TSP2 TRANSPORTATION SYSTEM PRESERVATION TECHNICAL SERVICES PROGRAM

AASHTO BRIDGE PRESERVATION

Innovative Technology Demonstrations Working Group (ITD)

FINAL REPORT
Innovative Technology Demonstration
of
Maintainable Weep Hole Filters
used in Box Culvert Preservation

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction:

The American Association of State Highway and Transportation Officials (AASHTO) created the Transportation System Preservation Technical Services Program (TSP-2) as an effective means to disseminate information to AASHTO member agencies for preserving their highway infrastructure, including both pavements and bridges. Bridge preservation includes actions or strategies that prevent or reduce the deterioration of bridges or bridge elements, restore the function of existing bridges, keep bridges in good condition, and extend their service life. There are currently four regional bridge preservation partnership working groups. When all four regional bridge partnership boards or committees agree that a bridge preservation topic should be addressed on a national level, a national working group is formed. One such national working group is the Innovative Technology Demonstrations Working Group (ITD). Under the ITD Working Group's guidelines, Jet Filter System partnered with the Michigan Department of Transportation (MDOT) to perform a demonstration of their Maintainable Weep Hole Filters (a.k.a. Jet Filters) at one of MDOT's existing box culvert structures. This TSP-2 Bridge Preservation demonstration highlights a new and innovative technology through an independent consultant generating interest and acceptance, with many States considering the use of Jet Filters. Per the ITD guidelines, the manufacturer of an innovative technology product, Jet Filter System, hired L.S. Engineering, Inc. (LSE) as the independent consultant.

Objectives:

Typical backfill drainage solutions for structures include weep holes or perforated pipe. Each solution generally integrates geotextile fabric to provide soil filtration. These solutions are buried under the backfill on the back (earth retained) side of the structure. Over time, the typical dewatering solutions can fail and incur large costs to replace. Jet Filter System incorporates removable geotextile fabric with a housing mounted to the front face of the wall or structure creating maintainable drainage with soil filtration. The objective of this demonstration was to investigate and report the effectiveness of the innovative technology's ability to 1) reduce hydrostatic pressure behind the walls and ceilings of the twin box culvert, 2) prevent soil leaching through the drainage system and, 3) allow for inspection and maintenance. Through reporting, interest and acceptance of this new and innovative technology will be generated with federal, state, and local agencies.

1. INTRODUCTION

1.1. What are Jet Filters?

Earth Retaining Structures (ERS) are failing daily due to clogged or insufficient drainage systems. JET Filter System provides an innovative solution at a fraction of the cost of traditional repair. Jet Filters, often called Maintainable Weep Hole Filters, provide both drainage and soil filtration. Installed through the front of any new or existing ERS, Jet Filters help prevent infrastructure failure as they reduce hydrostatic pressure and stop development of damaging voids and sink holes. Most importantly, they are easily maintained and can extend the life of our nation's infrastructure investments. Weep Hole Filters can be installed in a variety of earth retaining structures: bridge abutments, bridge wing or return walls, box culverts, stormwater channels, dam spillways, seawalls, bulkheads, and even underground parking garages. They are the perfect solution for a variety of materials: concrete walls, steel, vinyl, aluminum, or composite sheet pile walls, MSE walls, and even wooden walls.

In this application, Jet Filters were installed in a twin box culvert for the transportation market, but the technology can be used in any ERS in a variety of markets. Although they are known by many names depending on the market, this document will primarily reference the product as Jet Filters, maintainable weep hole filters, units, or product.

Jet Filter System manufactures three sizes of maintainable weep hole filters, 3" (replaces 2.5" steel units), 4", and 6" diameter. The unit's primary components include a 316L stainless steel housing, a UV Protected, durable ABS cartridge and a woven geotextile filter fabric (Mirafi FW300 standard). The units may consist of a backflow prevention valve and can be special ordered with other woven geotextile fabrics.

1.2. Demonstration Objectives

The objective of this demonstration was to investigate and report the effectiveness of the innovative technology over a range of product sizes, configurations, and geotextile filter fabrics.

2. DEMONSTRATION BACKGROUND

The existing 172', twin box culvert was built in 1963. The culvert is currently inspected every 24 months. The culvert inspection report indicates that the structure is in Good Condition (NBIS rating of 7). Noted under AASHTO Element Number 241 – Reinf Conc Culvert, both sidewalls of the culvert contain cracks that are wet indicating the presence of retained water behind the structure.

The existing culvert was originally designed with 3" diameter weep holes located approximately 9" up from the bottom slab. The weep holes are spaced at 6'-0" on center. The existing weep hole design simply consisted of coarse aggregate behind the weep hole to retain the sand backfill material. Over time, the coarse aggregate buffer was lost through the weep holes, this failure led to soil voids. As a result, most, if not all, of the weep holes had been grouted or plugged shut by the owner to prevent further voids. This eliminated the designed backfill drainage system resulting in an increase in the pore water pressure behind the wall which caused increased cracking of the concrete. Water leached through the cracks and would eventually cause rusting of the reinforcing steel and delamination of surrounding concrete, prematurely deteriorating the structure.

