified with a number of unique features allowing it to meet Caltrans' needs. As such, its deployment in Caltrans' operations has required close cooperation with the manufacturer to overcome numerous development and technical issues. This document reports on the efforts of AHMCT Research Center staff to facilitate the use of the PHP in Caltrans' operations. AHMCT staff has also provided equipment upgrades and repair along with a combination of classroom instruction and equipment operation training for Caltrans' operators.

The Python pothole patching machine is progressing through initial deployment testing operations in Caltrans Districts 3 and 4 and additional Caltrans deployment locations are being identified. The goal of the use of the PHP has been to develop the ability to conduct the majority of pothole patching operations in moving lane closures in conjunction with COZEEP/MAZEEP in order to maximize the production and safety benefit of the automated machine. Accordingly, the PHP has been used effectively in such an operation in District 4.

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List of Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology
ATIRC	Advanced Transportation Infrastructure Research Center
CALTRANS	California Department of Transportation
CAN	Controller Area Network
CARB	California Air Resources Board
COZEEP	Construction Zone Enhanced Enforcement Program
DUI	Driving Under the Influence
EPA	Environmental Protection Agency
I	Interstate
MAZEEP	Maintenance Zone Enhanced Enforcement Program
META	Maintenance Equipment Training Academy
PHP	Python Pothole Patcher

Disclaimer

The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center, within the Department of Mechanical and Aerospace Engineering at the University of California, Davis and the Division of Research, Innovation and System Information at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, state and federal governments and universities.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the STATE OF CALIFORNIA or the FEDERAL HIGHWAY ADMINISTRATION or the UNIVERSITY OF CALIFORNIA. This report does not constitute a standard, specification, or regulation.

Introduction

While highway maintenance and construction methods have progressed considerably over the last several decades, these activities depend relatively little upon high-technology equipment or procedures. Generally, they are labor intensive and can expose workers and travelers to the risk of injury.

Transportation system maintenance and construction is essential to ensure the safe and efficient delivery of people, goods, services, and information. However, many practices, procedures and equipment in common use today can be improved with innovative highway technology. The application of technological innovation and systems improvement can make highways safer for their stewards and travelers, speed task completion, improve mobility, and reduce associated costs.

Highway construction and maintenance operations are hazardous to both motorists and workers. In 2003, there were 109 fatalities in California work zones and 1,028 fatalities and 40,000 injuries in U.S. work zones [1]. The fatality rate for highway construction workers is twice the rate as for other types of construction. About 35% of worker fatalities are directly related to traffic moving through the work zone. Speeding, DUI, improper turns, and unsafe passing are the direct causes of 68% of all work zone deaths [2]. Meanwhile, national funding has declined for the maintenance of 1.7 billion miles of highway worth $1.75 trillion for the benefit of 90 million drivers of 70 million vehicles [3]. The 2007 bridge collapse in Minnesota [4] and the 2010 natural gas line failure in California [5] are representative of the aging US infrastructure and the potential catastrophic consequences.

Highway potholes typically emerge sporadically on the highways and rarely occur in concentrated areas. Their characteristic disbursement makes it impractical to schedule traffic lane closures for urgent repairs. Often maintenance crews merely rely on traffic breaks, with or without California Highway Patrol assistance depending on traffic flow, to make quick repairs. Frequently, a maintenance worker will quickly approach a pothole on the travelway during a brief traffic break. He will then cast a lump of cold patch asphalt into the void, as is and retreat after quickly tamping it with a shovel or boot. The result is an inferior, very temporary patch that relies on vehicles to complete the compaction process. The life span of this kind of patch is very short and they usually pop out after the first rain, resulting in a larger Pothole requiring a more aggressive maintenance solution for repair. Having workers on foot exposed to traffic in,

or adjacent to, traffic is always potentially hazardous, but the nature of current Caltrans pothole patching operations and practices makes this task even more risky.

The greatest potential safety gain is achieved by completely removing the workers from any direct traffic exposure on the highway. This can be accomplished by making use of automated patching equipment, that is, self-contained machines designed to patch potholes that can be remotely operated from inside the vehicle's cab. Such equipment has been on the market for several years and has achieved nationwide service on a modest scale. This type of machine typically dispenses either hot asphalt or an emulsion-based spray patch. While both processes have benefits, the hot asphalt process is the most traditional and draws nearly universal support. Also, the target use of this equipment is mainline highways and secondary highways with high-speed traffic, which favors the hot patch approach as well.

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center has been investigating the use of automated pothole filling equipment for several years. Most recently, AHMCT has purchased an automated machine, which has been undergoing initial qualification deployment testing with Caltrans. This document reports on the use and deployment testing of this machine.

