Design and Construction of a Full-Scale Testing Apparatus for Evaluating the Performance of Catch Basin Inserts

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Abstract: As stormwater runoff flows over impervious surfaces, it suspends and transports various pollutants from their original location and often conveys them into municipal separate storm sewer systems (MS4s). Most municipalities and state highway agencies in the U.S. have developed stormwater management guidelines to ensure compliance with the Environmental Protection Agency's (EPA) MS4 standards, including allowable methods and practices to remove pollutants from stormwater influent flowing into MS4s. Catch basin inserts (CBIs) have become an increasingly popular option for pollutant removal from stormwater. However, limited data is available to ensure that these practices meet required treatment standards. This study details the design, construction, calibration, and validation of an apparatus for full-scale testing of CBIs. CBI testing has been designed to evaluate total suspended solids (TSS) removal efficiency reduction at three flow rates: 1.7, 3.4, and 5.1 L/s (0.06, 0.12, and 0.18 ft^3/s) and an influent concentration of 450 mg/L (0.028 lb/ft^3). Testing of a non-proprietary CBI revealed that the device removed 62.1%, 65.1%, and 51.7% of sediment introduced and reduced average TSS by 57%, 53%, and 49% over flow rates tested, respectively.

Key words: catch basin inserts, stormwater, MS4, nonpoint source pollutants, full-scale testing

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Introduction

As stormwater runoff flows over impervious surfaces, it suspends and transports various pollutants from their original location and often conveys them into municipal separate storm sewer systems (MS4s) that will eventually discharge into lakes, rivers, streams, and other bodies of water. These MS4s are described by the Environmental Protection Agency (EPA) as public storm sewer systems that include roads with drainage systems, and municipal streets owned and operated by a public body that are not part of a combined storm and sanitary sewer (*EPA, 2017*). Pollutants of concern include heavy metals and petroleum products from urban roadways; common trash and debris; excess pesticides, herbicides and fertilizer from residential applications; and sediment from unstabilized areas such as improperly managed construction sites. These contributors, known as nonpoint source (NPS) pollutants, or pollutants from many diffuse sources, harm waterways and are detrimental to the environment (*EPA, 2016*). A National Rivers and Streams Assessment study conducted by the EPA estimated that 46% of accessed rivers and streams in the U.S. are in poor biological condition due to pollution (*EPA, 2009*).

The Nationwide Urban Runoff Program (NURP) was the first comprehensive study of urban stormwater runoff pollution across the U.S. NURP assessed stormwater runoff quality from 28 major metropolitan areas and verified urban runoff as a detriment to overall water quality (*EPA, 1983*). Since NPS pollutants threaten our national waterways through urban runoff, the EPA regulates effluent discharges conveyed by municipalities to ensure that it meets acceptable water quality standards before flowing into the surrounding environment through the National Pollutant Discharge Elimination System (NPDES) Phase II MS4 general permit (*EPA, 2017*).

Most municipalities and state highway agencies have developed stormwater management guidelines to ensure compliance with these EPA standards, including allowable methods and practices to remove pollutants from stormwater influent flowing into MS4s, prior to discharge. For example, the Ohio Department of Transportation has a comprehensive post-construction management plan including the use of numerous best management practices (BMPs) (*ODOT, 2018*).

Background

Post-construction BMPs treat stormwater runoff through methods including detention, infiltration, or filtration. Catch basin inserts (CBIs) are one example of post-construction BMPs. Catch basin inserts are manufactured systems consisting of bags, baskets, or cartridges placed into existing storm sewer inlets, or catch basins, which treat influent runoff before entering the MS4. CBIs come in different shapes and sizes that are inserted into specific catch basins requiring treatment.

Bag-type CBIs are composed of a filter media attached to a steel frame, which secures the bag in position below the inlet grate. The filter media is designed to catch suspended particles as the influent flows through the bag. The fabric bag can become clogged with sediment and other debris, negatively affecting its ability to pass flows. For this reason, bags are typically designed with overflow mechanisms to allow for bypass during high flow events, instead of impounding on the street and creating a localized flooding or safety hazards. Bag-type CBIs are generally considered easy to maintain because the insert can be quickly removed and cleaned, or replaced in the event a device is filled with debris (i.e., grass clippings, leaves, litter, etc.).

Basket-type CBIs have filter fabric similar to bag type CBIs but have a rigid support system around the fabric to provide greater support and durability.

Cartridge-type CBIs consist of a disposable cartridge that traps sediment and debris from the influent stormwater. Cartridge-type CBIs are easy to maintain because the disposable cartridges can simply be removed from the catch basin frame and replaced when maintenance is required. Selecting the appropriate CBI type based upon the needs of a storm conveyance system is crucial to developing an effective post-construction stormwater pollution removal plan. To minimize stormwater pollution and meet the standards set forth under the NPDES, the Ohio EPA specifies that alternative post-construction BMPs have a minimum total suspended solids (TSS) removal of 80% under both laboratory and field conditions (*Ohio EPA, 2014*). However, limited data is available to demonstrate the actual in-field performance of various CBIs to ensure that these standards are reached.