2.1. Demonstration Location

The demonstration box culvert carries both directions of US-31 over the North Branch of the Macatawa River, just southwest of Holland, MI near 144th Avenue and 60th Street. The

existing structure is a reinforced concrete twin box culvert and is 172’ in length. US-31 is a divided freeway with two lanes in each direction, paved shoulders, gravel shoulders, and a vegetated depressed median. The driven lanes are concrete pavement and are a total of 24’ wide in each direction. Hot mix asphalt (HMA) shoulders on each side of northbound and southbound US-31 composes another 14 ’ of width. Paved surfaces are more likely to shed rainwater and snow melt, while the vegetated median is more likely to be infiltrated by rainwater and snow melt. Surfaces over the culvert play a role in the presence of water behind the culvert walls.

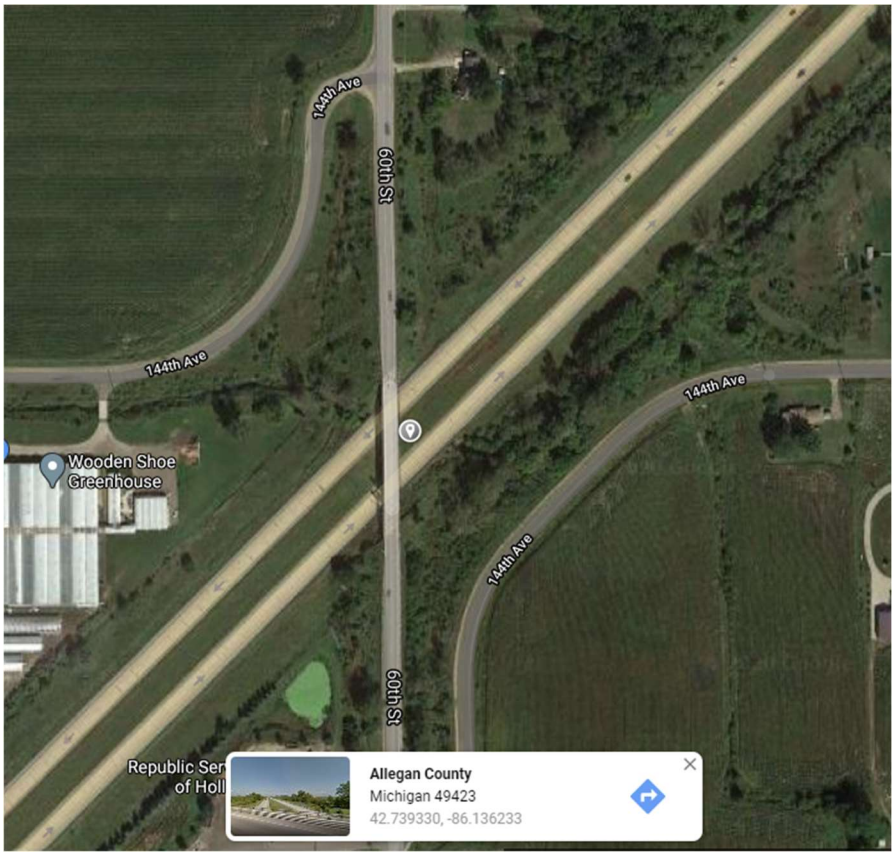


Figure 1 - Demonstration Location Map

2.2. Product Installation

MDOT utilized their own maintenance forces for installation of the Jet Filters. After soliciting bids, MDOT selected K&H Concrete Cutting to perform the core drilling portion of the

installation. As an independent consultant, LSE was on site for installation of the Jet Filters and produced detailed daily work reports documenting the work performed. Jet Filter System distributed the units to the installation crew as detailed in the installation matrix (Table 1).

To provide the most comprehensive test results, this demonstration utilized a variety of sizes, configurations, and filter fabrics. Both the 2.5"[a] diameter and 4" diameter Jet Filters were included. Five different TenCate Mirafi geotextile filter fabrics were compared in this demonstration: four woven and one non-woven. These geotextiles cover a wide range of properties that provided comprehensive results during the evaluation period. Both the open-end and the closed-end (backflow prevention) styles were installed to obtain additional test results. Appendix A contains the product data sheets for the styles of Jet Filters chosen for this demonstration. Appendix B contains the product data sheets for the geotextile filter media chosen for this demonstration.

LSE developed a detailed installation matrix (Table 1) to ensure the most comprehensive set of data for each of the geotextile fabric and each unit configuration. Unit configuration were varied along the length of the culvert. This accounted for the surface type above and the fact that water may infiltrate into the structure backfill differently depending on that surface type. The installation matrix also aided in readily identifying the unit configuration at a given location.

