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16. ABSTRACT

Many bridges have drainage systems and expansion joints that are not typically found on mainline roadways. Standard mechanical sweepers are well-suited for mainline roadways and standard drains; however, these machines tend to push incompressible debris into bridge drains, which can easily lead to blocking of the drains and to subsequent flooding. In addition, this incompressible debris can get inside expansion joints and other bridge features, leading to reduced component life, rapid deterioration, and potential failures. Vehicle traffic also pushes incompressible debris into bridge drains. Due to a lack of known systems to effectively clean bridge debris, Caltrans Maintenance frequently has to resort to labor-intensive methods and, due to traffic exposure, potentially hazardous manual cleaning of bridge drains, scuppers, joints, and transition structures. Caltrans needs a viable system for cleaning incompressible debris from bridge decks, thus reducing or eliminating the entry of incompressible debris into bridge drains, scuppers, joints, and other features. This research had two primary goals. The first goal was to identify applicable and effective commercial designs and systems that can reduce or eliminate the problem of incompressible debris entering into bridge drains and joints. The second goal was to identify targeted cleaning equipment and develop new equipment concepts if none were available and resources permitted. This report documents the detailed research effort and results.

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Improved Maintenance Methods for Bridge Drains and Expansion Joints

Wilderich A. White and Ty A. Lasky: Principal Investigator

Report Number: CA23-3704
AHMCT Research Report: UCD-ARR-23-03-31-01
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California Department of Transportation

Division of Research, Innovation and System Information

Executive Summary

This research reviewed and documented the challenges and needs of Caltrans bridge maintenance operations involving the cleaning of the bridge deck pavement, expansion joints, drains, and scuppers. Proposed solutions include modifying existing procedures and using unique, but commercially-available, equipment. The definition of problems and the development of proposed solutions were based on Caltrans and industry expertise.

Problem, Need, and Purpose of Research

California Department of Transportation (DOT) (Caltrans) maintained bridges have drainage systems and expansion joints that are not typically found on mainline roadways. Maintenance of these components is critical to bridge life and the associated costs.

Intrusion of debris into joints, drains, and sumps is problematic. Drain sumps tend to be smaller, requiring more regular cleaning to avoid flooding and failure of the drainage system. Incompressible debris gets inside expansion joints and other bridge features and lead to reduced component life, rapid deterioration, and potential failures.

The research was focused on documenting and defining these debris-related challenges to bridge maintenance and to recommend improvements to procedures and equipment.

Background

Caltrans' standard mechanical sweepers are well-suited for mainline roadways and standard drains; however, these machines tend to push incompressible debris into bridge drains, which can easily lead to blocking of the drains and subsequent flooding. Vehicle traffic also pushes incompressible debris into the joints and the bridge drains. Caltrans Maintenance frequently has to resort to labor-intensive methods cleaning of bridge drains, scuppers, joints, and transition structures.

Overview of the Work and Methodology

This research included a literature review that focused on commercially-available equipment and processes. AHMCT worked closely with the project manager (PM), the panel, and district personnel to define the needs, challenges, and potential solutions.

AHMCT made site visits to observe existing processes and consider potential solutions in coordination with district Maintenance personnel. The researchers met and consulted with personnel in the industry representing the equipment manufacturers, contractors, and commercial users.

The research evaluated commercially-available systems. The researchers performed in-house testing and evaluation of the regenerative vacuum sweeper and the common trailer-based vacuum excavator. The researchers facilitated the field testing of two different trailer-based vacuum excavator systems with District 11 bridge maintenance, one of which was purchased for further testing by District 11.

Major Results and Recommendations

The research and evaluation effort conclusions are as follows:

No proven commercially available equipment solutions are available to improve Caltrans cleaning operations for expansion joints. Vacuum equipment by itself will not remove hardened incompressible debris found on roads and bridges. Equipment that is currently being developed for porous pavement cleaning may be useful in the future.

Commonly available rented vacuum excavators with 3-inch hoses and 500 cubic feet per minute (cfm) flow rates are not adequate for drain sump cleaning. Systems with at least 4-inch hoses are required. Much higher flow rates are needed.

It is recommended that the effect of bridge deck sweeping on the filling of expansion joints and drains be investigated further. The quantity of material pushed into the joints and drain inlets by broom sweepers needs to be determined. Augmenting bridge sweeper operations with regenerative vacuum sweepers is expected to reduce the accumulation of incompressible fine and small debris. This may reduce the frequency and difficulty of expansion joint cleaning. Reducing fines, in particular, is expected to reduce hardness of the material that does collect. A proposed field test plan applying to expansion joints is included in Chapter 4 and Appendix C. Any recommendation related to regenerative sweepers should follow such testing by Caltrans or in future research.

It is recommended that regular bridge drain cleaning be performed by a crew using high-flow vacuum equipment similar to, but smaller than, the Caltrans vacuum truck (Vactor).

It is recommended that minor customization of vacuum systems be developed for bridge deck cleaning.

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Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
ARDVAC	Automated Roadway Debris Vacuum
ATIRC	Advanced Transportation Infrastructure Research Center
Caltrans	California Department of Transportation
cfm	Cubic feet per minute
DI	Drain Inlet
DOE	Division of Equipment
DOT	Department of Transportation
DRISI	Division of Research, Innovation and System Information
gpm	Gallons per minute
GVWR	Gross Vehicle Weight Rating
hp	Horsepower
MEP	Maximum Extent Practicable
META	Maintenance Equipment Training Academy
PM	Project Manager
psi	Pounds per square inch
TVE	Trailered Vacuum Excavator
UCD	University of California - Davis
UCPRC	UC Pavement Research Center

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Chapter 1: Introduction

Problem

Many California Department of Transportation (Caltrans) maintained bridges have drainage systems and expansion joints that are not typically found on mainline roadways. Caltrans' standard mechanical sweepers are well-suited for mainline roadways and standard drains; however, these machines tend to push incompressible debris into bridge drains, which can easily lead to blocking of the drains and subsequent flooding. In addition, this incompressible debris can get inside the expansion joints and other bridge features, leading to reduced component life, rapid deterioration, and potential failures. Vehicle traffic also pushes incompressible debris into bridge drains. Due to a lack of known systems to effectively clean bridge debris, Caltrans Maintenance frequently has to resort to labor-intensive methods and due to traffic exposure, potentially hazardous manual cleaning of bridge drains, scuppers, joints, and transition structures. Caltrans needs a viable system for cleaning incompressible debris from bridge decks, thus reducing or eliminating the entry of incompressible debris into bridge drains, scuppers, joints, and other features.

Objectives

This project had two primary research goals. The first goal was to identify applicable and effective commercial designs and systems that can reduce or eliminate the problem of incompressible debris entering into bridge drains and joints. The second, resources permitting, was to identify targeted cleaning equipment and develop new equipment concepts if none were available (not done).

The deployable product is an engineering evaluation of one or more commercially available systems for applicability to improve bridge deck cleaning and removal of incompressible debris, primarily expected to be vacuum-style sweepers; other commercial technologies and systems were considered in the literature and product review.

Research Methodology

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center initiated this research with a literature review that is documented in Chapter 2. The research evaluated commercially-available systems, including vacuum sweepers and other technologies, for the applicability for bridge deck cleaning and removal of incompressible debris located on the bridge deck (Chapter 2). AHMCT worked closely with the project manager (PM), the panel, and district personnel to set up site visits to observe existing processes and consider potential solutions in coordination with District Maintenance personnel (Chapter 3). The research also included the evaluation of a commercial regenerative vacuum sweeper (Chapter 4). Additionally, the research assessed concepts for modification of commercial systems to better address maintenance of bridge decks (Chapter 5). System evaluation included field testing by Maintenance personnel of at least one commercial system rented or procured for the research (Chapter 6). The researchers followed testing by interviewing the operators and supervisors to determine the effectiveness and applicability of the system for bridge debris removal.

Overview of Research Results and Benefits

The key deliverables of this project include:

- Literature and product review
- Assessment of commercially-available equipment for applicability in bridge deck cleaning
- Evaluation of a commercial regenerative vacuum sweeper
- Assessment of concepts for modification of commercial systems to improve bridge deck maintenance
- Field testing and evaluation of a commercial vacuum excavator for drain cleaning
- Development of a set of recommendations and conclusions for what works best, and what does not work, for bridge deck cleaning including drains, scuppers, and expansion joints.

Chapter 2: Review of Literature and Relevant Commercial Systems

Literature

AHMCT updated documentation of existing bridge cleaning systems and methods to further clarify the current problem. The literature reviewed information about alternative bridge drain and joint designs to determine if there are more maintenance-friendly designs. The intent was to guide subsequent research and possible deployment.

Published literature documented the importance of bridge maintenance. Maintenance is critical to the life of bridge structures. The importance of maintenance was reiterated in the meetings with the panel. No specific bridge design solutions were identified or considered. No industry-based solutions beyond the maintenance methods employed by Caltrans Maintenance were identified. Conceptual solutions were discussed, such as including sand or debris traps ahead of joints or drains, finding a way to cover the DI grates and bridge joints during the sweeping operation so the debris can bypass the grates and joints, or potentially revising DI designs. However, research efforts were focused on industry-based solutions.

Relevant Commercial Systems

The research focused on searching the internet and communicating with equipment vendors. Caltrans District 4 and District 11 staff provided descriptions of their experience with bridge cleaning equipment. AHMCT has previously worked on vacuum systems with Caltrans, including the system known as the Automated Roadway Debris Vacuum (ARDVAC).[1] The researchers met with representatives from Elgin, Tymco, Ditch Witch, and Vermeer. Additionally, researchers had extended discussions with representatives of Commercial Power Sweep, a sweeping contractor. Researchers contracted two four-hour sessions with Commercial Power Sweep during which the operators provided detailed demonstrations and explanations on the use of the regenerative vacuum sweepers. The researchers also contracted a two-hour session with the

[1] Porterfield, Andrew; Velinsky, Steven; White, Wilderich, "Development of a Prototype Telerobotic System for Debris Vacuum Positioning," AHMCT Research Report, UCD-ARR-00-09-14-01, September 2000 (https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-00-09-14-01.pdf)

University of California - Davis (UCD) campus maintenance operations, which owns and operates vacuum systems.

The use of commercially-available equipment was prioritized and only minor modifications would be considered as part of the research effort. The investigation was focused on sweepers and vacuum systems.