Literature Review

Previous CBI testing has either been conducted by installing CBIs in a field setting and monitoring the performance of the devices over time, or by introducing sediment-laden channelized flow directly into the device in a controlled testing environment. Each of these evaluation scenarios has inherent advantages and disadvantages. In controlled environments, CBIs are only exposed to the conditions applied by the researcher, which may only include the introduction of sediment. However, in a field application, a CBI will be exposed to sediment, chemicals, trash and debris. Field testing exposes CBIs to realistic influent characteristics, but is not repeatable and is hard to control from test to test.

Laboratory Testing of Catch Basin Inserts

Several studies have been conducted to evaluate the performance of a variety of proprietary CBIs using flow rates ranging from 1.1 to 34.0 L/s (0.04 to 1.2 ft^3/s) and sediment concentrations ranging from 30 to 300 mg/L (0.002 to 0.019 lb/ft^3) (*Morgan et al, 2005; Remley et al, 2005; NJCAT, 2005; MacLure, 2009*). These studies reported TSS removal efficiencies ranging from 10 to 91% for the CBIs tested. Table 1 provides an overview of the results obtained from testing CBI TSS removal efficiency for several laboratory studies that were reviewed. TSS removal efficiencies varied greatly in some of these studies because of the differences in influent flow rates and concentrations. CBIs were tested for a duration of 30 minutes for two of the studies, but durations for the remaining three studies was unknown. CBIs treat stormwater most effectively at lower influent flow rates and concentrations, while higher influent flowrates and TSS concentrations can cause CBIs to become clogged with sediment, forcing influent to flow through the bypass mechanism of the CBI. As influent flows through the bypass, polluted stormwater enters the conveyance system untreated, minimizing the TSS removal efficiency of the CBI.

Field Testing Review

A study by Kostaleros (*Kostaleros et al, 2010*) performed field-testing of six different CBIs installed at different locations resulting in each product being exposed to different influent rates, influent sediment concentrations, and maintenance requirements. Products were also monitored for different periods of time ranging from 12 to 15 months. All filters were monitored for maintenance purposes, and most filters were replaced at least once during the monitoring period due to failure over time. The number of CBI replacements and the dry weight of sediment captured were measured over the monitoring period and a daily sediment capture rate was calculated. Results showed that average sediment capture ranged from 0.03 to 0.25 kg/day (0.07 to 0.55 lb/day) (*Kostaleros et al, 2010*). Since the amount of sediment introduced into the CBI is unknown, the percent of sediment removed by the CBI could not be determined. This is an inherent limitation with field testing, as variables are harder to monitor and measure than in a controlled environment.

Discrepancies amongst controlled testing methods are evident upon a review of the literature. As summarized in Table 1, test procedures varied amongst applied flow rates, sediment concentrations, location of installation, and flow durations, simulating different conditions that produce a wide range of results. A consistent testing methodology is needed to evaluate the performance of CBIs that can be repeated amongst different tests, allowing for a more accurate comparison between products.

To represent a more realistic, field-like scenario, testing methods should include a means of evaluating performance over time. Of the laboratory studies reviewed, each product was only used for one test before being cleaned or disposed of and replaced for repeated tests. However, in field applications, CBIs will not be cleaned or replaced after each storm. Instead, CBIs can become clogged, or blinded, over time, hindering the flow through rate of the fabric. Multiple storm events or tests can also cause previously captured sediment particles to be re-suspended without being re-captured. For this reason, it is important to include a method for assessing long term performance of CBIs.

Research Objective

The objective of this research was to develop an apparatus for conducting full-scale testing of manufactured CBIs to evaluate sediment removal efficiency in a manner that would be both realistic by replicating field-like conditions, while also being a consistent and repeatable standard testing procedure.

Design Methodology

The overall design of the apparatus was conducted in accordance with the Ohio Department of Transportation (ODOT) Location & Design Manual, Volume Two (L&Dv2) (*ODOT, 2018)* since ODOT was the sponsor of the project. However, the apparatus has the ability to easily adjust flow and sediment concentrations introduced to perform testing more relevant to other geographical locations.

Determination of Flow Characteristics

L&Dv2 (*ODOT, 2018*) Section 1115 specifies that pre-manufactured, post-construction BMPs should be designed according to the runoff flow rate resulting from a 16.5 mm/hr (0.65 in/hr) storm event over the drainage area associated with the catch basin under consideration. Water quality flow (WQ_f) is calculated by the rational equation, found in L&Dv2 Section 1101.2.2 (*ODOT, 2018*), which specifies $WQ_f=kCiA$ where WQ_f is water quality flow in L/s (ft^3/s), k is a unit conversion factor of 0.00278 (1.0 for U.S. customary units), i is rainfall intensity in mm/hr (in/hr), and A is the contributing drainage area in ha (ac).