[a] The 2.5" Jet Filter has been replaced with a 3" model.

Table 1 - Detailed Installation Matrix

DAY 1 OF INSTALLATION – NORTH BARREL													
LEFT OF US-31 C/L													
OFFSET (FT)	75	69	63	57	51	45	39	33	27	21	15	9	3
ID #	101A	102B	103C	104D	105E	106A	107B	108C	109D	110E	111A	112B	113C
RIGHT OF US-31 C/L													
OFFSET (FT)	3	9	15.5	22	28.5	35	41.5	48	54.5	61	68	75	82
ID #	314B	315C	316D	317E	318A	319B	320C	321D	322E	323A	324B	325C	226A

DAY 2 OF INSTALLATION – SOUTH BARREL													
LEFT OF US-31 C/L													
OFFSET (FT)	76.5	70.5	64.5	58.5	52.5	46.5	40.5	34.5	28.5	22.5	16.5	10.5	4.5
ID #	201B	202A	203E	204D	205C	206B	207A	208E	209D	210C	211B	212A	213D
RIGHT OF US-31 C/L													
OFFSET (FT)	2	8.5	15	22	29	36	42	49	55.5	62	68.5	75	81.5
ID #	414D	415C	416B	417A	418E	419D	420C	421B	422A	423E	424D	425C	126A

NOTE: Offsets are measured along culvert wall and are approximate. Left and right directions are indicative of looking Northeast (along NB US-31).

Identification number elements represent the following:

1st Digit: 1 = 4" Diameter Open End Jet Filter
2 = 4" Diameter Closed End Jet Filter with Louver Vent
3 = 4" Diameter Open End Jet Filter with Louver Vent
4 = 2.5" Diameter Jet Filter

2nd & 3rd Digit: Jet Filters are numbered 01 through 26 from west to east along both the north and the south sidewalls.

4th Digit: TenCate Filter media – A = Mirafi FW300; B = Mirafi FW402; C= Mirafi FW404; D = Mirafi FW700; E = Mirafi 160N

Permanent identification tags were installed on each unit with the identification number shown for data collection purposes (Figure 2). The identification tags were installed under the upper, right-hand face plate mounting bolt.

Figure 2 – Jet Filter ID Tag

Installation of JET Filter System's maintainable weep hole filters began on June 4, 2019. A core drill was mounted to the culvert sidewalls at existing weep hole locations. Where possible, the 4" core bits were centered over the existing 3" weep hole. Existing grout and rubber stoppers did not require removal prior to core drilling. The first hole cored was at location 101A. When the core drill bit was backed out of the core hole, liquified sand backfill began pouring out of the core hole almost instantly. The crew had to wait until the core drill was unmounted from the culvert sidewall before installation of the unit which caused additional loss of backfill through the cored hole. MDOT and K&H Concrete Cutting modified their installation/core drilling process by unscrewing the core bit from the drill and removing the core drill from the culvert sidewall prior to backing out the core bit. With this improved portion of the process, immediately after core bit removal, MDOT installation crew was ready to place the Jet Filters into the cored hole and permanently mount them to the culvert sidewall with minimal loss of backfill material. Pilot holes for the mounting bolts were drilled in the concrete using the Jet Filter mounting flange as a template. Then concrete fasteners were screwed into the concrete to permanently mount the housing with the removable filter cartridge inside.

Figure 3 – Existing Weep Hole with Abraded Concrete

During installation, another modification was made to the installation plan. At some locations, the existing concrete had deteriorated below the existing weep hole due to decades of drainage water abrasion, see Figure 3. The damage was too significant and had the potential to not allow a sufficient seal around the full perimeter of the mounting flange gasket of the 4" units. The proposed modification was to offset the new maintainable drain to the left or right of the existing weep holes. By offsetting the cored hole and Jet Filter to an area with a smoother concrete surface, the gasket would seal better. The existing plugged weep holes were left intact or were grouted by the MDOT crew.

During the second day of installation, modification was made to the installation of the 2.5" Jet Filters. Given the uneven condition of the existing concrete culvert sidewall, a gasket was added between the flange and the concrete wall to the some of the 2.5" units. Units 414D through 419D were installed with no gasket as is typically done with the 2.5" units, and 420C

through 425C were installed with a gasket provided by Jet Filter System. The gasket material was the same material found on the back side of the 4" mounting flange.

3. PRODUCT EVALUATION

The installation process of the Jet Filters was evaluated, with recommendations noted from the MDOT installation crew. After installation of the Jet Filters, data was collected during the evaluation period for each product configuration included in this demonstration. The Jet Filters were inspected at scheduled and non-scheduled intervals.