A white paper by the Elgin Company[2] contains concise descriptions of types of sweepers. The Elgin paper is focused on the maintenance of porous pavement and is relevant to the deep cleaning that might apply to joints. The sweeper companies' websites provided further details.

Sweepers

Sweeper designs consist of three types: the broom sweeper, the regenerative vacuum sweeper, and the vacuum sweeper. The basic designs have not changed in decades. Technological improvements are very focused on optimizing the power trains for fuel and emissions efficiency. Designers have greatly improved the operator controls and cabins. Sweeper equipment reliability is an ongoing challenge.

Broom Sweepers

The most common sweeper is the broom sweeper, which according to Elgin, represents 70% of the sweepers in the United States. It is also commonly referred to as a mechanical sweeper. These sweepers use only brushes to collect debris from the roadway.

Caltrans uses broom sweepers (Figure 2.1) that are very effective for picking up the vast majority of roadway debris. They are also the most energy-efficient sweeper because they do not require a lot of power to run the centrifugal fan used on vacuum systems.

Gutter brooms (side brooms) are common to all sweepers and are located on both sides of the sweeper behind the cab. The gutter brooms are fully adjustable and will retract up and in when the vehicle travels between sweeping sites. During sweeping operations, the gutter brooms rotate to sweep debris forward and inward, directing debris underneath the chassis to be captured by the sweeper head. As the sweeper moves forward, the large rotating broom at the rear sweeps the debris forward and the debris is kicked

[2] Maintenance and Restoration of Porous Pavement Surfaces, Elgin Sweeper Company, Mark D. Kinter, (https://socwisconsin.org/wp-content/uploads/2012/10/Elgin-Updates-Porous-Pavement-White-Paper.pdf)

upward. The debris is tossed onto a conveyor that carries the debris upward into a bin.

Dust is raised by the broom action and can be a significant problem. Water is sprayed at various locations to suppress the dust. Operators must optimize the water flow and adjust for the conditions. Some broom sweepers use a vacuum to contain and capture dust.

Broom sweepers are less effective at collecting smaller sand and gravel particles. The rear broom action pushes debris along until it is captured as the sweeper moves forward. According to operators, the bristles of the broom will kick small debris forward 50 to 75 ft before it is picked up. This debris will fall into expansion joints and drains as the vehicle passes them, and the smallest debris will remain on the road.

Figure 2.1: Caltrans mechanical broom sweeper (Image from District 10)

Regenerative Vacuum Sweepers

The regenerative vacuum sweeper (Figure 2.2) is optimized for deep cleaning and excels at collecting dust on road surfaces. According to Tymco, the regenerative vacuum sweeper was originally designed to clean road surfaces after grinding and in preparation for the application of tack coatings.

Figure 2.2: Tymco 600 regenerative sweeper at dealer

A large fan blows air into the sweeper head, which then picks up the debris and collects it through a tube on the right side, taking it to the bin where the debris is dropped out of the air stream. Air is drawn back into the fan and theoretically never leaves this recirculating path.

The sweeper head is effectively a box with one side open to the road surface. The box is the full width of the sweeper, and it rests and slides along the road on two metal skids. The left skid is clearly seen in the image. The forward and rear edges of the box are lined with stiff rubber flaps that adjust to the geometry of the road surface. The forward flap will ride over objects in the road. Gravel rolls under the flap easily, but an object, like a can or bottle, tends to be kicked forward and does not easily enter the sweeper head. Usually the front flap is adjusted to have a small gap to facilitate the entry of larger items. Air entering the edges of the box cause some recirculating air to be ejected at another point. Generally, this causes dust to escape and reduces the vacuum’s effectiveness.

The unique and critical feature of these sweepers is a structure within the box that causes incoming air from the blower to be forced through a slot extending the width of the box, which creates a sheet of air also known as an air knife. This sheet of air impacts the road surface and kicks up the debris being collected.

Regenerative sweepers are not ideal for most highway sweeping because larger items cannot be picked up. Due to the air knife, they do very well with smaller material. Gravel up to about three-quarters of an inch in diameter is easily picked up. They are popular with municipalities where they are operated closer to the public. Leaves and paper will generally slip under the flaps. Generally, less dust is emitted around these sweepers.

Vacuum Sweepers

The vacuum sweeper draws the air into the bin and ejects it into the atmosphere. In the case of the Elgin Whirlwind (Figure 2.3), air is drawn in through pickup heads located on either side of the sweeper. Only one pickup head is used at a time. This system is simpler than the regenerative system and is very useful for the collection of leaf litter. It is more commonly used in regions with heavy leaf fall.

The high flow of air is drawn thorough the pickup head. It enters the bin where the debris drops out of the air stream. The air is ejected above the left rear tire as shown in Figure 2.3.

Figure 2.3: Elgin Whirlwind vacuum sweeper at dealer

This vacuum has a concentrated flow at the pickup head (Figure 2.4) and could potentially be used to vacuum alongside the bridge deck edge with the gutter brooms retracted. Based on parking lot demonstrations, this unit might vacuum some loose debris out of expansion joints and possibly the DI grate. Based on demonstrations, this vacuum is not expected to be effective for bridge sweeping unless modified. Field testing and demonstrations of this unit on actual bridges are recommended.

Figure 2.4: Close-up of debris swept toward the pickup head

This fan-powered high-air-flow vacuum moves a large volume of air. It is similar to the VacAll ARDVAC, which had some success removing debris from bridge drains in District 4. If the shape of the nozzle matches the profile of the surface being cleaned while a small clearance is maintained, it will be effective at removing loose material. This type of system can potentially be optimized for debris collection at the road edge of bridges. Conceptually, a customized sweeper head would slide along the edge of the bridge curb or wall. The vacuum would draw out debris from scuppers, the top of grates, and the end of the expansion joint, which is where the incompressible debris starts collecting. This process could potentially reduce the frequency of manual cleaning efforts.

General Vacuum Systems

A search was conducted to identify vacuum system equipment that has the potential for use in bridge debris removal. Table 2.1 provides a list of some vacuums that are familiar to most maintenance staff. The compilation provides approximate values of bin size, air flow, and the maximum working negative vacuum pressure. This information and related equipment is described further in the following sections of this chapter.

Table 2.1: Comparison of vacuum systems

Vacuum Description	Bin Size	Flow Rate	Water Column	Air speed at Nozzle Elevated 1 inch
Home Vacuum 2-inch hose	15 gal (.07 yd^3)	150 cfm	2 ft WC	32 mph
Ditch Witch FX30 3-inch hose	500 gal (2.5 yd^3)	500 cfm	17 ft WC	87 mph
Vactor 2100i PD 8-inch hose	2000 gal (10 yd^3)	5,000 cfm	20 ft WC	325 mph
VacAll ARDVAC 12-inch hose	2600 gal (13 yd^3)	12,000 cfm	2 ft WC	520 mph

In industry, the vacuum pressure is usually defined in inches water column (inch WC) or inches mercury (in Hg). A unit of ft WC is used in the comparison because it is a simpler scale for comparing this equipment and represents the maximum height a column of water can be lifted. Centrifugal fan-driven systems, like the home vacuum cleaner (genericized trademark Shop-Vac) and the VacAll ARDVAC, will not lift a column of water beyond 2 ft. Other systems use positive displacement blowers and will lift a column of water 15 ft or more. Systems that operate between these two values are rare.

In vacuum applications for bridge cleaning, a column of water would potentially need to be drawn from the bottom of a drain sump to the inlet to the tank, which is about 4 ft above the road. Positive displacement pumps will do this. A known advantage to using a trailered vacuum is that the tank inlet is lower than it would be if mounted on a truck bed, which is a consideration for vacuum equipment collecting water and slurries.

Liquids and materials can be lifted higher than the indicated water column height if the air flow is sufficient. When the nozzle end is only partially submerged and the air flow is sufficient, water and materials will break apart into droplets or pieces and be easily transported to higher elevations.

Industrial vacuum systems are very heavy. The multiplication of the cfm rating and the water column defines the peak power requirements of a vacuum. The flow of the Ditch Witch FX30 is only 3.3 times greater than the home vacuum cleaner, but the peak horsepower requirement increases by a multiple of more than 28. Heavy robust components, such as hoses, tanks, and filters, are scaled up. The weight of the home vacuum could be 25 lb, but the Ditch Witch weighs 5,465 lb when empty, a multiple of more than 218.

Another point of comparison is the final column 'Air speed at Nozzle Elevated 1 inch', a calculated nominal average air speed for the air drawn between the nozzle and a surface. This comparison assumes that a round nozzle equal to the diameter of the respective hose is held 1 inch above the surface. This air flow agitates and lifts up the debris from the surface. The Ditch Witch flow is only higher by a factor of 2.2. Of course, the nozzle size can be reduced to increase this speed, but that is not normally done. The home vacuum is usually supplied with a narrow tip that quickly increases the size and quantity of debris that can be picked up.

Vacuum Excavators

The Ditch Witch FX30 (Figure 2.5) is a vacuum excavator (also known as a hydrovac). The genericized trademark Ditch Witch is sometimes applied to this type of equipment as well as to trenching equipment, which is confusing. The term vacuum excavator and hydrovac is applied to the full range of sizes, including large truck mounted systems. Inclusion of a pressurized water system is a common element and may be used to dig, clean surfaces or clean the equipment itself. This equipment is commonly used to dig and find existing underground utility lines, which is also known as keyholing, potholing, daylighting, and locating. These terms are sometimes used as modifiers to distinguish it from the large equipment.

Figure 2.5: Ditch Witch rented for use in District 11

When digging, pressurized water will agitate soil, which is drawn up into the bin of the vacuum. Normal water usage is under 10 gallons per minute (gpm). To avoid damaging utilities when digging, the straight tip max pressure is 2,500 pounds per square inch (psi) and a rotary tip can be operated at 3,000 psi. The slurry of water-logged debris must always be dumped into special drying ponds.

For this report the term vacuum excavator is used to identify this smaller trailered system. Evaluation of this type of equipment is described in Chapter 5. The large truck-mounted (hydrovac) vacuum (Figure 2.6) is referred to as a vacuum truck in this report. In the Caltrans fleet, most hydrovacs are outfitted with the hose reel seen in Figure 2.6. These hose systems (rodders) use special tooling to clean culverts and drain lines. The vacuum truck is also known as vactor truck, vac-con truck and sewer truck. Vactor and Vac-Con are genericized trademarks. The vacuum pump is typically used to draw liquids, sludges, and slurries into the tank. As shown in Table 2.1, the flow rates are very high, and the vacuum truck is a very effective vacuum cleaner. The vacuum truck size, weight, and expense will limit its use.