While the coefficient of runoff (i.e., 0.9 for impervious areas) and rainfall intensity, 16.5 mm/hr (0.65 in/hr), are specified by L&Dv2 (*ODOT*, *2018*), an appropriate drainage area must be selected to determine the flow rate that CBI products are expected to treat based upon ODOT typical conditions. An examination of ODOT field installation sites concluded that typical drainage areas contributing runoff to catch basins ranged from approximately 0.06 to 0.10 ha (0.15 to 0.25 acres). As a result, it was determined that each CBI would be evaluated at three different flow rates, representative of a small drainage area of 0.04 ha (0.1 acre), medium drainage area of 0.08 ha (0.2 acre), and large drainage area of 0.12 ha (0.3 acre). Flow rates associated with the small, medium, and large drainage area according to the rational equation can be found in Table 2.

While L&Dv2 does not specify that pre-manufactured, post construction BMPs be designed to meet water quality volume standards, Ohio EPA's Construction General Permit (OH000004) specifies that "Alternative Post-Construction BMPs" could be used in place of BMPs typically used to treat stormwater runoff volumes with the requirement that the BMPs be able to treat the water quality volume (WQ_v) discharge rate (*Ohio EPA*, *2013*). Therefore, the water quality volume calculation method was used to determine the total volume of water and flow durations for each test. WQ_v was calculated according to the following equations as specified in L&Dv2 (*ODOT, 2018*), which states $WQ_v=(PAC_q/k)$, where WQ_v is water quality volume in m^3 (ac-ft), k is a unit conversion factor of 0.05 (12 for U.S. Customary units), P is precipitation in mm (in.), A is contributing drainage area in ha (ac) and C_q is a coefficient of runoff of 0.9 for impervious drainage areas. L&Dv2 specifies a precipation of 19.05 mm (0.75 in.) for design purposes.

WQ_v can be divided by WQ_f to determine the duration for each test. This will ensure that each practice is exposed to an adequate amount of runoff volume to determine overall performance. Table 2 summarizes the water quality flow rate, water quality volume, and duration of testing for each of the proposed drainage areas.

Sediment Introduction

CBIs are tested in accordance with ODOT Supplemental Specification 995 (SS995) "*Precast Water Quality Structure*", which specifies a maximum laboratory test influent concentration of 450 mg/L (0.028 lb/ft^3) while using an OK110 particle distribution with a specific gravity of 2.65 or less (*ODOT, 2012*). The OK110 particle distribution, shown in Figure 1, has d_{50} of roughly 110 microns with minimal variance in particle size, representative of a fine sand. At this concentration, the small, medium, and large drainage areas used for testing result in total sediment loads of 3.22, 6.44, and 9.66 kg (7.1, 14.2, and 21.3 lb), respectively.

Particle size distribution (PSD) plays an important role in evaluating the performance of CBIs because different distributions can be used to represent different locations and conditions. Soils containing high concentrations of sands are more likely to settle out of suspension quickly due to larger, heavier soil particles. Whereas soils with high amounts of clay can quickly cause fabrics to become clogged, or blinded, because of the tendency of the clay particles to remain suspended and make contact with the fabric at all elevations of the water column.

The proposed drainage areas provide a precise representation of flow rates, volumes, durations, and sediment loads that CBIs would be exposed to in a field setting. These full-scale tests were designed to create repeatable conditions to maintain a controlled testing environment to accurately measure sediment removal efficiency of the CBIs under consideration.

Performance Evaluation of CBIs

The primary focus of the CBI testing was to characterize performance by quantifying sediment removal efficiency. Prior to installation, the CBI was weighed to determine the pre-test weight for comparison against the post-test weight to calculate total sediment captured within the media for each product type. Each product was installed based upon manufacturer installation protocols. Upon completion of the test, the saturated CBI was placed in an industrial oven at approximately 103°C (217°F) for at least 12 hours to ensure that all moisture was removed from the sediment and the filter media. The weight of the sediment introduction system, shown in Figure 1(c), was also recorded before and after the test so that the amount of sediment introduced can be determined. Any excess sediment that may have fallen out of suspension on the platform prior to entering the catch basin was also collected and allowed to dry in the oven for at least 12 hours before being weighed. Sediment removal efficiency was calculated by dividing the weight of sediment captured in the CBI and the weight of sediment introduced.

The secondary focus of the CBI testing was to measure TSS reduction. TSS reduction was determined by analyzing 1.0 L (32 oz) grab samples taken at five minute intervals, upstream and downstream of the installed product throughout the duration of the test. The entire 1.0 L (32 oz) sample was used for TSS analysis. Upstream and downstream TSS was determined using the method specified by American Public Health Association Method 2540D *Total Suspended Solids Dried at 103-105°C* (*APHA, 1997*).