The first inspection of the installed JET Filter System's maintainable weep hole filters occurred two days after the installation. The purpose of this inspection was to observe the drainage performance and confirm soil filtration. The second inspection of the installed units occurred nine days after installation. This inspection only observed drainage performance to relieve hydrostatic pressure.

The condition of the filter media, contained in the units' filter cartridges, was evaluated four times during the year following the installation. Filter media were removed from one quarter of the Jet Filters at each of the four inspections. The inspection periods were 30 days, 90 days, 180 days, and 1 year. Additional inspections are planned to take place annually if possible, for the next four years with a quarter of the filters evaluated each year. The actual inspection schedule will be modified as required and findings will be reported as addenda to this final report.

3.1. Installation

The original demonstration installation plan included filling voids surrounding the cored hole with MDOT 6A stone. However, the high hydrostatic pressure causing the existing sand to be in a saturated or liquified state, prevented any stone backfill from being placed. The existing

backfill was a permeable, class II sand. This allowed the Jet Filters to be installed without adding stone. To minimize material loss, the units were installed as quickly as possible. The original installation step would only be achieved in drier conditions for retrofit construction, or for installation on new structures.

Installation of the Jet Filters required four 3/16" pilot holes to be drilled into the concrete culvert sidewall with a hammer drill, then, the provided 1/4" diameter stainless steel concrete screws were driven into the holes. The crew used a battery powered impact driver to drive the screws. On some screws, the head sheared off from the concrete screw during tightening. Each time, the crew had to pull the Jet Filter from the culvert sidewall and then rotate the housing flange slightly to allow for new pilot holes to be drilled. For Jet Filters 423E and 424D, the crew modified their process to include final tightening by hand with a wrench. The installation crew suggested possibly utilizing larger diameter mounting screws or wedge anchor type mounting bolts.

3.2. Drainage Performance

Initial inspection of the double barrel concrete box culvert on June 3, 2019 (the day prior to installation) indicated high levels of retained water, approximately half the height of the culvert wall. Existing vertical sidewall cracks, top slab cracks, and construction joints showed presence of moisture and leaching soil. This damp or wet condition was also noted on the Culvert Safety Inspection Report completed by MDOT on March 20, 2019 which indicates a consistent issue with drainage of the culvert backfill. Upon initial installation of the Jet Filters, drainage of retained water was significant, with water flowing from every drain. Drainage flow rate was measured from at least one Jet Filter containing each type of filter fabric. Measurements were

taken upon completion of the installation and during the 2-day inspection. Flow rates shown in Table 2, for June 5, 2019 and June 7, 2019, indicate a correlation between the fabric type and the flow rate of drained water. Units with Mirafi FW300 (A) fabric allowed the highest flow rate for both dates. Mirafi FW402 (C) and 160N (E) fabrics were measured either 2nd or 3rd highest flow rate for both dates. Mirafi FW404 (B) fabrics were measured 4th highest flow rate for both dates, and Mirafi FW 700 (D) measured the lowest flow rate for both dates.

Date: 6/5/2019

Jet Filter ID	207A	208E	210C	211B	204D
Flow Rate (L/Min)	0.351	0.211	0.192	0.137	0.086

Date: 6/7/2019

Jet Filter ID	111A	108C	110E	208E	107B	109D
Flow Rate (L/Min)	0.162	0.142	0.12	0.104	0.086	0.036

A = Mirafi FW300; B = Mirafi FW402; C= Mirafi FW404; D = Mirafi FW700; E = Mirafi 160N

Table 2 - Flow Rate Measurements by Date

When comparing the fabric properties, found in Appendix B, there is a direct correlation found between measured flow rate and the specifications of apparent opening size, permittivity, and specification flow rate. Tables 2 & 3 show how higher permittivity, higher flow rate, and larger apparent opening size contribute to higher measured flow rates of drained water in the field. However, it should be noted that the non-woven fabric (160N, designated ‘E’) does perform differently than the woven fabrics.

	TenCate Mirafi Specifications		
	Apparent Opening Size (AOS)	Permittivity	Flow Rate
	ASTM D4751	ASTM D4491	ASTM D4491
Fabric	(mm)	(sec^{-1})	($gal/min/ft^2$)
FW300 (A)	0.600	1.5	115
160N (E)	0.212	1.5	110
FW404 (C)	0.425	0.9	70
FW402 (B)	0.425	2.1	145
FW700 (D)	0.212	0.28	18

Table 3 - TenCate Mirafi Specifications

Another correlation investigated was the flow rate relative to the position of the filters in the culvert. As noted in Section 2.1., the concrete pavement and HMA shoulders of US-31 are generally impervious and shed water from the roadway. The median between the divided highway and side slopes beyond the outside paved shoulders are vegetated topsoil over sand embankment and allows rainwater and runoff from the impervious surfaces to infiltrate. The position of the maintainable drains with respect to the surface type above them did not, however, correlate to the initial measured flow rate of drained water. Jet Filter ID numbers 207A, 208E, and 108C were located under impervious pavement areas of US-31, and 111A was located under the grass median and these drains were measured at high flow rates. Jet Filter ID numbers 204D and 107B were located under impervious pavement areas, and 109D and 211B were located under the grass median, all had lower flow rates.