Figure 2.6: Vacuum truck supporting porous pavement cleaner (Image from Elgin dealer)

VacAll ARDVAC

Caltrans bought two VacAll ARDVAC systems in 2008 (Figure 2.7), and District 4 personnel have experience using it for bridge debris removal. The remote-controlled articulated vacuum nozzle (ARDVAC) was developed around 2000 at AHMCT[3] using a Leach VacAll platform. It is no longer manufactured and is no longer supported.

The VacAll ARDVAC has a 12-inch diameter nozzle and uses a centrifugal fan to generate air flow at 12,000 cfm. As shown in Table 2.1, this is approximately twice that of a typical vacuum truck with a positive displacement pump. It can be operated remotely from within the cab while driven forward. Most vacuum trucks are operated while stationary.

The flow rate is the maximum found in truck vacuum equipment. District 4 reported that the ARDVAC has no effect on expansion joint cleaning. It works well on deck drains. ***Caltrans does not consider it a viable option for future use.***

[3] Evaluation and Development of High Flow Vacuum Systems for Roadway and Roadside Litter Collection (Final Report) UCD-ARR-14-06-14-04, 2014, https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-14-06-14-04.pdf

Figure 2.7: Testing of a Caltrans VacAll ARDVAC (Image from Caltans)

Catch Basin Cleaners

Very large centrifugal fan-powered vacuum trucks are often referred to as catch basin cleaners. They use the high flow to collect materials but are not intended to pump liquids. The vacuum hose is usually mounted on the bin at the rear. The VacAll ARDVAC is a variation of a catch basin cleaner configured with an extendible boom off the front of the vehicle.

Vacuum and regenerative vacuum sweepers can be configured with a catch basin hose as shown in Figure 2.8. If a regenerative vacuum sweeper is utilized on bridge decks, it may be feasible to configure it to be a catch basin cleaner.

Figure 2.8: Catch basin cleaning using Tymco Regenerative Vacuum Sweeper[4] (Image from the Tymco website)

Small Vacuum Options

Vendors of vacuum hydro excavator equipment offer palletized systems that use smaller 100- to 150-gal tanks that can be carried in a pickup truck. They are less commonly available and are not practical for most users. The systems use 500-cfm blowers.

Centrifugal fan-powered systems are used in small trash collection vacuums, such as the Madvac LP61-G (2,200 cfm).[5] These use relatively small bins and are not intended to be used with wet or abrasive materials.

Centrifugal fan-powered small vacuum sweepers are designed for urban environments and parking lots and have the potential to be adapted for use in

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[4] Tymco 600 (https:/www.tymco.com/sweepers/model-600/).

[5] Madvac (https://madvac.com/).

debris removal. Most are not designed to be driven at highway speeds. Some are configured with a catch basin cleaning hose. Examples include the Tennant Sentinel (no longer manufactured) and the Madvac LS 175. District 11 has considered testing one such unit in drain-cleaning operations. They would be trailering it to the job site and probably leaving it on the trailer to do the work. ***District 4 tested small sweepers on a bridge deck and did not consider them effective.***

The processing industry uses a wide variety of air blowers, vacuums, and filters for handling materials. Products are generally customized, immobile, and powered with large electric motors. The RUWAC USA Company[6] offers a small vacuum powered by a 15-horsepower (hp) gas engine. It is rated at 630 cfm with 80 in WC (about 7 ft WC). The vacuum shown in Figure 2.8 is rated at 630 cfm and is considerably more effective than the most powerful industrial plug-in electric powered vacuums, which are limited to about 2 hp on a 20 amp circuit. Building construction crews can use these in open air environments. Ruwac recommends pairing it with a centrifugal separator on a drum, as shown in Figure 2.9. The system as shown would take the floor space of two 50-gallon drums and could be temporarily installed in the back of a truck. As shown, it could be used with a 4-inch hose, and it has an air flow rate greater than the Ditch Witch in Table 2.1. With some further modifications, it could be useful as a general purpose vacuum on the Caltrans bridge maintenance truck.

[6] Ruwac USA (https://www.ruwac.com/)

Figure 2.9: RUWAC vacuum

Special Tooling

Researchers looked for tooling that could improve the effectiveness of pressurized water systems and vacuums for debris removal. Pressurized water is necessary for the majority of cleaning of any hardened debris collection. When cleaning expansion joints, the backsplash and the scattering of wet material makes the task onerous. This process coats operators, nearby workers, equipment, and road surface with mud. Workers wear personal protective equipment, and the clean-up process is an additional effort. Workers have the option of setting up shields around the work area or on the spray wand itself to protect themselves from back spray. ***Given that the practice has not been seen in any images nor described by a witness, it is assumed to be impractical.***

Tools that utilize shielded rotating pressure washer jets are used to clean concrete. If used on expansion joints, the backsplash may be reduced, but the dislodged material will simply settle back in place into the joint. In concept, the cleaning operation can be improved by vacuuming the dislodged material concurrently.

Equipment that combines a vacuum with pressurized water was found at [Bunyan Industries (https://www.bunyanusa.com/)](https://www.bunyanusa.com/). The Bunyan BIRD (Figure 2.6) utilizes the vacuum truck to clean porous pavement and is commercially available. A smaller walk-behind unit (Figure 2.10) is an earlier concept that is apparently no longer available. A variety of the walk-behind version could potentially be useful for cleaning expansion joints. The walk-behind device is not practical for porous pavement cleaning because the hose system is too heavy for workers to maneuver. A very short hose hanging on the end of the vacuum truck would be needed for expansion joint cleaning. No other relevant equipment was identified.

Figure 2.10: Porous pavement cleaner

Chapter 3: Observation and Assessment of Existing Processes and Potential Solutions

AHMCT worked closely with the PM, the panel, and district personnel to define the problem, set up site visits to observe existing processes, and consider potential solutions in coordination with district Maintenance personnel. Aspects of existing cleaning operations have previously been observed, including use of the existing Caltrans broom sweeper, use of the Caltrans vacuum truck, and the ARDVAC VacAll. AHMCT worked closely with the PM and the panel to select specific operations and identify concepts for subsequent evaluation.

Focus Meeting Input

Initial meetings with the PM, the panel, and district personnel defined a wider set of problems. Discussions quickly focused on the problems affecting present day maintenance operations. In the initial meeting, personnel from the following groups were present: District 4 Bridge Maintenance, District 11 Bridge Maintenance, Storm Water Maintenance, Environmental Quality, and Structures Maintenance and Investigations. The group discussed sweeping operations and the removal of debris from DIs and sumps, expansion joints, and scuppers.

District 4 Bridge Maintenance is responsible for structures in the San Francisco Bay Area. District 11 Bridge Maintenance is responsible for San Diego area bridges. Both districts are located in very urban areas and maintain multilane roadways. Work on roads in urban areas is particularly challenging because of the high traffic volumes.

The districts presented the operations and challenges in their respective areas. During the meetings, images were shared to provide details of the maintenance challenges. Real-time images were provided from mobile phones in the field. Google Street View was used to provide a virtual presentation of the bridges. Selected images from the districts are presented in following sections of this chapter. The following sections also include paraphrased staff statements that are used to define the noted challenges. The last section lists the research priorities selected.

Notes on Bridge Design and Maintenance

Staff in the focus group, who were not in the bridge maintenance group, discussed aspects of bridge design that were new to the researchers. The following list compiles paraphrased statements important to the research and new to the researchers.

- Maintenance of the joints, drains, and scuppers is important to maintaining the life of the bridge.
- Specific expansion joints types and details were discussed but not fully captured. Gland[7] leaks were noted. Improvements continue to be required.
- The Trelleborg design in the new section of the Bay Bridge was mentioned as needing specific attention by Maintenance. Some types of unusually large debris have been caught in this joint.
- Maintenance of expansion joints is very important. If a joint fills up with incompressible debris, then the joint can't move back and forth and something will break.
- Joints are degraded by the presence of debris.
- Researchers noted that designs varied widely and many did not appear easy to maintain.
- DI and sump design are not standardized. Photos and descriptions of drains provided in the focus group meetings were considered typical.
- Shallow drain sumps (4 in) are common. Some are sloped. Depths of 3 ft are also common. Newer drains are commonly deeper, which extends the time between cleaning and reduces maintenance needs.
- DI and scupper designs vary.

Maintenance Issues

Maintenance operations involve mostly manual labor with shovels and basic tools. Sometimes Bridge Maintenance will use the vacuum truck to clean expansion joints and clear drains. Sweeping is the only operation that does not require workers on foot. Water blasting, water flushing, air jetting, and sewer drain jetting are examples of manual work tasks.

Notes on lane closures:

- Work is done on some shoulders without closure of the adjacent traffic lane. Lane closures are generally common during cleaning operations.
- District 4 cannot close the upper deck of the Bay Bridge during the day.
- District 11 has some connector ramps that are extremely difficult to close.

[7] A device, such as the outer sleeve of a stuffing box, designed to prevent a fluid from leaking past a moving machine part.

- Maintenance organization varies. District 4 has a lot of bridge crews. Other districts use general maintenance crews for bridge work.
- District 4 operates sweepers on the shoulders every two weeks. Other bridge decks are accessed for maintenance every two weeks.
- Every two weeks, in the eastern region of District 11, a crew will do night closure on connectors from 02:00 AM through 12:00 PM on Saturday. Twenty minutes of closure are required for each connector.

Notes on debris:

- All debris tends to be pushed to the roadway shoulders due to the action of the passing traffic. This debris collects along the shoulder.
- Most joint issues are restricted to shoulders because the joints begin filling with the incompressible debris at the outer edges of the roadway. The filling action usually starts against a curb or wall and as time passes, moves toward the travel lanes.
- High traffic volumes and speeds tend to clean the joints in the travel lanes.
- If joint debris is not removed in time, the joint filling action will continue into the travel lanes.
- Joint debris may build up across the width of the bridge. This situation occurs most frequently on smaller, low-volume rural bridges.
- Sweepers collect the debris on the shoulders. District 4 sweepers are operated every two weeks on the bridge decks. Although some regenerative vacuum sweepers have been used on bridges, mechanical broom sweepers are currently in use.

