Report

ENGINEERING OVERVIEW OF A ROAD RECYCLING MACHINE FOR PORTLAND CEMENT CONCRETE PAVEMENT

Submitted to

John Wojakowski, P.E.
Materials and Research Center
2300 SW Van Buren
Topeka, Kansas 66611-1195
Phone (785) 291-3844
Email address: JohnW@ksdot.org

By

Dennis A. Pauls, P.E.
DAPTECH, LLC

and

Lakshmi N. Reddi, Ph.D., P.E.
Professor and Head
Department of Civil Engineering
Kansas State University

Project Overview

Currently, many Portland cement concrete pavements (PCCP) in the United States are in need of rehabilitation or reconstruction. Extensive rehabilitation involving cracking and seating or rubblizing (where feasible) makes use of the material and some of the existing structure. It may result in a pavement with perhaps half the life of a new one. Total reconstruction currently requires an inefficient multi-step process of breaking, manual steel cutting, removal and crushing or disposal of the old pavement. Overcoming the shortcomings mentioned requires an economical, quick removal of the old pavement and recycling of the old pavement. The final product will be a new, long lasting pavement.

A machine that could effectively and efficiently remove and crush PCCP on the roadway would be of great benefit to this country. Desirable features would include the ability to quickly remove the pavement without disturbing the base, to crush the pavement into a coarse aggregate, to handle and separate any type of steel contained in the slab, and to deliver the coarse aggregate to the base, a window, or trucks as desired. One such concept currently exists and several key aspects have been individually tested. However, engineering and fabricating an integrated road machine will require substantial effort and resources. The resulting product should substantially improve PCCP reconstruction in terms of environmental impacts, construction time, and economy.

In September 2000, the Small Business Innovative Research (SBIR) Program awarded a contract for recycling of Portland cement concrete pavement to Road Processing Resources of Vail, Colorado. John Wojakowski of the KSDOT, who headed a task group to evaluate the proposals, submitted the problem statement. The current Contracting Officer’s Technical Representative (COTR) is Dennis Dvorak of the Kansas Division of the Federal Highway Administration.

The proposal to the SBIR problem statement addresses economics of road recycling in three ways. First, the projected cost of removing and crushing PCCP can be about one-third of the current costs. Second, the recovery of usable coarse aggregate from the recycled material may be 80 to 90 percent versus the current 50 percent. Third, by recycling a lane-mile per day, and not disturbing the subgrade the efficiency of the process should be able to save time (and thereby cost). All of the above will contribute to the use of more recycled material in an environmentally sound manner. The Kansas Department of Transportation (KDOT) has been recycling nearly 15 miles of two-lane pavement yearly for the last ten years. Having an effective and efficient process would insure economic recycling for many years throughout the nation (and even the world).

The project has two phases. Phase I ($100,000) is a feasibility study whereby the essential feature(s) of the proposal must demonstrate the ability to solve the key elements of the problem statement. In this project the anvil-hammer concept for effectively and efficiently crushing hollow core panels has already been demonstrated in a stationary machine. The extension to solid pavement slabs (and the design of an appropriate hammer head) is the critical area needing development in Phase I. Phase II ($750,000) will be the development of a prototype (mobile) Road Recycling Machine. Planning and evaluation for Phase II (the Road Recycling Machine) is the subject of this project.

Although the concept has been shown feasible by a previous engineering study to properly evaluate the chances of success, an engineering overview evaluating and finalizing the components of the Road Recycling Machine, in light of ongoing developments and current equipment, needs to be done. This study can identify critical components and problem areas, propose solutions and assess the probability of a successful development.

Project Objectives

Specific objectives of this project are:

1) Documentation of the existing concept;

2) Calculation of necessary performance parameter for the machine;

3) Comparison of the needed parameters to existing and planned componentry;

4) Forming and coordinating a design advisory team representing the proposer, the Kansas Department of Transportation, contractor(s), manufacturing facility, and component supplier to assure compatibility of design and operational requirements;

5) Finalize the design; and

6) Prepare a report addressing items 1 to 5, including presentation material.