The Jet Filters re-established the drainage of the culvert backfill material as was originally designed with the existing weep holes. As seen in Figure 4, the effects of drainage were almost immediate, with flow rates dropping quickly. Within two weeks, some flow rates were too low (weeping) to be measured. This indicated the units were functioning as designed. Even after

heavy rain events, measurements showed even more decrease after 30 days, with many units so low they could not be measured.

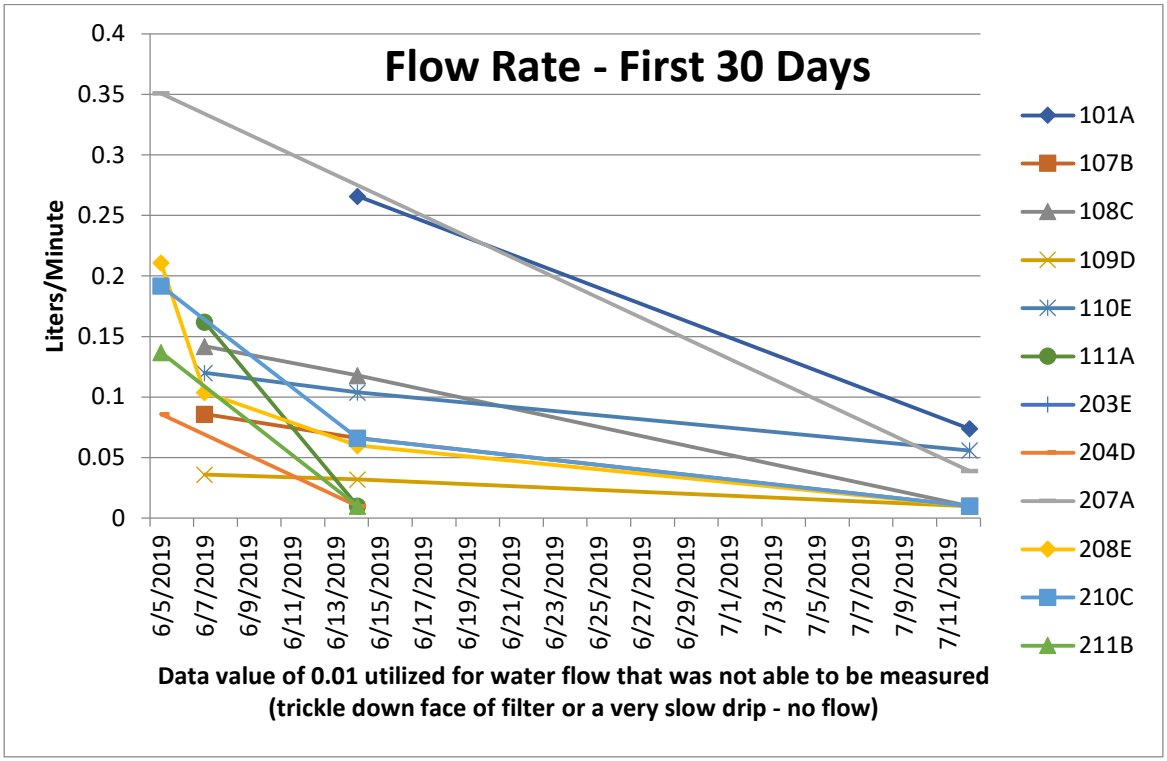


Figure 4 - 30-Day Flow Rate Measurements

After 30 days, the flow rates leveled off at low values as seen in Figure 5. In addition to flow rates leveling off, the correlation between flow rates and fabric type are no longer present.