Notes on sweepers:

- Mechanical broom sweepers are much more effective than vacuum sweepers for removing the majority of debris from roadways. Aggressive brushing action is needed for the majority of debris removal.
- Mechanical broom sweepers will effectively pick up heavier, bulkier items, such as bottles and pieces of wood.
- Regenerative vacuum sweepers will effectively remove finer material from the roadway but not the heavy bulkier items.
- Mechanical broom sweepers push incompressible debris into joints and drains and will leave finer debris on the roadway.
- The gutter broom rotation pushes debris into scuppers.

Notes on vacuums, storm water, and environmental issues:

- Environmental and storm water quality issues were discussed.

- Maintenance activities and the associated problems with the handling of water were reviewed.
- District 4 cleaning requires the use of pressurized water, and they are able to collect 90% of water with the vacuum truck when cleaning expansion joints.
- District 11 uses air lances at 150 psi, but there are air quality issues. District 4 does not use the air lance because of air kick-back into worker eyes. Water jetting is preferred. This also reduces damage to passing vehicles.
- To clean drains, District 4 uses pressurized water and a vacuum truck or trailered vacuum excavator.
- In District 11, general sweeping is good enough for joints. The deck drains need attention or regularly scheduled cleaning, but the vacuum truck is too large for the work.

Types of Debris

No new debris mitigation solutions were identified. Construction vehicles drop a significant amount of sand and gravel. Tires on all vehicles, not only construction vehicles, move debris along roads. Figure 3.1 shows an example of debris in District 11.

Dirt and debris enters the expansion joints and builds up. District 4 begins joint debris removal by chipping it out with steel tools before using water jets. The noted hardening of debris may be the result of the rehydration of concrete dust as described in Appendix E.

Figure 3.1: Two examples of debris-filled grates (Images from District 11)

District 4 Operations

The District 4 Bridge Maintenance crews maintain seven large bridges on and around the San Francisco Bay. District 4 has over 2,000 other bridge structures, necessitating a large number of bridge crews.

The designs of the various bridge features vary significantly, requiring different solutions for debris removal. Due to traffic flows, access for maintenance is challenging. For example, maintenance work on the upper deck of the Bay Bridge occurs only at night. The photos in Figures 3.2 through 3.5 were shared as examples.

Figure 3.2: Bay Bridge joints before cleaning (Images from Caltrans District 4)

Figure 3.3: Bay Bridge joints after cleaning (Images from Caltrans District 4)

To clean the expansion joint, first the maintenance crew scrapes materials out with a tool similar to a crowbar. Then material is collected with a broom or perhaps a Ditch Witch. A pressure washer is then used, which ejects more material from the bottom of the seal.

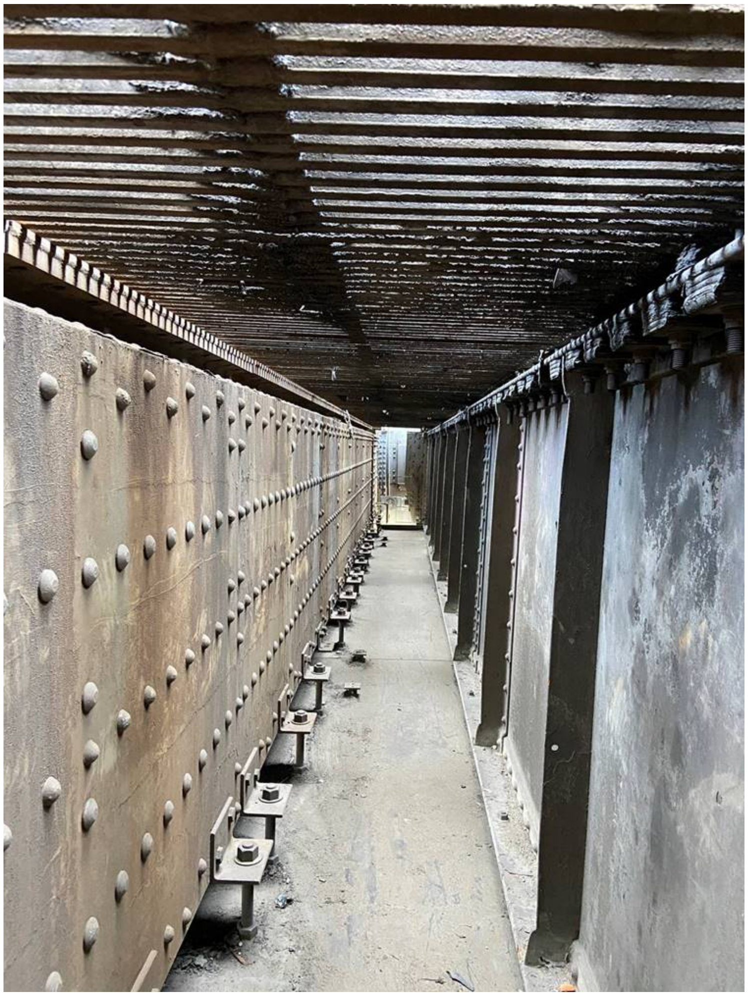

Figure 3.4: Bay Bridge pan that is cleaned by hand every six months (Image from Caltrans District 4)

Bay Bridge Maintenance cleans the upper deck bridge pan (Figure 3.4) every six months. If the debris gets wet, corrosion begins, and Maintenance needs to replace the pans. One pan worth of debris will fill a 500-gallon vacuum excavator. The Bay Bridge has horizontal drains that are filled up with debris and no longer function. The debris cannot be removed with the best available drain cleaning systems.

Figure 3.5: Drain cleaning on the Bay Bridge (Google Street View image Dec 2020)

Typical Bay Area bridge scuppers are shown in Figures 3.6 and 3.7. Debris, including larger items, gets stuck in scuppers and must be pulled out by hand. Scuppers can be 18 in to 24 in deep. San Mateo Bridge illustrates the extensive amount of scuppers, which empty into the bay.

Figure 3.6: Scuppers (Google Street View image Dec 2020)

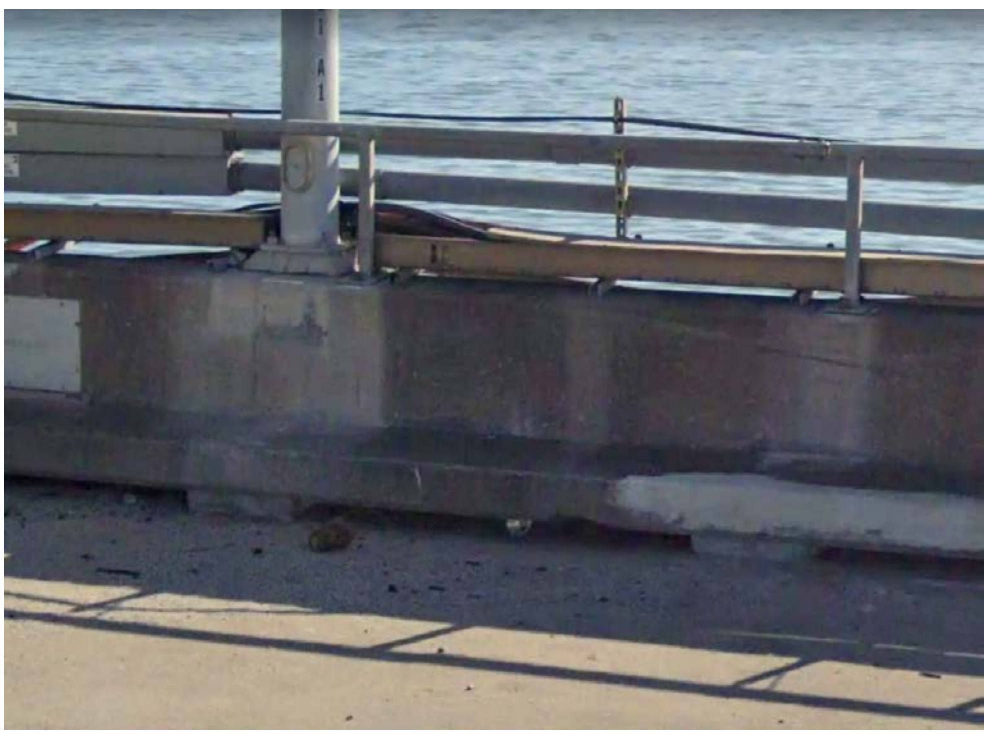

Figure 3.7: Scuppers on San Mateo Bridge (Google Street View image Dec 2020)

District 11 Operations

District 11 noted that drain debris accumulation rates vary by location and are dependent on road sweeping frequency. Some bridges build up heavy debris even if swept daily. Examples were provided of drains filling up within weeks. Figure 3.8 shows an example.

Figure 3.8: Example of drain cleaning on bridge in District 11 (Images from District 11)

Prioritization of Research Effort

As a result of focus group discussions, research was focused on the following district needs:

- District 4 emphasized the challenge of cleaning large expansion joints.
- District 11 emphasized the challenge of cleaning bridge deck drains.
- Both districts suggested that the broom sweepers are filling joints and drains. Sweeper operation might be improved by use of a regenerative vacuum sweeper.

Only commercially available equipment with small modifications was considered. The VacAll ARDVACs were not included because they are no longer available.

Chapter 4: Evaluation of Regenerative Vacuum Sweepers

The regenerative sweeper was evaluated by demonstration and testing at AHMCT's Advanced Transportation Infrastructure Research Center (ATIRC) facility at UCD.

ATIRC Test Facility

The facility includes a non-public, 1,000-ft-long two-lane test road with 100-ft diameter turnaround areas at each end. It is an asphalt surface with good quality smooth straight sections. The turnaround areas include pavement sections of chip seal with areas of significant cracking. Cracks were full of incompressible debris that have been undisturbed for several years. Prior to testing of the sweeper, construction of research test pavement sections that had deposited common incompressible debris materials was performed on the test road.

Demonstration

A private contractor—Commercial Power Sweep based in Napa, CA—was contracted to demonstrate one of their Tymco 600 regenerative sweepers in two separate four-hour sessions.

In the first session, the operator was focused on demonstrating the machine operation, while sweeping the test road. The company understood the research goals and assigned a highly experienced operator who was enthusiastic about the opportunity to explain the details of the work and the equipment. During the demonstration, the operator demonstrated their perspective from within the cab and provided an extensive walk-around. The roadway was thoroughly swept and finally the bin was emptied and cleaned.

An approximately 40-yd^2 section of one turnaround had accumulations of soil up to an inch deep. This area was mostly avoided but briefly demonstrated a worst case of dust emissions. The sweeper collected approximately one cubic yard of dirt, sand, and gravel with diameter up to three-quarters of an inch.