DAPTECH LLC was subcontracted to fulfill these objectives. The work performed is detailed in the following sections.

Engineering Overview

As a first step, an engineering overview of the Road Processing Resources, Inc. "Fast-Track Pavement Recycling Machine" has been completed. Information from RPR's booth at an ACPA conference and other documents furnished by John Wojakowski or KDOT were reviewed. These included the following:

- A document entitled "Company Overview" with the concept illustrations by Deems Pfaff of the Road Processing Resources, Inc.

- A document entitled "One Step Concrete Removal Process" with reference letters, DOT communications, an engineering proposal from Richard Cox, P.E., CMI SF-6004 Paver brochure, Deems' illustrations, and miscellaneous vendor information.

- A bound copy of Rogers, Freels and Assoc. "Report of Concept and Feasibility Study"

- A copy of Loram's Double-Track Auto Plow brochure for RR Track removal, and

- Misc. vendor information.

In addition, a copy of Deems Pfaff's patent #4,309,126 (Jan 5, 1982) and some of the cited references were ordered. The RPR's Phase II proposal to SBIR was also consulted.

After studying the relevant information and consulting with Deems Pfaff, the process of calculating and documenting the performance parameters for the machine was begun. Attached is a 3-page spreadsheet document entitled "01128 CALCULATION / SPECIFICATION / COST SUMMARY" which includes, in addition to other information, a complete summary of the final calculated performance specifications for the machine.

A design advisory team to assist with the establishment of formal design specifications was formed. This team consisted of the following members:

Dennis Pauls: Daptech LLC, Subcontract Engineer (to KSU)
John Wojakowski: KDOT Project Contact (Project Sponsor)
Deems Pfaff: Road Processing Resources (Machine Innovator/Developer)
Dale McCartney: Erie Press Systems (Power-Drop Hammer Vendor)
Roger Bockes: Heavy Equipment Manufacturing Co. (Subcontract Mfg.)
Robert Bockes: Heavy Equipment Manufacturing Co. (Subcontract Mfg.)
Dr. Lakshmi Reddi: KSU Project Director (Principle Investigator)

Design and Dimensional Specifications

Our objective in this project was to use 3-D CAD technology to develop a design that related the form, fit and function of scaled-to- size components planned for use in the machine.

The performance parameters listed in the attached spreadsheet are used to develop a CAD model of the machine that was to serve as a basis from which to develop the final specification and design.

The machine was modeled to true size in the CAD system to serve as as the starting point for development of the final specification. A bound report noted as a "Preliminary Concept Thought-Provoker" was prepared for the first advisory team meeting that was held in the KDOT offices at Bonner Springs Kansas on 4/1/02 (attached). The summary of that meeting is included below:

> Through drawings, illustrations (booklet passed to everyone) and discussion, Dennis Pauls of DAPTECH, LLC went through the design process he has been working on. The following issues were identified and discussed:
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> HAMMER SIZE: Hammers as currently proposed are too tall. O/A height of the machine is almost 20' with hammers up and only reduces to 15' when they are down on the anvil.
> DECISION: Maximum working height (hammers up) of the hammers cannot exceed 13'0" so that pavement machine can remove pavement under bridges. This will also assure that shipping height on a 24" high drop deck will be within 13'6" legal limit. (Hammers down). Further review is needed to see if thickness can be added to the mass and high pressure air (up to 250 psi) can be used with a shorter stroke to maintain the maximum kinetic energy (34,981 ft-lb) in a hammer design that keeps a working height (hammer by itself) of about 11'0".
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> HAMMER PIVOT: The rubber dampened pivot mount point for the hammer frame would be better if it were on the bottom of the guide frame than on the top as shown in the illustrations. This would reduce the longitudinal bending moment potential for the hammer/frame.
> DECISION: Redesign the pivot to the lower part of the frame as close to the working surface of the hammer as possible. Put the spring cylinder towards the top of the guide frame.
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> 2 TRACK VS 4 TRACK: Dennis' illustrations show a 2 track machine 12' wide that can be loaded on a flatbed trailer using side ramps. There was considerable discussion on the merits of either design for transfer of crushed rock and steel into trucks. The loading and job-to-job transport of the machine was also discussed.
> DECISION: Dennis is to investigate a 4-track machine with the tracks on wings that can be swung around similar to a CMI 6000 series 4-track paver. (Deems gave Dennis a CMI brochure of the SF-6004 model.) It seems to have the best potential because the "gap" between the tracks on either side of the pavement allow for more options to get crushed rock out and separated from the steel. It would load by driving up on a flatbed trailer with its nose on the ground. Maximum allowable outside width = 15' and maximum loaded height is 15' per Robert's research. It is best to keep the loading track outside-to-outside width under 8'6" and the overall width under 12'.
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> HANDLING OF STEEL: Most common steel in old pavements is 12' long pieces of wire mesh. Some have longitudinal continuos rebar and some have dowels in baskets. Baskets with their potential to break spot welds and drop dowels will be the most difficult to handle. The trick is to get the basket assemblies transported over the lateral crushed concrete conveyor without loosing dowels into the crushed concrete flow.
> DECISION: It was decided to eliminate steel cutting and loading requirements on the first machine. The machine will separate the steel from the concrete and then lay it back on the ground between the tracks for removal by a secondary process. Investigate the possibility of "straw-walker" type conveyor slats to carry baskets/steel towards the back and drop on the ground between the tracks. Slats spaced to let concrete drop through and carry steel back.