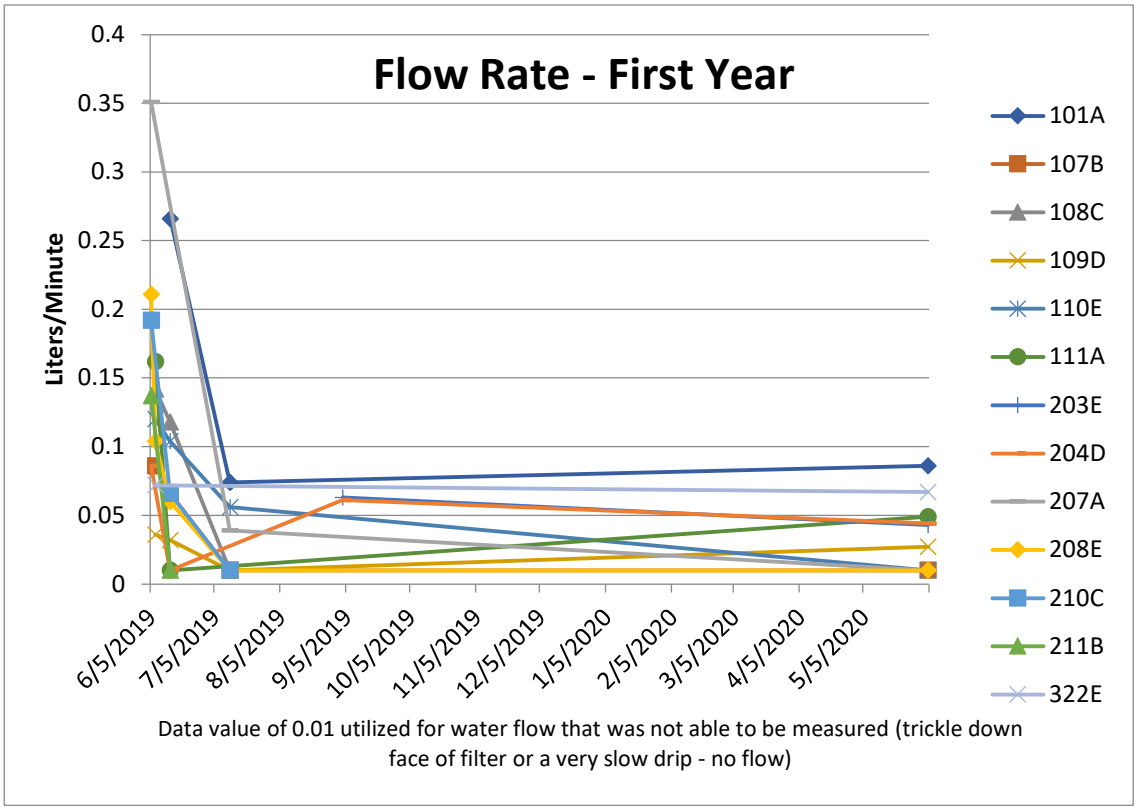


Figure 5 - 12-Month Flow Rate Measurements

The Jet Filter configurations with backflow prevention valves were installed in units numbered 201 through 213 and 226. These units drained water well but were observed to retain water behind the valve approximately one third the height of the drains (approximately 1”). The valve’s rigidity was designed to prevent backflow, as a result it also resists flow out of the units during very low-pressure conditions. This minor water retention did not impact the effectiveness of the units. After observations in this demonstration, in similar future applications the open-end units would be a preferred choice over the closed-end backflow prevention valve units. In applications with continuous or fluctuating higher water levels such as seawalls, flood channels, etc. the closed-end backflow prevention valve may be the preferred choice.

3.3. Soil Retention Performance

Soil retention is an integral component of the Jet Filter product. Culverts are typically backfilled with a granular material which supports the roadway above. Upon initial installation of the units, samples were taken of the drainage water and comparisons were made by visual inspection. Figure 6 shows a sample of the variable amount of suspended sediment at five locations with different filter fabrics.

Figure 6 – Soil Filtration Samples taken June 5, 2019

Samples were inspected from Jet Filter units 204D, 207A, 211B, 210C, and 208E (shown left to right in Figure 6) on June 5, 2019, the same day as installation. These units were chosen to compare filter fabric material. As seen in Figure 6, unit 204D allows the least amount of sediment to pass, followed by 207A, 211B, and 210C, in order of increasing amounts of sediment. The largest amount of sediment occurs in the drainage from 208E, evidenced by the dark color. This indicates that generally the larger the apparent opening size (AOS) of the filter fabric, the more sediment would be allowed to pass through. The Mirafi FW700 fabric (designated 'D')

which has the smallest AOS of the woven fabrics. However, the largest AOS specification belongs to the Mirafi FW300, (designated 'A'). In the samples taken, 207A contains the second least amount of sediment. The unit 208E showed the most suspended soil. The principal observation from the samples taken is that the non-woven filter fabric allows more sediment to pass through than any of the woven fabrics. Even though the AOS specification of the Mirafi 160N (non-woven, designated 'E') is the same as the Mirafi FW700 (woven, 'D'), the woven fabric demonstrated better results.

Over time, the sediment passing through all Jet Filter's filter cartridges decreased. A sample from ID 208E which was the darkest of the samples from June 5, 2019, was significantly lighter in color when sampled just two days later, on June 7. See Figure 7.

Figure 7 – Drain 208E Sample Sediment Comparison

A sample was also collected on June 7, 2019 from location 322E with the 160N non-woven fabric to compare the same filter fabric at different locations. This sample was clear, as seen in Figure 8.

Figure 8 – Drain 322E Sample

Samples were also taken from units that did not have valves, at the two-week inspection on June 14, 2019 and sedimentation amounts were examined. As shown in Figure 9, samples 101A, 107B, 108C, 109D, and 110E all showed no visible sediment.