The discussions with the operators were very useful to the researchers. Both operators were also operators of broom sweepers and confirmed the value of the two types of sweepers in different applications. No information on plain vacuum systems was available. The following observations were noted.

An experienced operator is required to optimize the effectiveness of the regenerative vacuum sweeper. The operator is in control of sweeper traveling speed, steering, obstacle avoidance, vacuum centrifugal fan speed, gutter broom speeds, and water injection for dust suppression. Experienced operators will be able to maximize effectiveness while suppressing dust. It is common practice to reduce the vacuum fan speed. In addition to the control instrumentation and visible cues, the operator relies on sound cues, such as the gravel entering the bin.

Road surface characteristics, debris properties, and moisture levels are all factors affecting debris sweeping operations and dust suppression. Each machine has different characteristics, and effectiveness tends to reduce with wear and tear. Repaired impact damage to the sweeper head may be invisible, yet can result in permanently impaired performance. Working along the curb of a bridge must be done carefully to avoid hitting the sweeper head.

Dust is created by the gutter broom, but under some circumstances, it is emitted from the sweeper head. Conceptually, because of the regenerative design, there is no reason that air would leave the sweeper head. In real-world operation, for example, low points in the road surface will let a volume of air seep in under the sweeper head edge. As a result, an equivalent volume of dust-filled air will exit at some other location along the edge. The debris-filled air passes from left to right within the head, causing it to leak out to the right side. Air gates can be opened within the regenerative circuit to reduce this effect by reducing the air being blown into the sweeper head while maintaining the air flow being drawn into the bin.

Spray heads deposit water to dampen dust before it is removed from the road. This action is performed ahead of the gutter brooms and also beneath the front bumper of the sweeper. Water use must be limited to avoid turning the dust to a thin layer of mud that becomes difficult to remove.

It is recommended to fill 1 to 2 in of water into the sweeper bin before beginning sweeping operations. The layer of water removes dust from the air entering the bin.

In many construction operations, both regenerative and broom sweeper machines are used. When using a broom sweeper, the sweeper must be run 50 ft to 75 ft beyond the end of the debris-covered surface for complete debris pick up. However, this factor is sometimes not accounted for in work zone plans. One operator described a challenging job on a surface street where he had to enter a live intersection to complete each pass.

The operators had no experience drawing material out of expansion joints.

Test of Simulated Expansion Joint Cleaning

At the second session, a different operator brought the same Tymco 600 machine out to the test road to test the sweeper operation on a simulated expansion joint. The objective was to provide a qualitative evaluation. Researchers prepared a relatively simple test to quantify approximate sweeper debris removal rates. Drain cover grates were used to approximate the grooves in an expansion joint.

Researchers built a shallow concrete case to hold five Type 24 grates (24 in by 24 inch by 3.5 in; see Figure 4.1). The frames were embedded into the concrete so that the grates were flush to the concrete. A concrete parking curb was used to simulate the bridge curb or wall.

Figure 4.1: Installation of grates used to simulate an expansion joint at ATIRC

The grate slots were spaced at 11/16 in apart. Figure 4.2 shows a view of the bottom side of the grate. As can be seen, the slots are continuous for each grate, but stop at the ends. The grates were oriented to make the slots perpendicular to the sweeper direction of travel.

Based on the observations in the first session, researchers anticipated that a substantial amount of debris would be removed from the grate. The goal was to quantify the amount of material removed in passes at up to three different sweeper speeds. The speeds were defined by the operator to represent a slow, medium, and high sweeping speed.

Figure 4.2: View of grate bottom

The testing procedure was implemented only on the one grate next to the curb, using the following steps:

1. Sweep the test road before and after the test section. Place the curb at the edge of selected grate to represent the edge of the lane.
2. Using a scale and bucket, fill the one grate next to the curb so that gravel fills all the slots. Record, by weight, the amount of gravel needed to fill the grate.
3. Run the sweep at low speeds with the gutter broom retracted. Video record the sweeper as it passes over the grate to review and calculate speed.
4. Lift the grate out, collect, and weigh the remaining material.
5. Repeat Steps 1 through 4 for low, medium, and high speeds. For each test, fill the grate with the same weight recorded in the first filling.

The material selected to represent debris was 3/8-inch pea gravel, which would be more difficult to remove than smaller debris particles. Figures 4.3 and Figure 4.4 show the sweeper preparing the site and a test run.

Figure 4.3: Sweeper cleaning track before testing

Figure 4.4: Sweeper approaching grate for a test with sand

The first pass of the sweeper at slow speed picked up a very small amount of the gravel, which was an unexpected result, and the test procedure was aborted. The remaining time was spent experimenting to understand this unexpected phenomena. Variations included passes at extremely slow speeds and substituting sand instead of pea gravel. One slow-speed pass is shown in Figure 4.5. At the very end, the sweeper was run perpendicular to the grooves. Appendix B contains additional pictures and notes on this activity.

Results and Conclusions

Demonstrations of the road surface sweeping operation confirmed the following expected conclusion regarding the regenerative vacuum sweeper:

- The sweeper does effectively remove fine debris and gravel up to three-quarters of an inch diameter.
- The sweeper does not easily pick up large items that cannot easily slip or roll under the front flap of the sweeper head. An empty plastic bottle (2.5-in diameter), for example, could not be picked up.

No attempts were made to define the limits of the sweeper capabilities. It was apparent that dense material becomes progressively more difficult to pick up as particle size increases.

At the first session, it was demonstrated that random cracks of up to three-quarters inch width were cleaned successfully to a depth of at least one inch. Researchers expected that the sweeper could be used to remove loose incompressible debris from the simulated expansion joint.

The test to remove debris from the grate was inconclusive. Based on the best understanding of what is occurring within the sweeper head, the researchers made the following conclusions and predictions:

- The air flow no longer functions as designed because the spreader box seal to the road surface is broken as it passes across the grate. Abnormal turbulent flow is generated throughout the box. The flow of the air knife effect is disrupted and made less effective.
- The air flow in the sweeper head will be different on an actual expansion joint.
- It is predicted that the sweeper can remove some loose debris from the slots of an expansion joint if operated extremely slowly. The sweeper air brake prevents a smooth, slow speed movement, resulting in a start-stop action. Multiple passes may be required. Field testing with Caltrans maintenance crews on actual expansion joints is recommended.
- Hardened debris in an expansion joint cannot be removed.
- Expansion joint designs vary. Field testing on actual joints is required to establish the potential use of the regenerative sweeper in the cleaning of specific expansion joints. If shown to be successful, further testing at a facility like ATIRC could be used to develop joint cleaning equipment, or

qualify equipment. Selection, purchase, and installation of representative expansion joint designs would be guided by the field testing results.

Figure 4.5: Sweeper head passing across grate after briefly stopping

Proposed Field Testing of the Sweeping Operations

Field testing of the regenerative vacuum by District 4 is recommended. The following questions are proposed:

1. How much debris does traffic push into the expansion joint in two weeks (the broom sweeping cycle on District 4 bridges)?
2. How much debris is added by one pass of the broom sweeper?
3. How much of the total loose expansion joint debris can the regenerative vacuum sweeper remove from the expansion joint?
4. How much road surface debris does the regenerative vacuum sweeper pick up after the broom sweeper pass?
5. Does adding a regular regenerative vacuum sweep run periodically during a six-month cleaning cycle reduce the expansion joint cleaning operation?

The proposed sequence of testing outlined in Appendix C would provide detailed quantitative answers to the questions above. In lieu of this type of rigorous testing, it would be informative to make observations and take photos to document the progression of debris filling after deep cleaning and immediately before and after the first brush sweeper pass. Qualitative testing and demonstration of the regenerative vacuum sweeper can also be achieved.

Chapter 5: Testing the Vacuum Excavator

Based on the information from the focus group meetings, equipment search and follow-on discussions with the District 11 Bridge Maintenance, researchers recommended testing a vacuum excavator for drain cleaning.[8] District 11 offered to support field testing, and the researchers rented a Ditch Witch FX30 for the District 11 bridge crew to use for a month. The FX30 is a commonly available model and has a 3-in hose with an airflow of about 500 cfm. Researchers followed up with a two-hour demonstration of the same model owned and operated by UCD campus operations and demonstrated at the ATIRC facility.

Based on the testing with District 11, researchers searched for a rental unit with a 4-in hose, 1,000 cfm airflow, limited to a gross vehicle weight rating (GVWR) of 10,000 lb. A search for a rental of the Vermeer model in the District 11 area was unsuccessful. After demonstrations of the Vermeer CV573SGT to researchers and the PM at ATIRC, the decision was made to purchase and deliver the unit to District 11 for testing. This process was accomplished and the final evaluation results, based on survey and interview, are included in Appendix D.

Field Testing with District 11

The goal was to determine if the Ditch Witch FX30 equipment can improve the debris removal process which presently involves shovel work. A researcher accompanied the crew on a full day of drain cleaning with the crew. The crew spent an hour at the end of the work day to provide detailed opinions to the researcher. Additional information was provided after the end of the rental period.

The work attended by researchers was performed in a closed left lane on the connector from westbound State Route 56 to southbound Interstate 5. A brush sweeper followed the crew. The crew first collected large debris that would not be swept by the sweeper (Figure 5.1). The first few drain sumps were cleaned with a shovel (Figure 5.2). Debris was thrown downstream of the drain for the sweeper to pick up. If a sweeper is not available, the crew will collect the debris into buckets and return with it to the yard for later disposal. The vacuum nozzle

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[8] AHMCT wishes to explicitly knowledge the extensive support provided by District 11 for the field testing. John Miller and his District 11 Maintenance crew were extremely helpful.

and pressure washer are shown in Figure 5.3. Shovels are used to break up vegetation and remove the grates.

Figure 5.1: Large debris ahead of sweeper

Figure 5.2: Shoveling debris downstream of the grate for the sweeper to pick up

Figure 5.3: Cleaning with 3-in nozzle and swiveling power washer head

Figure 5.4: Clearing plugged hose

The following observations were noted when operating the Ditch Witch FX30:

- The debris in the drain has the texture of soft loamy soil with compost. The spray tip has virtually no effect on the debris. The energetic high flow is simply absorbed like a sponge.
- The special rotating spray tip does not appear to improve the operation. A plain tip is likely sufficient.
- Use of the spray tip is only necessary to add water to assist the vacuum process. (The crew had been directed by the rental agency to always use water to avoid dust getting into the blower.)
- A shovel is required to lift the grate and break up roots.
- The work can be done quicker with a shovel. Using the water and vacuum will clean the surfaces very well, but it is not necessary.
- Burying the water tip makes it nearly ineffective.
- Burying the vacuum nozzle makes it nearly ineffective. It takes many seconds to build up the negative vacuum pressure.