The Python Pothole Patcher (PHP) was selected as the commercially available machine that matches Caltrans requirements. It automates the traditional hot asphalt patch process: 1) air jet blast pothole clean, 2) tack oil spray, 3) hot asphalt fill, and 4) high pressure roller compaction of the patch. The quality of the resulting patch can range from long-term to permanent, depending primarily on pothole preparation and cleaning. The goal is to conduct the majority of pothole patching operations without the establishment of fixed lane closures in order to maximize the benefit of the automated machine. The patch can be applied very quickly within a moving closure operation or a very high quality patch is possible when more time is available for blowing out the hole and applying a tack coat. The machine can be easily configured for different types of patching requirements and it is simple to clean. Several features of the PHP are as follows:

- The average hole can be patched in about two minutes
- Compaction – provided by a hydraulic pressure controlled roller
- Can operate in a wide temperature range and in wet conditions
- All functions are controlled from inside the cab by a single joystick

- Multi-axis working arm gives a wide range of control - side to side, forward or reverse
- Working arm extends to 4 feet from under the cab, with 6 feet of side-to-side motion
- The amount of asphalt delivered is controllable.
- The location at which the asphalt is delivered is controllable.
- The operator stays in the cab for a safer and more comfortable working environment
- Good driver/operator visibility
- Has the ability to dispense a variety of asphalt mixes
- Provides asphalt at appropriate dispensing temperatures
- 5 Ton (10,000 lb) Asphalt hopper capacity

Python Manufacturing has been building PHP machines for many years and the patching capabilities of this design have been well established. The Caltrans version PHP should nevertheless be considered a prototype in a number of respects due to the many innovative machine features. Two auxiliary hopper heating systems were specifically developed for this version and custom designed to enable Caltrans crews to extend the time asphalt can remain in the hopper without dumping. An environmental friendly citrus solvent cleaning system was developed to eliminate the use of diesel solvent. The specifications of the Caltrans PHP are as follows:

- 35 gallon heated tack oil tank
- 20 cubic feet per minute air compressor with dual 17 cubic feet air tanks
- Heated asphalt hopper
- EPA 2007 and CARB 2007 certified Cummins 6.7 Liter diesel engine
- Hydrostatic drive geared to travel at highway speeds (55 miles per hour).

For successful deployment, AHMCT staff has been providing training to operators. Operator training for the PHP is a combination of classroom instruction and equipment operation training. The Caltrans' Maintenance Equipment Training Academy (META) and the AHMCT Research Center have been collaborating on the initial PHP program. AHMCT is further developing the machine operation training procedure to match the specific use characteristics of the PHP on the

highway. Representatives from META and AHMCT recommend that dedicated operators be designated for each Caltrans District. If practice potholes are not available at the District, AHMCT has developed a wide variety of practice templates. The templates allow for operator training off the roadway, in a safe, controlled environment. The Python Pothole Patcher is progressing through initial deployment testing operations in Caltrans' Districts 3 and 4, and additional Caltrans deployment locations are being identified. During deployment testing with Caltrans maintenance personnel, a significant use of the Python machine was identified – the patching of roadway edge drain. As opposed to pothole patching in which the machine's operations (i.e., air blast cleaning, application of tack oil, delivery of pothole aggregate, compaction) are discrete serial operations, the patching of edge drain requires all of these to function concurrently. That is, the edge drain is sealed in a continuous manner as the machine moves along the roadway, as opposed to the stationary pothole discrete process. The practical implementation of edge drain sealing is likely the subject of a continuation study.

Python Pothole Patcher

AHMCT staff was responsible for providing training, training materials, related training consumables, addressing maintenance issues and arranging heavy transport services to facilitate long distance moving of the Python Pothole Patcher (PHP) (see Figure 1) between Caltrans districts. AHMCT staff also acted as a liaison between Python Manufacturing, Caltrans and warranty service providers. The PHP spent a good portion of this research task deployed to Caltrans District 3 Rancho Cordova and District 4 Foster City, CA when operable.

AHMCT trained operators from Rancho Cordova and Foster City to operate the PHP for eventual roadway deployments. The PHP saw limited use while at the Rancho Cordova facility due to mechanical and technical issues making the PHP unreliable and unsafe to operate on the road. AHMCT staff addressed numerous mechanical and technical issues experienced by the PHP during this task.

Figure 1. Python PHP 5000 Pothole Patcher During Testing at ATIRC

AHMCT worked with Python Mfg. to resolve outstanding maintenance issues to get the PHP back in to service. Numerous equipment malfunctions, observed by Deployment staff or reported by either Caltrans operators or Python Mfg. representatives, were directly attributed to the CARB mandated Tier 4 diesel engine, associated drive train assemblies and electronic interface components. Among the numerous observed and reported equipment issues existed two specific vehicular driving issues in need of immediate resolving. First, in the spring of 2010, Caltrans operators experienced a loss of engine power during a drive to the District 3 Rancho Cordova maintenance yard. The loss of engine power stemmed from the drive train assembly issue. In addition to the engine power loss issue, also in the spring of 2010, a Python representative experienced the vehicle's emergency brake system lock-up while conducting a road test drive. The brake lock-up occurred three times with the final occurrence causing the brake system to seize. The brake system lock-up resulted from the electronic interfacing of multiple components.