Figure 9 – June 14, 2019 Samples

On June 14, 2019, samples were also taken at two 200 series drains to observe the performance of the units with backflow prevention valves. The 208E sample contained the most sediment when sampled June 5, 2019, and then had significantly lightened in color when sampled June 7, 2019. However, when sampled again on June 14, 2019, drain 208E had approximately

the same color as when sampled on June 7, 2019 as shown in Figure 10. Drain 210C sample showed the same color as when it was sampled on June 5, 2019 as shown in Figure 11, which indicates no significant reduction in sediment content.

Figure 10 – Drain 208E Samples
June 7th & June 14th

Figure 11 – Drain 210C Samples
June 7th & June 14th

Samples were taken again at the 90-day inspection on September 3, 2019 from drain 208E and 206B to see if the 200 series drains had cleared up over time. As shown in Figures 12 and 13, both drains appeared clear with no sediment visible. As the backflow prevention valves retain a small amount of water, it is thought that soil particles are also retained behind the valve and are slower to wash out.

Figure 12 – Drain 206B Sample
September 3, 2019

Figure 13 – Drain 208E Sample
September 3, 2019

The specific reason for the generally high initial suspended solid content that eventually tapered off was not determined as a result of this demonstration. It is possible the existing backfill being disturbed during installation caused the initially high soil content in the water drained. Given the existing backfill at this structure was permeable sand, the geotextile fabrics could have acquired a buildup of sand particles that aided in the filtration of finer soil particles, causing the suspended soil content to diminish over time. However, it is clear that the Jet Filters perform well retaining backfill soil, thereby preventing voids in the backfill and depressions in the top surface.

3.4. Maintainability

As part of Jet Filter System's maintainable weep hole filter demonstration, approximately one quarter of the filters were inspected for maintainability. The Jet Filters consist of a metal housing that is permanently attached to the concrete culvert sidewall and a removable filter cartridge that contains the geotextile fabric which retains the culvert's backfill material. Two sizes of Jet Filters were installed for this ITD demonstration, 2.5" diameter and 4" diameter.

The removable filter cartridge of the 2.5" diameter units is held in place by integral clips, as seen in the detailed drawings in Appendix A. To remove the cartridge, the clips are pushed in toward the center of the cartridge, and then the cartridge can be pulled from the metal housing. Upon the first maintenance inspection at 30 days, the 2.5" diameter cartridges were found to be difficult to remove by hand and replace back into the filter cartridge. This may have been due to the liquified nature of the existing backfill during installation. Once removed however, the 2.5" diameter cartridges and filter fabric were easily cleaned by rinsing the cartridge in the river water and simply brushing any sediment buildup away with a finger.

The removable cartridge of the 4" diameter units is held in place by four bolts. These bolts are unscrewed and then the cartridge is pulled out of the metal housing. Even with liquified sand backfill conditions, the filter cartridges of the 4" diameter units were still able to be easily reinstalled after inspection. The cartridges were rinsed in the river water and any sediment buildup was brushed from the filter fabric with a finger. The woven fabrics were noticeably more rigid than the non-woven fabric allowing for easier and more effective cleaning.