- The action of the vacuum nozzle is sluggish.
- A larger diameter nozzle and hose would simplify the vacuuming, but handling it will be more difficult.
- Carrying and handling the nozzle with the hose draped over the shoulder requires significant manual effort.
- Plugging of the vacuum hose occurred at least twice at each drain.
- Unplugging the hose was tedious. Various techniques to unplug it were tried. The spray tip was used to run water into it to help unplug the hose. In several attempts, the hose was punctured by the spray.
- Adding water to the debris appeared to reduce the chance of hose plugging.
- At the end of the job, the vacuum excavator was towed to a dump location and was half full. It was commented that dumping at the special dump site is easy and using water in a system is not a problem. Wet debris must be dumped at designated decanting sites which have sufficient capacity.

The actual work at the site consumed four hours, but it was done at a slow pace because of discussions. The crew agreed that it takes twice as long to use the vacuum excavator than the usual shovel work.

A few minutes were used to check the action of the vacuum system on the small expansion joints. The vacuum had no effect. The spray nozzle did knock material out, but the nearby Jersey wall was quickly covered with mud. The sweeper operation was observed closely, and it was noted that the gutter broom knocked some debris into the freshly cleaned drain, but it was less significant than expected. It was anticipated that more would end up in the drain at normal operating speed. Most of the sweeper debris was remains of a recent methacrylate treatment of the pavement.

The concluding recommendation was that it was important to have a 4-in hose. A higher vacuum flow rate was very important. It was understood that the systems with 4-in hoses are built into larger trailers (GVWR ~18,000). It is very helpful to the crew to limit the trailer to a GVWR of 10,000 lb so that a smaller pickup and driver with a Class C license can tow it. The 500-gallon debris tank was ideal. The preference was to be able to use the system dry when possible, and a 100-gallon water tank was sufficient but not ideal.

Researchers looked for a larger system with the preferred specification and an airflow of 1,000 cfm. None could be found in the rental market. After consultation with the panel and Division of Equipment (DOE), researchers purchased the Vermeer LP573SGT to meet the research goals and timeline. The specification for the unit is in Appendix A. This system met the DOE requirements that the unit be commercially available and therefore could later be incorporated in the fleet if testing proved it to be successful. The unit was delivered for further testing in District 11. The final assessment of the unit is positive and included in Appendix D.

Use of the vacuum excavator will require additional crew training. For example, a larger work space may be required to use the vacuum excavator safely and this may require closure of additional lanes. Appendix D presents additional details on the use of the vacuum excavator.

Other Demonstrations

Researchers contracted an operator, and the same model Ditch Witch FX30 was located through UCD campus operations. UCD employees maintain all the utilities on campus, including water supply, sewage, electricity, and heat and cooling. The campus owns the noted Ditch Witch and a full-size vacuum truck.

The operator provided a detailed walk-around and a demonstration of the vacuum excavation operations at the ATIRC facility. The details of cleaning and maintaining the machine were described. After the digging demonstration, the discussion reviewed what the researchers observed at District 11 and the work performed on campus. The following important points were made:

Material in drain sumps will always be moist despite the long, dry summers in California. The debris in the drain sumps (catch basins) at UCD is usually full of healthy earthworms.

Any moisture in the material will begin sticking to the internal diameter of the hose and build up to the point that the hose is plugged up. Water must be added periodically to keep the hose clear.

The exact same phenomenon occurs in the much larger vacuum trucks.

The vacuum truck is always preferred because of its much higher flow rate.

The vacuum excavator is almost never used for drain cleaning.

The operator recommended the use of the semi-transparent hose on their machine. It is allows the operator to see the build-up of debris on the hose and see where the plug is located.

As a result of the demonstrations and field testing and the comments from District 4 at the focus meetings, the very common 500-cfm vacuum excavator with a 3-inch hose is not ideal for drain cleaning.

Chapter 6: Deployment and Implementation

Implementation of the solutions will require Caltrans to acquire less commonly available or specialized equipment. Field testing is required and will require scheduling coordination among various groups. Further development of solutions to the debris removal problems will require access to expensive equipment like the large vacuum truck. Short tests using dealer demonstration equipment are also difficult.

Problems and Issues that Affected Product Deployment

Economic disruptions due to the COVID-19 pandemic exacerbated access to equipment for testing, but the follow observations are noted:

- Finding specialized rental equipment is difficult. Rental equipment inventories include only the most commonly used pieces of equipment in the most basic configurations. New equipment dealers cannot provide equipment to test for an extended period. They might be able to verify which rental yards they sold the machine to that you want to test, but the rental yard may not be able to find it. Rental companies will readily move equipment to meet an immediate customer need, but they do not usually reserve a specific model if a similar alternate can be substituted.
- Dealers will usually only have a few pieces of equipment to provide for demonstration. These will typically be rotated over a multi-state area. Coordinating demonstrations with other dealers is challenging.
- Sophisticated equipment, such as a regenerative vacuum sweeper, requires experienced operators who are very familiar with the equipment. Demonstrations of less-complicated equipment, such as the vacuum excavator, will also be most effective if operated by experienced personnel.
- Caltrans maintenance schedules and logistics are affected by events that make coordination of demonstrations difficult.

Solutions to Noted Problems and Issues

In order to proceed in deployment, field testing, or development efforts, the following steps are required:

- The search for equipment must be completed before commitment to additional field testing or deployable vacuum machine development.
- Plans for finding skilled operators of the equipment must be defined. Private contractors may be a useful source, especially if the equipment matches that being tested.
- Access to rental equipment may be facilitated by experienced persons within Caltrans.
- Further testing and demonstrations may be needed in controlled environments, such as ATIRC or the Maintenance Equipment Training Academy in Sacramento (META) facility. Fabrication of exact replicas of items, such as expansion joints, may be required. These will likely require long lead times.

Issues Expected to Affect Full Implementation

The proposed testing of the regenerative sweeper on District 4 bridges will require coordination between the district and statewide equipment management. The bridge maintenance group will need support.

Testing the regenerative vacuum sweepers will require extensive coordination by the bridge maintenance group and will require at least one six-month cleaning cycle. Documentation of this cycle will be very important.

A well-designed preliminary test and demonstration must be developed before committing to a full cycle of testing.

Demonstrations by the dealer of a vacuum-only sweeper will have value, but must be further investigated before a field demonstration.

Obtaining and using more effective vacuum systems for drain cleaning will require access to high-flow vacuums that are not readily available.

Other Considerations for Reaching Full Product Deployment

Implementing changes to drain cleaning operations will require support of multiple groups within Caltrans. A search for specific configuration of equipment will be needed. The ownership of the equipment must be defined, including confirmation of space availability in the fleet.

Chapter 7: Conclusions and Future Research

Key contributions of this research project included:

- A thorough expert Caltrans panel review of the current challenges of debris removal from bridge deck expansion joints, drains, and scuppers.
- A complete search for commercially-available equipment that might improve Maintenance debris removal operations on joints, drains, and scuppers.
- An assessment of the role of sweepers, including an evaluation of the regenerative vacuum sweeper.
- An evaluation of vacuum systems used in debris removal operations on bridges.

The research and evaluation effort conclusions are:

1. No novel commercially-available equipment solutions are available to improve present day cleaning operations for expansion joints.
2. Common vacuum equipment by itself will not remove the typical hardened incompressible debris found on roads and bridges.
3. Common high-flow vacuum equipment by itself will potentially draw out loose incompressible debris from not more than 1 in deep in expansion joints and similar features.
4. Dry vacuuming systems are not practical for roadway debris cleaning operations because pressurized water is usually required to dislodge hardened debris and vacuum hoses must be regularly unclogged by flushing with water.
5. Broom sweepers are more effective than regenerative and other vacuum sweepers for cleaning most (larger) roadway debris, but they will push incompressible debris into joints and drains.
6. Adding regenerative vacuum sweepers into bridge deck sweeping operations is likely to reduce the rate at which incompressible debris fills the joints and drains.
7. Commonly available rented vacuum excavators with 3-in hoses and 500 cfm flow rates are not adequate for drain sump cleaning. Systems with 4-in hoses and at least 1,000 cfm should be used.

Since debris removal is critical to bridge life and the associated costs, the following future work is recommended:

1. Evaluate regional solutions to the problem. For example, establish the value of assigning bridge drain sump cleaning responsibilities to the regular Caltrans sweeper crews as was done at one time in District 11. These crews could utilize specialized equipment with grate-lifting devices to quickly clean the bridge drain sumps out in a moving lane closure scenario. Even if workers have to be briefly on foot, overall worker hazard exposure will be reduced. This dedicated truck-mounted high-flow vacuum system will not be as expensive as the general-purpose large vacuum trucks presently within the fleet. This equipment will be customized for the work.
2. Evaluate the use of regenerative vacuum sweepers in bridge deck cleaning. Although broom sweeping will continue to be necessary, it is likely that a pattern of cleaning with some combination of broom and regenerative sweepers will significantly reduce the amount of incompressible debris that enters joints and drains. Quantifying the debris pushed into joints and drains by the broom sweeper is important. District 4 reportedly had to use crowbar-like tools to break up debris in joints. Reducing the build-up of very fine debris is expected to reduce the hardness of the compacted debris as discussed in Appendix E), which should reduce the cleaning effort. Appendix C contains the outline of a proposed field test plan to evaluate the effectiveness of the sweepers on bridge deck expansion joints specifically. Similar testing on drains is recommended.
3. Continue to support testing of the Vermeer trailer to firmly establish the minimum flow requirements for this type of system in drain cleaning. Rental yards might be encouraged to carry this type of equipment to support Caltrans maintenance operations.
4. Investigate the development of equipment for the cleaning of porous pavement. This equipment may potentially be repurposed to clean large expansion joints.
5. Investigate the potential of customizing the regenerative sweeper head to clean debris from expansion joints. The solution would require redirecting the air knife flow directions and the addition of water spray heads.
6. Investigate the potential of customizing high-flow street vacuums, such as the Elgin Whirlwind, to clean debris from expansion joints, DIs, and scuppers.