Each CBI is tested at the low, medium, and high flow rates previously discussed. In the event that a CBI performs adequately and captures 80% or more of the sediment introduced during the 70-minute test, the CBI will then undergo longevity testing. Longevity testing is another component of the testing methodology not commonly found in other studies, providing an additional means of performance evaluation. The purpose of longevity testing is to determine the ability of a CBI to maintain structural integrity over a more strenuous testing cycle, while also measuring sediment removal performance over the duration of multiple storm events. CBIs behave differently over time due to excess loading, clogging of filter material, and resuspension of previously captured particles. Longevity testing consists of multiple consecutive tests on a single installed CBI. The flow rates for the tests will be at the maximum flow rate that was determined in which the CBI was capable of providing 80% TSS removal. Longevity testing continues until failure occurs, which could include structural failure or degradation of sediment removal performance. Upstream and downstream grab samples were taken at five minute intervals to determine TSS concentrations similar to the methods used in proposed performance evaluation testing. Upstream samples were taken at the discharge point of the flow conveyance system, and downstream samples were taken at the downstream discharge point of the effluent collection platform shown in Figure 3(g).

CBIs were also visually inspected during testing to monitor for structural degradation, clogging of material, and untreated flow bypass. Photo documentation was performed from predetermined and ad hoc locations to visually show pre- and post-test conditions. During each test, photo and video documentation was also performed to capture important flow characteristics.

Construction of Testing Apparatus

The construction of the CBI testing apparatus consisted of three primary components that included the water and sediment introduction system, flow conveyance system, and the drainage platform, which are shown as a schematic in Figure 2. Each component is further described in detail and shown in Figure 3.

Water & Sediment Introduction System

Water is pumped from an on-site supply pond into a water equalization tank located at the upstream end of the apparatus, shown in Figure 3(a). This tank is equipped with a calibrated, 90-degree, V-notch weir that allows for controlled discharge into the flow conveyance system by adjusting drainage valves to maintain the water level in the tank at a desired depth. Effective head, or depth according to the weir was calculated according to theoretical weir equations, and verified using flow capture to further calibrate and validate the desired discharges.

The V-notch weir discharges into a 15.2 cm (6.0 in.) polyvinyl chloride (PVC) flow conveyance system. Just downstream of the water introduction point, a vertical tee is placed in the flow conveyance system that allows for the introduction of sediment into the flow, shown in Figure 3(b). An end cap is placed over the open side of the tee to prevent wind from disrupting sediment introduction.

A Schenck AccuRate® series volumetric feeder with a 1.91 cm (0.75 in.) diameter helix and a 7.08 L (0.25 ft^3) hopper was used for sediment introduction, which is shown in Figure 3(c). This system is equipped with a three-digit thumbwheel speed potentiometer for enhanced repeatability, with the intent of providing a consistent and accurate means of sediment introduction. The auger discharges sediment into the flow conveyance system through a pre-drilled hole placed in the vertical tee in order to protect introduced sediment from being disrupted by wind.

Flow Conveyance System

The flow conveyance system consists of approximately 6.1 m (20 ft) in length by 15.2 cm (6.0 in.) diameter PVC pipe laid at a 2% slope that conveys sediment-laden water from the upstream introduction point to the drainage platform, as shown in Figure 3(d). A transition point was constructed in the middle of the flow conveyance system to produce turbulent flow for the sediment-laden water and cause soil particles to mix more evenly.

Drainage Platform

The drainage platform was constructed on a stable and level area so that influent would spread evenly across the platform. The lower support frame was then constructed using treated 10 x 10 cm (4 x 4 in.) nominal lumber and using treated 5 x 10 cm (2 x 4 in.) nominal lumber as cross-bracing. The manufactured ODOT Type 3A catch basin (*ODOT, 2016*) frame was then placed on top of the lower support frame, and the upper platform was constructed around the catch basin frame. The upper platform consists of two 1.22 m x 2.44 m x 1.9 cm (4 ft x 8 ft x 0.75 in.) plywood sheets to create an 2.44 m by 2.44 m (8 ft by 8 ft) surface. The plywood was installed at a 2% slope both in the downstream direction and toward the middle of the platform to direct sheet flow into the catch basin from the discharge point of the flow conveyance system. The 2% slope was selected to be representative of a typical roadway cross-sectional slope. Additional plywood was installed at an angle similar to the slope of the catch basin frame to simulate the curb.

The platform was then sealed with silicon caulking and covered with a rubber sealant material. The platform was sprayed with a LINE-X® coating to provide a water-tight seal Finally, 14 gauge sheet metal was placed on top of the platform as a finished surface that would allow influent to flow as sheet flow into the catch basin without causing disturbances that could result in sediment falling out of suspension prematurely. Edges and corners were again sealed with silicone caulking to prevent leaking. The completed drainage platform is pictured in Figure 3(e).