LANE/SHOULDER SEPERATION It was decided that this process would be done by existing technologies. The result will be a 6" wide slot cut full length through the pavement between lanes and if necessary between the lane and the shoulder.

CONTROL SYSTEM: The machine will be controlled by a PLC. Inputs, outputs and operator interface are to be defined. The machine will self-steer by following one of the precut slots. It will have manual steer override. Leg barrel/Track height will be automatically maintained by PLC system with manual override capability.

OPERATOR CONVENIENCE: There needs to be a catwalk system all the way around the hammers. The team felt that the operator would have sufficient vision if his control station were positioned behind the hammers, looking through spaces in the support frame.

POWER: Even though the propulsion force is large, the speed is low and it will require less than 35 hp. Air hammers will require the most hp. It cannot be accurately calculated until hammer design is tied down a little more. Total HP is estimated to be in the 200 to 300 range. Preference is for a single power unit such as a Caterpillar C-12.

WEDGE DESIGN: Discussed "shovel nose" design (favored by Deems) and "bull nose with chisel teeth" (favored by Dennis). Objective is to get an action on the wedge that will "automatically "seek" the interface between the subgrade and the pavement without gouging or hanging up on either.

PUSH OR PULL ON THE ANVIL: Deems' experience leads him to believe that the anvil must be "pulled". His concept sketches show a plate extending upward from the anvil with the attach point for the link slightly above the top of the pavement that is on top of the anvil. Dennis believes that this will induce a tipping moment on the anvil that will reduce its effectiveness with the hammer and throw heavy shock loads into the link and frame. Dennis' concept shows the anvil being "pushed" along its centerline from behind. No resolution has been reached.

After the advisory team meeting, it was decided to finalize and acquire design and dimensional specifications on 3rd party componentry and apply them to a 4-track design based upon the rough dimensions of a CMI SF-6004 series tractor. Erie press systems worked on the design of their hammer system and was able to accomplish the design objectives desired. Their new hammer is 5,500 pounds with a 31” stroke and produces the same kinetic energy as the first but it requires 250 PSI compressed air for the drive cylinders.

Using all the new information and specifications, a rough 2-D CAD layout of the proposed machine was developed with copies sent to Deems Pfaff and John Wojakowski for review. On 5/16/02, another meeting was held between Deems Pfaff, Dennis Pauls, and KDOT. The purpose of the meeting was to finalize design specification issues. A summary of that meeting is included below:

HAMMER SIZE: On 5/6/02 Erie Press Systems, Inc. submitted a drawing of a revised hammer design. They were able to meet the envelope size by redesigning the hammer. The thickness remained the same. They just "filled In" the sides so they were solid and straight. This raised the hammer weight to 5500# (from 3600#). Using 250 psi instead of 120 psi on the air cylinder, they were able to maintain the maximum kinetic energy in the 34,000 Ft-Lb range.