Appendix A:
Specification for Vacuum Excavator

Defining the Minimum Requirements

A minimum set of requirements for a trailered vacuum excavator was defined in conjunction with the District 11 bridge crew. The requirements for a vacuum excavator for use in bridge drain cleaning are listed below:

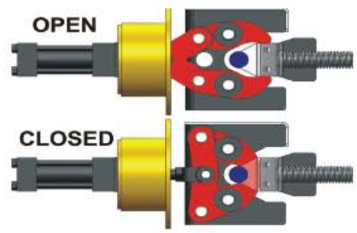
<u>Specification for Trailered vacuum excavator (TVE)</u>

The specified TVE shall be of the type used in industry and construction for the vacuuming of dirt, sand, dust, and slurries. Minimum requirements are:

1. TVE shall operate in wet and dry applications.
2. TVE shall have gross vehicle weight less than 10,000 lb.
3. Debris/spoils tank shall be 500 gallon in size with hydraulic driven door lock and tank tilting/dumping mechanism. The tank shall have an integrated washout.
4. TVE shall be configured with a 4-in (nominal diameter) vacuum hose rated for use at TVE system pressures. Tools typical used in digging for potholing or drain cleaning shall be included. Tool length and hosing shall permit vacuuming from ground level to at least 4 ft below ground level. Hose and tooling shall be nominally 4-in internal diameter and 25-ft minimum length.
5. The vacuum pump shall be a lobed positive displacement type operating at 1,000 cfm and 14-in hg vacuum.
6. TVE shall include 4-way valving that reverses air flow. The valving shall be operated by a single lever. The reversed air flow will pressurize the tank to allow purging of the tank through a dump valve at bottom of tank or through the hose.
7. TVE will be configured with a boom at least 15 ft in length at the rear of the trailer to support the hose above the operator.
8. TVE shall have a pintle hook trailer hitch.
9. TVE trailer shall be supplied with a hydraulic surge brake system.
10. Engine shall be a gasoline type producing at least 37 hp. Gasoline tank shall be at least 30 gallon in size.
11. An engine cover shall be included to cover and protect the engine and pump system and to reduce noise.
12. The pressurized water system shall be at least 4 gpm at 3,000 psi. Water tanks shall hold 200 gallons.
13. A multi-stage air filtration system shall include a water separator, cyclone filter and a washable .5-micron cartridge filter designed to remove dust and liquid from the air stream before it enters the vacuum blower.

Vermeer specification for 2023 Vermeer LP573SGT purchased for testing with District 11

.5 MICRON FILTRATION. Cyclonic filtration separator as well as a secondary filter to clean the air down to .5 microns.



REAR HYDRAULIC CLAW DOOR. Rear hydraulic claw door has an over-center locking mechanism for a no-fuss positive lock and unlock.

POLYMER LINER. The polymer liner inside the debris tank on the bottom half makes for ease of dumping and cleanout.

STRONG ARM (OPTION). With 270-degree rotation, the strong arm supports the weight of the vacuum hose, and the roller head makes handling efficient by allowing smooth, fluid movements and adjustments.

REVERSE PRESSURE. Reverse pressure to offload liquids and dislodge debris in hose.

I BEAM TRAILER. Units are built from start to finish at our factory, including the trailer which consists of a sturdy I beam construction.

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Vermeer
EQUIPPED TO DO MORE.

CV SGT VACUUM EXCAVATOR

DIMENSIONS - SKID	573 SGT	873 SGT	1273 SGT
Length	N/A	230 in (584 cm)	N/A
Width	N/A	97 in (246 cm)	N/A
Height	N/A	81 in (206 cm)	N/A
Weight	N/A	4,800 lb (2,177 kg)	N/A
DIMENSIONS - TRAILER			
Length	228 in (579 cm)	246 in (625 cm)	248 in (630 cm)
Width	93 in (236 cm)	97 in (246 cm)	102 in (259 cm)
Height	89 in (226 cm)	89 in (226 cm)	122 in (310 cm)
Empty weight	4,850 lb (2,200 kg)	5,350 lb (2,427 kg)	7,350 lb (3,334 kg)
GVWR	9,995 lb (4,534 kg)	14,000 lb (6,350 kg)	24,000 lb (10,886 kg)
Trailer axles	(2) 7,000 lb (3,175 kg)	(2) 7,000 lb (3,175 kg)	(2) 12,000 lb (5,443 kg)
ENGINE			
Make and model	Kohler EFI gas	Kohler EFI gas	Kohler EFI gas
Horsepower	38 hp (28.3 kW)	38 hp (28.3 kW)	38 hp (28.3 kW)
Fuel tank capacity	15 gal (56.8 L)	15 gal (56.8 L)	15 gal (56.8 L)
Enclosure	N/A	N/A	N/A
WATER TANK			
Water tank capacity	200 gal (757 L)	300 gal (1,136 L)	400 gal (1,514 L)
Number of tanks	2	2	2
High pressure pump flow rate	4 gpm (15.1 L/min)	4 gpm (15.1 L/min)	4 gpm (15.1 L/min)
High pressure pump	3,000 psi	3,000 psi	3,000 psi
High pressure hose length	50 ft (15.2 m)	50 ft (15.2 m)	50 ft (15.2 m)
Low water shutoff	Electric	Electric	Electric
SPOIL TANK			
Spoil tank capacity	500 gal (1,892.7 L)	800 gal (3,028.3 L)	1,200 gal (4,542.5 L)
Door type	Hydraulic	Hydraulic	Hydraulic
Tank lift type	Hydraulic	Hydraulic	Hydraulic
VACUUM			
Type of filters	.5 micron	.5 micron	.5 micron
Hose length	30 ft (9.1 m)	30 ft (9.1 m)	30 ft (9.1 m)
Hose width	4 in (10.2 cm)	4 in (10.2 cm)	4 in (10.2 cm)
Vacuum	1,000 cfm (1,699 m³/hr)	1,000 cfm (1,699 m³/hr)	1,000 cfm (1,699 m³/hr)
Vacuum blower type	PD blower	PD blower	PD blower
Vacuum mercury	14 in hg (.5 bar)	14 in hg (.5 bar)	14 in hg (.5 bar)
CONTROL PANEL			
Controls	Curbside	Curbside	Curbside
Gauges	Analog	Analog	Analog
OPTIONS (FOR ALL)			

- Strong arm
- Recirculation kit
- In-tank washout system
- Hydraulic jack

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Appendix B:
Photos of Regenerative Sweeper Tests

Figure B.1: Test#1 (3/8-inch pea gravel before sweeper pass)

Figure B.2: Test#1 Pass 1 (3/8-inch pea gravel after sweeper pass at normal 2.2 ft/s speed)

First pass and minimal pea gravel has been removed. Speed was about 2.2 ft/s or 1.5 mph.

Figure B.3: Test#1 Pass 2 (3/8-inch pea gravel after sweeper pass at very slow speed

A second sweeper pass at slowest speed including a start/stop action. Sweeper head was over the grid for about 10 s.

Figure B.4: Test#2 Pass 1 (3/8-inch pea gravel after very slow sweeper pass)

Grate was filled again. Sweeper passed at slowest speed possible including some start/stop. Conditions are similar to Test#1 Pass 2 (Figure B.3.) This view is opposite that shown previously. Some gravel has been transferred to previously empty grate on left.

Figure B.5: Test#3 Pass 1 (sand after normal speed sweeper pass at normal 2.2 ft/s speed)

Gravel was removed and the grate was filled with sand. Speed was about 2.2 ft/s or 1.5 mph. Conditions were similar to Test#1 Pass 1 (Figure B.2) Again minimal sand is removed. Wetting appears to cause sand to stick.

Figure B.6: Test#3 Pass 3 (sand after extensive stopextensive stopping)

Pass 2 and Pass 3 did remove additional sand each time. Total time stopped is approximately 30 s. Sand is more easily removed than 3/8-inch pea gravel.

Appendix C: Proposed Field Test Plan for Expansion Joint Debris

In order to determine the value of using regenerative sweepers to clean bridge decks, a set of questions were proposed. The following outline of a proposed test plan will answer these questions. The details of this proposed test plan must be reviewed by bridge maintenance personnel and others to confirm that it can be implemented and that the measurements are relevant to their operations. In lieu of performing the measurements as prescribed in the test procedure, visual inspection and photographic documentation at the various steps may be sufficient for a qualitative evaluation.

The following question are defined:

Question 1: How much debris does traffic push into the expansion joint in two weeks (the broom sweeping cycle on District 4 bridges)?

Question 2: How much debris is added by one pass of the broom sweeper?

Question 3: How much of the total loose expansion joint debris can the regenerative vacuum sweeper remove from the expansion joint?

Question 4: How much road surface debris does the regenerative vacuum sweeper collect after the broom sweeper pass?

Question 5: Does adding a regular regenerative vacuum sweep run periodically during a six-month cleaning cycle reduce the expansion joint cleaning operation?

Proposed Testing Procedure

A comprehensive series of measurement in the field would be required to answer the questions proposed. The steps should be performed at multiple joints if practical.

Step 1: Broom sweep the bridge deck as usual.

Step 2: As soon as possible, deep clean the expansion joint as per usual procedures. Avoid removing debris on the road surface upstream of expansion joint. This debris upstream is expected to migrate into the joint due to the action of passing traffic.

Step 3: Wait two weeks for the regular broom sweeping operation cycle. Coordinate the test measurements to meet with the broom sweeper and bring out the regenerative sweeper with a clean and empty hopper.

Step 4: Operate both sweepers from the beginning of the bridge until the expansion joint. The regenerative sweeper will follow behind the broom sweeper and collect the fines that are not collected by the broom sweeper. Stop the sweepers 100 ft before the joint.

Step 5: Use a vacuum to collect, bag and weigh the debris in the joint. (This quantifies the debris that traffic has deposited in the expansion joint, Question 1)

Step 6: Run the brush sweeper across the joint.

Step 7: Repeat Step 5. (This quantifies the debris that the broom sweeper has deposited in the expansion joint, Question 2)

Step 8: Collect from the road way, an amount of debris similar to that removed in Step 7. Weigh the debris and distribute this evenly into the joint.

Step 9: Run the regenerative sweeper across the joint and repeat Step 5. Compare the weight to the amount distributed in the joint. (This quantifies loose joint debris that the regenerative vacuum sweeper removes from the joint, Question 3.)

Step 10: Continue the operation of the sweepers across the bridge. Measure the total amount of debris that the regenerative sweeper collected. (This quantifies the amount of debris left behind the broom sweeper without previous deep cleaning, partial answer to Question 4).