A 15.2 cm (6.0 in.) PVC coupling was placed at the upstream side of the drainage platform. This allows the operator to change the length of pipe based upon the flow rate that the test is being performed at, as seen in Figure 4. For low flow rate tests, the flow conveyance pipe is extended closer to the catch basin, and for high flow rate tests, the conveyance system ends at the coupling, and no additional piping is used. The purpose of this adjustment is to ensure flow enters the catch basin grate [Figure 3(f)] at a consistent velocity across all three flow rates and prevent particles from falling out of suspension on the platform prematurely due to slowed velocity.

Calibration & Validation of Apparatus

After the construction of the testing apparatus, the calibration and validation phases were essential for ensuring that the apparatus would satisfy design parameters developed in the first phase of the project, as well as, meet the original goal of simulating field-like conditions for CBI testing. The calibration phase consisted of adjusting water and sediment introduction rates to meet design parameters, while the validation phase consisted of performing tests on a non-proprietary CBI to evaluate the performance of the testing apparatus.

Flow Rate Calibration

The calibration of the water introduction system was performed using a barrel in the shape of a truncated cone. The flow conveyance system introduced water into the barrel, and the time required to fill the barrel was measured. Since the dimensions of the barrel are known, the volume of water was calculated and flow rate was determined based upon fill time and volume. During calibration testing, the time required to fill the barrel was 61.23, 32.46, and 21.83 seconds to fill 106.8, 112.1, and 109.6 L (3.77, 3.96, and 3.87 ft^3), resulting in a flow rates of 1.7, 3.4, and 5.1 L/s (0.06, 0.12, and 0.18 ft^3/s) for the low, medium, and high flow rates, respectively.

Sediment Introduction System Calibration

The sediment introduction system consisted of a Schenck AccuRate® series volumetric feeder that came equipped with a three-digit thumbwheel speed potentiometer, allowing the auger speed setting to easily be modified between tests. The calibration of this device was performed similarly to the water introduction system. An auger speed was selected using the potentiometer and the system was allowed to transfer sediment from the hopper to the container for a measured amount of time. The container was weighed before and after being filled with sediment, and the sediment introduction rate was calculated by dividing the difference in weight over the amount of time to fill the container.

The sediment introduction rate was then multiplied by the duration of the test, 70 minutes, to ensure that the rate was acceptable according to values presented in Table 2. This process was repeated for all three sediment introduction rates.

Validation of Apparatus

In order to ensure that the testing standards set forth in the design phase of the project could be achieved by the apparatus, validation testing was performed using a non-proprietary, bag-type CBI that was developed by the research team. The CBI was a 40.6 cm (16.0 in.) wide by 73.7 cm (29.0 in.) long by 45.7 cm (18 in.) in depth bag constructed of 0.12 kg/m^2 (3.5 $oz./yd^2$), nonwoven geotextile fabric. The fabric had an average apparent opening size of 300 microns, which is greater than the 110 micron average diameter of the soil particles being introduced. PSD of the introduced soil type can be seen in Figure 1. Apparent opening size, or mesh size, greatly affects flow through rate, as larger mesh sizes allow more water to flow through the material, inhibiting impoundment and negatively affecting sediment retention. However, mesh sizes too small, can easily become clogged, preventing water from flowing through the fabric, and forcing it either through bypass openings or flooding water above the grate and onto the road surface. Overflow openings were positioned near the top of the CBI on all four sides. The non-proprietary CBI was tested under all previously discussed conditions at the three flow rates.

Table 3 summarizes the results from the three tests. Sediment introduction weights ranged between 4.0% to 11.1% higher than target values. However, this issue was easily resolved by decreasing the auger helix speed for future tests. The average upstream TSS for all samples taken was 382 mg/L, which is a 15% error from the target concentration of 450 mg/L. This is largely due to a small sample size related to the limited testing of the nonproprietary product. However, additional tests on proprietary products, not reported in this manuscript, have been performed and provided a much large data set that resulted in an average upstream TSS concentration of 462 mg/L, which is only a 2.7% error, further validating the testing apparatus.

While it was expected that the percent of sediment retained would decrease as flow rate increased, sediment retention percentage was actually highest during the medium flow rate test. However, there was a significant drop in sediment retention between the medium and high flow rate tests, and average TSS removal percentage did decrease with each increase in flow rate. At the low flow rate, the depth of water inside the CBI did not reach the overflow point as shown in Figure 6(b). However, as flow rates increased for the medium and high flow tests, the CBI did reach the overflow point, with overflow occurring sooner for the high flow test than the medium flow test. This caused a significant impact on the sediment retention capabilities of the CBI because large volumes of water exited the CBI through the bypass openings untreated. Bypass flow conditions also created turbulence inside the CBI, which may have resulted in re-suspension of particles previously settled in the bottom of the bag, further decreasing sediment retention and increasing downstream TSS. This is supported by the decrease in average TSS removal with increasing flow rate, as shown in Table 3. Overflow conditions can be seen in Figure 6(c) and Figure 6(d) compared to pre-test conditions in Figure 6(a) and normal flow conditions in Figure 6(b).