The issues not related to the vehicle's power train or the electronic component interfacings were as follows:

- The material supply belt had intermittent problems, which were related to programming issues. It was resolved by software updates provided by the manufacturer.
- The cab's air conditioning system failed intermittently.
- The boom assembly was modified to allow for expedited belt replacement in the event of failure. AHMCT staff designed and implemented the modification, which has since been incorporated into the manufacturer's machines.
- At times, asphalt would adhere to the material supply belt thus requiring the operator to physically clean the belt. Python Mfg. developed and integrated a belt cleaning brush to overcome this issue.
- An electronic brake issue arose that was resolved by Python Mfg. shipping replacement parts, which were installed by AHMCT staff.

The loss of engine power was a major concern and Python Manufacturing concurred. The PHP would inexplicably lose drive train power while it was being operated on the roadway. Deployment staff informed Python of the problem. Python responded by having a local vendor test and trouble shoot the PHP CAN Bus communication system and drive train.

Berendsen Fluid Power of West Sacramento, CA investigated the intermittent drive train power loss issue and a possible link to the CAN Bus communication system. Berendsen enlisted the help of regional Sauer Danfoss technical staff, the manufacturer of drive train electronic components. Sauer Danfoss provided the required CAN Bus interface tools and expertise required to isolate and resolve the problem.

Together they determined that the computer signals feeding the PHP acceleration circuitry was being overloaded causing the CAN Bus system computer to crash intermittently. The result was an unexplained and inconsistent loss of engine power. Sauer Danfoss technicians adjusted the acceleration signal bandwidth and pulse count to appropriate signal levels rectifying the problem. The PHP drive train is now functioning.

AHMCT personnel took an active role in identifying PHP components and assemblies that needed modification, repair or replacement and routine preventative maintenance. Python Manufacturing did an exceptional job of responding to warranty items requiring service or repair

and expediting the shipment of replacement parts as needed to AHMCT or service providers. AHMCT staff also made suggestions to improve the PHP by making it more robust and versatile.

Python Manufacturing was very receptive to suggestions that could potentially make the PHP more useful to Caltrans maintenance crews tasked with roadway surface repairs such as edge drain patching for example (see Figure 2). Python fabricated boom attachments that would control the dispensing and application of hot mix. Python also modified software options for the operator while in patch mode at AHMCT's request to facilitate slow rolling continuous patching consistent with linear edge drain repairs.

Python added a belt clean out feature allowing the operator to select the amount of time the asphalt conveyor belt clean out system would run, from 0 to 7 seconds. This was previously not an operator setting that could be altered and will ultimately improve patching productivity and efficiency.

The PHP is currently deployed to Caltrans District 4 San Jose, CA and performing as designed. Figure 3 shows the PHP at work in Millbrae, CA. Maintenance crews and management have provided positive feedback regarding the PHP and its contribution to making roadway pothole patching safer, more effective and productive.

Continuing Research

A second phase of this project is continuing under the most recent AHMCT contract. This phase of the project is aimed at assessing available methods and devices for pothole patching. The ultimate goal is to remove all workers from direct traffic exposure either through protected work zones or by placing the workers within the confines of a vehicle during pothole operations. The AHMCT Research Center has been following the development of machines for the remediation of potholes since the early 1990s. Generally, the automated machines are of two general types: 1. Spray injection devices and 2. Automated conventional hot or cold asphalt application devices. As noted, AHMCT has purchased a Python PHP 5000 Pothole Patcher, which is based on conventional asphalt application methods, and has been tailoring the machine for Caltrans' operations. This work has included training of personnel and limited field deployment. The current project has several aspects and continues in the evaluation of methods and materials for Caltrans' use.

Figure 2. Example of an Edge Drain

Figure 3. Python PHP Filling Potholes in Concrete Pavement N.B. I-280 Millbrae, CA

First, as part of the project, the AHMCT team will continue to work with the manufacturer of the Python machine to ensure that the existing machine including its modifications meets Caltrans' needs. Additionally, the project will include continued field deployment and testing of the Python machine to allow detailed cost benefit analysis and development of specific guidelines for its use. Additionally, the project will include continued assessment of machines, materials (such as epoxy/polymer based materials) and processes for pothole patching. Based on a preliminary assessment through literature review and surveying of other states and municipalities, several new approaches will be investigated in more detail. This work will include, as necessary, demonstrations and testing of products and devices. For the most promising approaches, a detailed investigation will follow that may include assessment of machine/process modifications to ease Caltrans' use and eliminate workers' traffic exposure. This work may entail conceptual design of such devices/machine/tools. The overall goal is to assess the efficacy of pothole methods and materials based on a combination of enhanced safety for maintenance workers and motorists, labor savings, reduced injury costs, operational efficiency, and improved repairs.

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