HAMMER PIVOT: Erie press expressed some concern with the 4/1/02 concept for mounting the hammers. They want to see the mounting "moment" as small as possible. i.e. they want the pivot point in as tight to the centerline of the hammer as possible. They were also opposed to a bottom pivot because of the severity of the hammer swing it imparts by being closer to the working surface.

ANVIL SIZE: The mass of the hammer has increased from 3600# to 5500#. To maintain the 1:1 mass ratio of the hammer to the anvil in its "shadow" would require a substantial increase in anvil size. Since the total kinetic energy does not change, it is decided to keep the size the same. Dennis pointed out the challenge to get the discharge conveyor system in place behind the existing anvil but his preliminary drawings show that it is feasible.

4-TRACK PAVING TRACTOR Dennis brought preliminary drawings to the meeting showing a CSI 4-track frame married to the new hammers, anvil and discharge conveyors. It actually works out quite well and meets the height, width and transport considerations outlined at our 4/1/02 meeting. Issues with the placement and function of various components were discussed to everyone's satisfaction. It was noted that the engine compartment could be moved just underneath the operator's platform, which would open up lots of room.

ANVIL PUSH OR PULL: With the preliminary drawing, Dennis had a concept that would allow for either push or pull of the anvil on the prototype machine. Published drawings will show the machine set up for "pull". The pull mechanism will also have means to hydraulically adjust the angle of the pull link. If prototype testing shows this feature to be unnecessary it can be removed from production machines to realize the cost savings.

ROAD CROWN: John Wojakowski of KDOT reports that road crown is a "V" the center of the "V" at the joint between the two lanes. Since the RPR machine does one lane at a time, the 3/16" per foot crown does not affect it except to make the machine lean slightly to the "ditch side" of the pavement.

PAVING THICKNESS IRREGULARITIES: For all practical purposes, pavement thickness is uniform. The "wedge" will be detachable and interchangeable with different nose designs. The objective is to get an action on the wedge that will "automatically "seek" the interface between the subgrade and the pavement without gouging or hanging up on either.

Our next step was to develop a CAD layout of the concept machine for fit and function of components that the final specification anticipates for use in the machine design. Considerable effort was expended on engineering and design to tie down exact specifications for the final components and make sure that they will fit and function together to produce a machine with the desired performance capabilities.

The bulk of our value added to this project is in this CAD master design layout where the true sizes and interface characteristics of all of the machine components are worked out. Essentially the machine is built electronically and we can determine exactly how (and if) everything will fit together and work properly.

The most difficult system to engineer and design was the transfer and discharge conveyor systems. The desire was to minimize the anvil height. This left little space to fit a conveyor system in place with the capacity necessary to carry away all of the processed material. It was further complicated by the need to create a system that could discharge to either lane side without interfering with the pavement "step" in the unprocessed lane.

Attached are three sections of drawings with the following titles:

Working Mode: CAD model drawings of the machine in its working mode.
Transport Mode: CAD model drawings of the machine in its transport mode.
Construction Details: Detail and Exploded views of specific components.

These drawings are renderings of the master CAD layout model showing the machine from different views, in its different operation modes, and showing exploded details of key sub-assemblies.

From the CAD layout and design specification, we were able to develop a bill of material and detailed manufacturing cost estimate for this project. This information is tabulated in the attached 3-page spreadsheet document entitled "01128 CALCULATION/ SPECIFICATION/COST SUMMARY". It has been structured to give a detailed look at our calculations, design specifications and component cost information in one concise and easy to read document.

All of the information created can be used in the ongoing project to develop literature and presentation materials for reports and on-going marketing efforts. The master drawings are also available in several electronic formats.

In our opinion, this is a good design with extremely good technical merit. We have concluded with a great deal of confidence that this machine is feasible to build and that its final performance will be close to the expectations that RPR and KDOT have for the process. It will have a major impact on the cost, efficiency and time required to recycle older PCCP highways. This work will serve as a good basis for the final engineering and design of the prototype machine in RPR's phase II proposal.