Limitations

This study focused on the ability of a CBI to remove 80% of the sediment loading of the influent that discharges into storm sewer systems. This study does not consider other pollutants (i.e., trash, debris, oils, and other hydrocarbons) that may also be transported from roadways and parking lots into a stormwater system through a catch basin. This study does not have the capability to evaluate removal efficiency of pollutants other than sediment at this time.

Furthermore, this study focused on hydrologic conditions consistent with the state of Ohio, including flow rates and volumes. The authors recognize that other geographic areas may vary in precipitation amounts and runoff volumes, which may affect the performance of CBIs under consideration. Sediment concentrations of influent stormwater runoff vary greatly in field conditions and are dependent upon the location of the inlet, the surrounding environment, and the storm event. This study only evaluates CBIs sediment removal performance using one influent sediment concentration and soil type. However, as previously discussed, the apparatus is designed to efficiently adapt to any flow rate or sediment loading necessary and can be tailored to specific geographic locations, as desired.

Next Steps

To further validate the apparatus' ability to simulate real life conditions, a future research objective is to install and monitor the non-proprietary CBI in various field locations, and compare the sediment capture performance of the field installed CBIs to those tested with the apparatus. While field testing characteristics can vary in terms of influent flow rates and sediment loadings, the field collection data can still be used to ensure that the apparatus is evaluating the performance of CBIs in a realistic manner. Various characteristics can be evaluated and compared, including by not limited to clogging potential, and overflow or bypass conditions observed.

In performance evaluation tests, captured sediment can also be analyzed to determine PSD. Comparing influent PSD to that captured in the CBI allows the researcher to further assess the CBI's sediment removal performance in terms of different particle sizes and soil types.

Once formal testing of the CBIs commences, a second soil type will also be used to further analyze the performance of the CBIs. This second soil type will be a sandy loam, in accordance with the Technology Acceptance Reciprocity Partnership (TARP) for Stormwater Management Innovation program. Contrary to the OK110 silica sand, the sandy loam soil will have the addition of smaller silt and clay particles. The concentration level of the influent will also be lower than the OK110 concentration to meet the average concentration requirements specified by the TARP program. This will allow the researchers to further analyze sediment removal performance given different influent concentrations and soil types.

Conclusions

The objective of this research was to develop a controlled system for the evaluation of CBI products under conditions indicative of ODOT post-construction stormwater applications. Influent flow rates of 1.7, 3.4, and 5.1 L/s (0.06, 0.12, and 0.18 ft^3/s) and concentration of 450 mg/L (0.028 lb/ft^3) were designed in accordance with ODOT design standards for typical catch basin drainage areas of 0.04, 0.08, and 0.12 ha (0.1, 0.2, and 0.3 acres) found in Ohio. However, for potential future advancement of this study, the apparatus was developed in a way that would also allow for easy modifications to the flow and sediment introduction systems in order to simulate other localities based upon testing requirements.

The apparatus consists of three primary components: (1) the water and sediment introduction system, (2) the flow conveyance system, and (3) the drainage platform. Water is pumped from an on-site supply pond into a water equalization tank located at the upstream end of the apparatus. The tank is equipped with a V-notch weir for regulated water flow rates into the flow conveyance system. A Schenck AccuRate® series volumetric feeder is used to introduce sediment into the flow, which allows for the controlled discharge of sediment-laden flow at the desired concentration of 450 mg/L (0.028 lb/ft^3) into the 15.2 cm (6.0 in.) PVC flow conveyance system. To determine the required flow rate, volume, and sediment loading, the ODOT L&Dv2 was referenced and appropriate calculations that were representative of an ODOT highway were used to determine these flows. The flow conveyance system discharges onto the 2.44 m by 2.44 m (8 ft by 8 ft) drainage platform, allowing the sediment-laden sheet flow to enter the catch basin. The effluent collection platform then collects any flow exiting the catch basin and discharges off-site.

The water and sediment introduction system was calibrated through a series of repeated tests in which discharge was measured over an allotted time and discharge rate was then calculated. To validate the applicability of the testing apparatus, a non-proprietary, bag-type catch basin insert was developed and tested under the designed conditions. From this testing, it was determined that the product did not meet Ohio EPA pollutant removal standards, and that time of overflow was a primary factor indicating a degradation in TSS removal efficiency.

This system allows researchers to examine CBI performance in ways that would be much more difficult in a field or small-scale testing environment, such as monitoring leakage between catch basin frame and CBI, measuring bypass flow rate, and evaluating TSS reduction capabilities, all factors that were observed during the validation tests.