Step 11: Wait two weeks for the next regular broom sweeping operation cycle. Bring out the regenerative sweeper with a clean and empty hopper. Run the regenerative sweeper behind the broom sweeper and repeat Step 10. (This quantifies the amount of debris left behind the broom sweeper two weeks after deep cleaning, partial answer to Question 4).

Step 12: Continue sweeper operations as usual with the regenerative sweeper behind the broom sweeper until the next 6-month joint cleaning cycle. Perform Step 5 on the joint before cleaning. It is assumed that cleaning would not be required after the debris is collected for weighing. (This is a partial answer to Question 5)

Step 13: Repeat Step 12 after using only the broom sweeper. (This is a partial answer to Question 5)

Points of Discussion

To answer Question 5, Step 12 must be repeated once with and once without regenerative sweeper cleaning to quantify the value of using regenerative sweeper. Rains will affect the amount of fines on the roadway. A more valid comparison will require weather in each of the 6-month cycles to be similar requiring 1.5 years of testing.

Can the debris be successfully collected from the expansion joint with a vacuum? This must be established before committing to the test. If this cannot be done with a simple nozzle that reaches into the folds of the joint, this step will require a more complicated system of blowing out with a pressurized air stream while collecting the debris. Collecting material out of the joint (Step 12) is expected to be difficult because of the tendency to harden.

How can the debris collected by the regenerative be weighed in Step 10? This procedure requires a location to collect and dry the debris dumped and washed from the regenerative sweeper hopper.

The amount of sand in the joint that will be removed by the regenerative sweeper will vary depending on speed. Prior testing should be used to determine a methodology and speed that will be effective. This could involve multiple passes in which the sweeper head is raised, backed up, and moved forward slowly a few times.

Is the quantification of debris collected by the broom sweeper important enough to include measurements as performed in Step 10? Given the effort defined in this test procedure, adding the material weight of the broom sweeper may be useful.

Appendix D: Final Operator Evaluation of the 1,000-cfm Vacuum Excavator

The District 11 Bridge crew used a 2023 Vermeer LP573SGT (4-in hose and 1,000 cfm, per Appendix A) for drain cleaning operations. They operated the machine to determine if this configuration of a vacuum excavator would be useful in their operations. The basis for comparison is the vacuum excavator with a 3-in hose and 500 cfm airflow described in Chapter 5.

The Vermeer vacuum excavator was received by District 11 on February 8, 2023. Testing began after the temporary operating permit was delivered to D11 on February 23, 2023.

Results were provided in meetings with AHMCT, the PM, and John Miller on February 27, 2023 and March 13, 2023. John Miller provided an initial conclusion in an email March 10, 2023.

Edited text from John Miller's email:

Since delivery of the Vermeer Vac Trailer February 8, 2023, we have used the trailer five times with a total of 68 drains cleaned using the Vac Trailer. After a modification of cutting off 8 feet of the suction hose, making the hose more manageable, it seems to have helped with the plugging issue. I know we talked about cutting holes in the nozzle, but the crew will take the nozzle and hold tight to the ground to increase the suction to help clear the debris. So far, the trailer is working great and finding value as a tool in our toolbox. The only drawback is that we really must have lane closures to use it, but that's not a big problem to have as it does increase employee safety working on foot in a closure instead of working from the shoulder shoveling debris into a truck or bag to be hauled off and disposed of or waiting on a sweeper to collect the debris if one is available. It also worked great for cleaning the bridge joints, normally my crew just use compressed air to clean the joint out to a shoulder and sweep up the material or again wait for a sweeper to pick up the debris. With the Vac trailer the employees can control the suction nozzle at the water jet and pick the debris being removed from the joint.

I don't remember if we discussed this or it is something we missed when we started this research. The use of the vacuum benefits our storm water management program and the Best Management Practices we follow for storm water runoff and contamination. The Bridge program at this time does not have a clear Best Management Cut Sheet for Bridge deck drain cleaning on bridges so we follow the Drain and Culvert Maintenance cut sheet and it is also our duty to practice what they call, “Maximum Extent Practicable” (MEP). The Vac trailer allows us to collect solid and liquid waste and transport to our disposal site. Past practice is to remove the solid waste with shovels that leaves some sediment in the basin allowing the remaining solid waste to enter the storm drain system or drain directly to a water course. When using the Vac trailer, there is little to no sediment left after cleaning.

Evaluations questions and answers

Question 1: Is the vacuum excavator with a larger hose (4 in instead of 3 in) and higher air flow (1,000 cfm instead of 500 cfm) significantly better for drain cleaning?

- Yes. The combination of larger hose and higher flow has made it more effective. The 4-in hose size and the 1,000 cfm should be considered the minimum requirements for a vacuum excavator used in the drain cleaning operation.

Question 2: What features contribute to the improvements in the operations

- The larger diameter hose allows the vacuum to pick up larger pieces of debris and will plug less often.
- The increased air flow is necessary to move debris through the hose.
- The hose boom is generally useful but it cannot always be used when working in narrow working spaces. The boom can swing out into active traffic lanes in some configurations. This is a potential hazard which may prevent its use unless an additional lane is closed.
- The flow reversing valve is useful when attempting to unplug the hose.

Question 3: How does it compare with using shovels?

- Using the vacuum excavator will require more time than many manual operations. When using the vacuum trailer, a lane closure is almost always required. Additional time is required to set up the lane closure and position the trailer. It is estimated that five bridges could be done by hand without lane closures compared to two bridges with the vacuum excavator and lane closures.
- Using lane closures is recommended and preferred for maximum protection of workers.
- Using the vacuum excavator reduces the labor-intensive exertion of shoveling and will improve working conditions.
- Cleaning with the vacuum excavator removes debris more completely.
- When using shovels, debris must be left on the road for a sweeper to collect or transported back to a Maintenance facility for disposal if a sweeper is not immediately available. Debris may end up depositing into

joints and other drains due to the action of the sweeper, traffic, or weather. The vacuum excavator removes and contains all debris immediately.

- Deeper drain sumps are easily reached and cleaned with the vacuum excavator. A shovel is virtually useless when cleaning deep drain inlets (DIs).

Question 4: What are the drawbacks to using the vacuum excavator?

- Size of the unit will require lane closures in more locations.
- Cost and maintenance of the equipment.
- Need to provide training to field personnel.

Question 5: What are other road or bridge maintenance operations that can use the vacuum excavator?

- Expansion joint cleaning – The combined pressurized water and vacuum will easily clean joints. This is an improvement over using air lances.
- Utility work – Plumbers and others will use it for digging and other operations.
- Cleaning of bridge bearings – The vacuum will collect and lift materials from below the bridge deck up to the trailer which is presently a labor-intensive activity.
- Deck spall repairs – The vacuum will reduce the dust when preparing the bridge deck in the repair process. This can be a wet or dry operation.
- Scupper cleaning – The vacuum will assist in scupper cleaning.
- Concrete cutting – The vacuum may be use in dust suppression when cutting.
- Cleaning voids that cannot be reached with other tools – The vacuum will access locations that shovels and other tools cannot reach.
- General clean up – The vacuum will be useful for more complete removal of debris that is otherwise left behind when working with shovels and brooms.
- Bridge deck drains

Question 6: In lieu of placing a vacuum excavator unit in the fleet, would you recommend rental of a larger trailered vacuum excavator (18,000 GVW) with the same 4-in hose and 1,000 cfm?

- Generally a trailer under 10,000 lb GVWR is preferred. Obtaining the 1,000 cfm flow rate and 4-in hose size is the primary concern.

Question 7: What modifications have been tried or considered?

- The hose length was reduced from 30 ft to 22 ft. This simplified the handling of the hose and reduced the tendency to plug. Working with the smallest length possible is recommended.
- Notching the tip of the nozzle was considered but the flat tip is better for complete cleaning of the drain sump.
- The use of a second bag house filter was considered to allow swapping of filters to allow complete drying of the filter after washing. When removing the wet debris from the drains, virtually all the material is dropped into the tank. An insignificant amount of debris reaches the cyclone filter or the bag house filter.
- The use of a semi-transparent hose could be tried to more easily locate hose plugging.

Question 8: What is the final recommendation?

- The vacuum excavator with a 4-in hose and 1,000 cfm airflow is recommended and is a useful piece of equipment in bridge debris removal and other maintenance operations.
- Higher flow rates greater than 1,000 cfm will be helpful but hoses large than 4 in will make cleaning of drain sumps and general vacuuming less practical.

Appendix E: Pavement Researcher Indications on Debris Hardening in Bridge Joints and Implications for Cleaning

Jeffrey Buscheck, UC Pavement Research Center (UCPRC), Lab Manager at the ATIRC Materials Lab

Concrete is essentially sand and gravel glued together with cement paste. Traditional Portland cement is processed limestone powder blended, heated, and then ground into a powder form. The cement paste glues the aggregate (sand and gravel) matrix together through crystallization, which hardens in the presence of moisture. From this basic design, concrete designs have added chemical admixtures, fibers, supplemental materials, rebar, dowels, etc., to change or improve properties like we would with different steel grades or epoxy types.

The debris on the roadway is likely a combination of silt, sand, and rock, plus oil/gas/diesel/coolant that leaks off vehicles, powdered rubber from tire wear, and anything else that is spilled onto the road.

I guess that what you are finding in the expansion joints is some combination of silt/dirt/worn concrete, etc. that is being solidified together with a bit of oil/gas/diesel/rubber tire powder/water, and this is creating some unique waste material. When it's wet from rain or exposed to other moisture, it hydrates, and then in the peak of the summer heat, it dries and hardens. If there is any asphalt mixture in the bridge deck or line striping paint, those materials can also break down and create a solid when their powders are hardened or solidified.

Dust from the concrete can rehydrate and almost always maintains some slight reactivity. The cement crystallization does not reverse its process, but not 100% of the cement powder in the concrete is always reacted, which leaves minor reactivity when it is crushed into dust. Sometimes it's very small, and sometimes it's high. The layman's example is the "farmers' base" commonly used in agriculture haul or low-cost gravel roads. This is just a crushed, recycled concrete aggregate base that still has some reactive properties, is laid down with moisture, and compacted into a better-than virgin gravel road. A unique version of this could be found in the bridge deck joints.

In short, by frequently cleaning the joints, they will be much easier to clean as not to allow the material to build up, solidify, and harden over long periods.

If Caltrans wanted to follow up on this, I recommend getting 5-10 random samples of the materials found in the expansion joint and sending them out for chemical and physical property analysis. The UCPRC lab and other labs on campus have the equipment to do some of this.