The development of this research has the potential to substantially improve the evaluation of CBIs as a primary post-construction stormwater pollutant removal tool. The ability to simulate a field-like experience from a controllable testing environment allows regulators to more precisely assess sediment removal efficiency of CBI products to ensure compliance with environmental regulations, while also allowing manufacturers of proprietary CBIs to identify potential ways of improving their product.

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TABLE 1 Summary of Previous Laboratory CBI Testing Studies

Study	No. of Products	Influent Flow Rate (L/s)	Influent Concentration (mg/L)	TSS Removal Efficiency [Ranges (Avg.)]	Duration (min)
Morgan et al. 2003	4	13.0-13.6	225	10-42% (29.5%)	30
Remley et al. 2005	4	13.0	180	25-62% (48.3%)	30
NJCAT 2005 (TTU)	1	5.7-34.0	200	18-89% (61.4%)	-
NJCAT 2005 (AIRL)	1	1.1	100-300	78-83% (80.5%)	-
MacLure 2009	1	1.3-12.7	30-50	83-91% (86.6%)	-

Note: Duration unknown for three studies.

TABLE 2 Summary of Testing Characteristics for Proposed Drainage Areas

Drainage Area Size	Drainage Area (ha)	Flow Rate (L/s)	Volume (L)	Duration (min)
Small	0.04	1.7	7153.9	70
Medium	0.08	3.4	14271.7	70
Large	1.2	5.1	21407.5	70

TABLE 3 Summary of CBI Performance

Flow Rate (L/s)	Weight of Sediment Introduced (kg)	Weight of Sediment Retained (kg)	Percent Retained (%)	Average Upstream TSS (mg/L)	Average Downstream TSS (mg/l)	Average TSS Removal (%)	Start of Overflow (min)
1.7	3.35	2.08	62.1	472.4	203.5	57	N/A
3.4	6.87	4.47	65.1	315.6	148.9	53	24
5.1	10.73	5.55	51.7	359.1	181.6	49	13

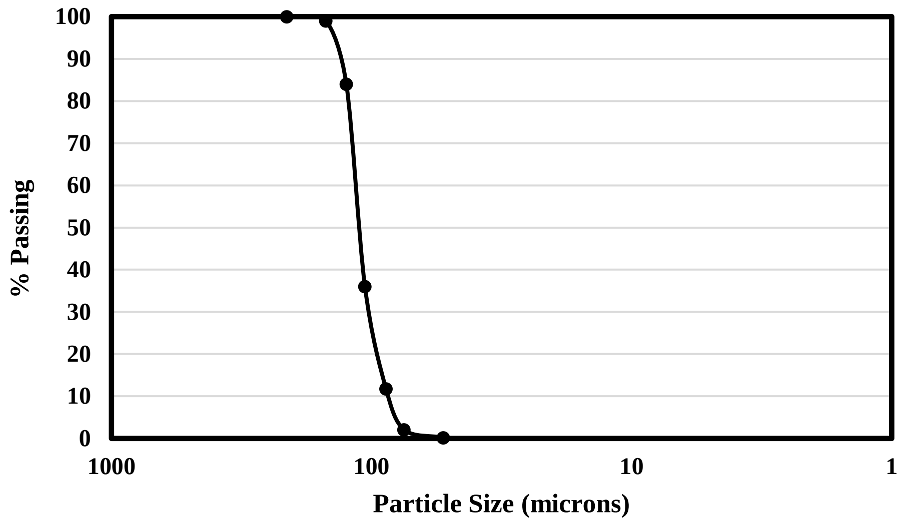


Fig. 1. Particle size distribution of OK-110 silica sand.

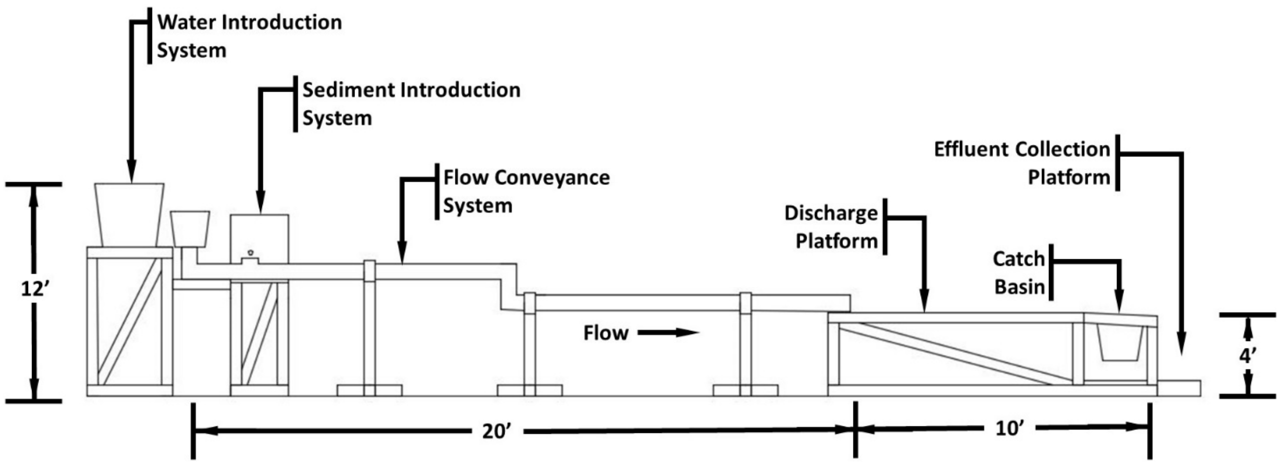


Fig. 2. Schematic of CBI testing apparatus.

(a) water and sediment introduction system

(b) sediment introduction zone

(c) Schenck Process Model 106M Material Feeder

(d) flow conveyance and transition point

(e) discharge and test platform

(f) catch basin grate

(g) effluent collection platform

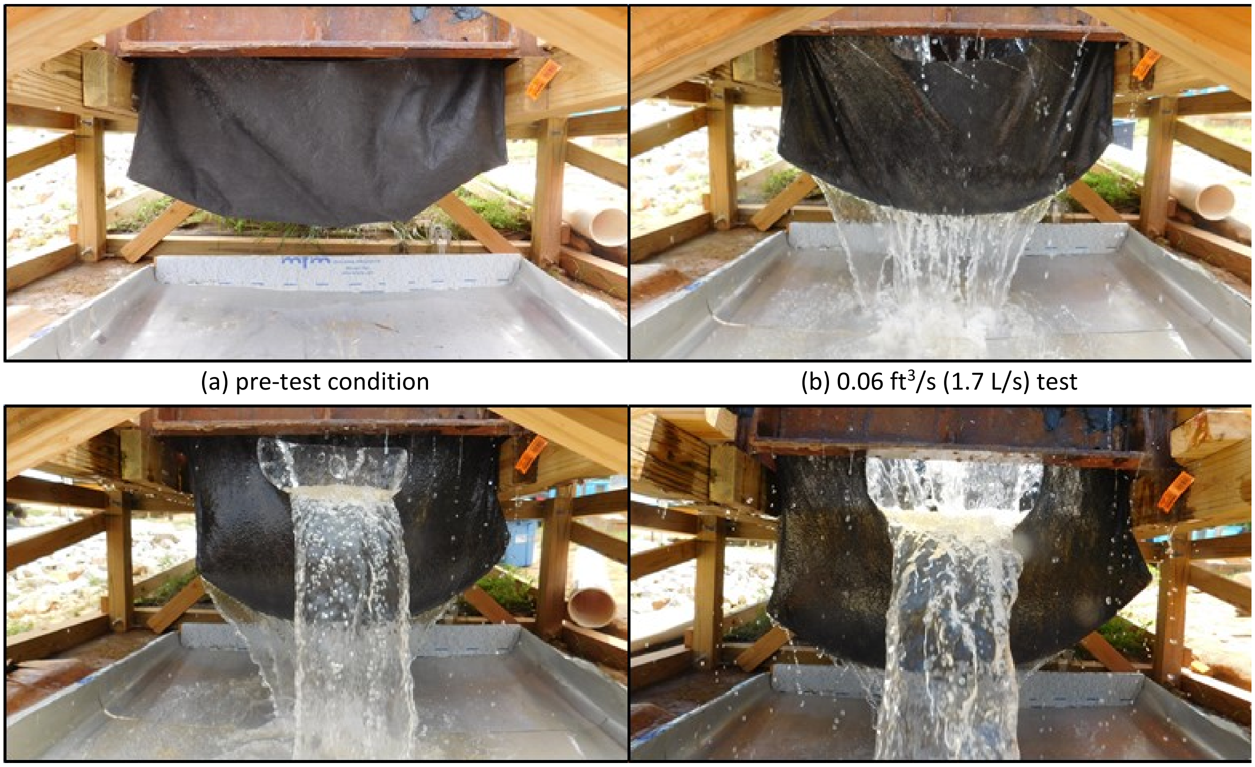
Fig. 3. Catch Basin Insert (CBI) Testing Apparatus.

(a) low flow rate (b) medium flow rate (c) high flow rate

Fig. 4. Modifications to flow conveyance system based on flow rate.

(a) interior of non-proprietary CBI (b) exterior of non-proprietary CBI

Fig. 5. Non-proprietary CBI.



(a) pre-test condition

(b) 0.06 ft^3/s (1.7 L/s) test

(c) overflow during 0.12 ft^3/s (3.4 L/s) test

(d) overflow during 0.18 ft^3/s (5.1 L/s) test

Fig. 6. CBI Performance during testing of low, medium, and high flow rates.