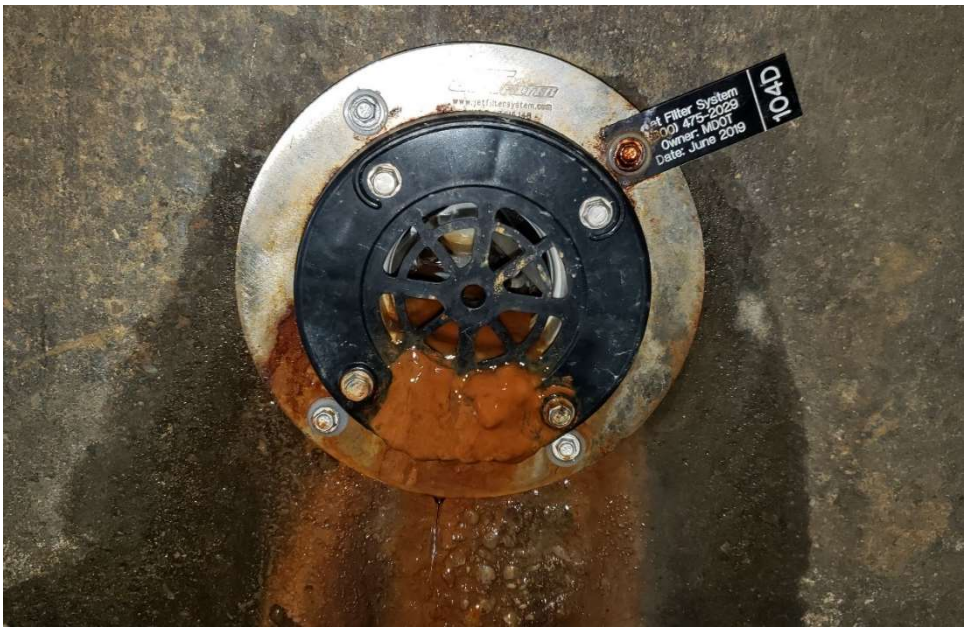


Figure 13 - Iron Ochre Buildup in Jet Filter

Iron ochre was discovered during the 90-day inspection on September 3, 2019. Buildup was seen on the outside of the open-ended units, as shown in Figure 14. This substance is the byproduct of an iron mineral eating bacteria. Iron ochre buildup could impact the drainage performance of the Jet Filters over time but appeared to be permeable and allowed water to flow through the filters. The iron ochre was easily cleaned from the filters by rinsing the filter in the stream. The iron ochre did leave staining behind after cleaning, but this did not appear to impact the performance of the units.

4. SUMMARY AND CONCLUSIONS

4.1. Summary

The purpose of the AASHTO TSP-2 Innovative Technology Working Group is to help bring forward information and knowledge of innovative technologies for the preservation of our transportation infrastructure through demonstrations. The box culvert hosting this demonstration is owned by MDOT and carries US-31 over the North Branch of the Macatawa River. The existing structure was designed with 3" diameter weep holes spaced at 6'-0" on center. This equates to 26 weep holes in each culvert sidewall, located approximately 9" above the bottom slab. The weep holes were designed with a pocket of coarse stone backfill at the drain surrounded by finer granular material. Over time, the weep holes systems began to fail and allowed finer backfill material to escape. The existing weep holes were then plugged by the owner to prevent additional loss of culvert backfill material. By installing the innovative technology of Jet Filters as part of this demonstration, proper drainage was restored to the culvert backfill.

4.2. Conclusions

Drainage and soil filtration components of existing structures such as this culvert are integral to the design of the structure. Adequate drainage prevents increased soil pressures that occur with the presence of water. Adequate drainage also preserves a structure by preventing water from leaching through various cracks in the top and sides of the culvert and corroding reinforcing steel. Repair of the existing culvert backfill drainage system by replacing the coarse aggregate and adding geotextile behind the culvert sidewall as originally designed would be very intrusive and costly. This repair would require road detours or partial width construction,

removal of the approach roadway and existing backfill, repair of the weep hole locations, replacement of the culvert backfill, and replacement of the roadway, and could take several weeks. This demonstration has shown that by retrofitting the drainage system from inside the existing culvert sidewall using Jet Filters, the backfill drainage component of this culvert can be restored at a significantly lower cost than repairing the existing weep holes from the back side of the culvert sidewall. Also, retrofitting with the Jet Filters saved time, as 52 installations were completed in 1.5 working days.

Maintainability is an innovative part of the Jet Filter product. The existing weep holes designed in the culvert did not have maintainable components. The ability to remove and inspect the filter fabric housed in the cartridge poses an advantage over the existing design. A difference in the design of the 2.5" diameter and 4" diameter products did show advantages of the 4" unit design. The 2.5" diameter units were more difficult to remove and replace after a periodic inspection due to the integral clips that held the filter cartridge in place along with the potential presence of liquified sand backfill flowing during maintenance. Woven fabrics utilized in this demonstration were more rigid than the non-woven fabric and were more easily maintained when cleaned during periodic inspections. However, during the course of this demonstration, the maintainability of the woven and non-woven fabrics did not impact the performance of the Jet Filters.

A variety of product features were utilized for this demonstration as well as a variety of filter fabrics within the drains. The 2.5" diameter units did not drain retained water as quickly as the 4" units and over time, the flow of water slowed down much sooner than the 4" units. Upon inspection, the 2.5" filter cartridges were not plugged; it is assumed that the drainage slowed

significantly more due to the 2.5” units having much less surface area. The open-end 4” units are the preferred configuration for installation into an existing culvert such as the demonstration structure. The open-end allows for easier visual inspection into the filter cartridge which provides a time savings during periodic inspections. The louvered vent covers and the backflow prevention valves did not allow the inspector to see inside the filter cartridges without removing the cover and valve. The backflow prevention valves also were found to retain some water within the filter cartridge. High water events do not last long at this location and would not be detrimental to the structure if water were to penetrate the backfill through the drain, as would occur in the original design. Backflow prevention is not required in applications such as this culvert. Filter fabrics utilized for this demonstration showed some differences after initial installation. As expected, woven fabrics with larger openings and other properties indicative of allowing water to pass through more freely and the non-woven fabric allowed higher flow rates than fabrics with smaller openings and related properties. However, over time, the correlation did not continue and the different filter fabrics all drained water at similar rates. Soil retention was also analyzed for the various fabrics utilized in this demonstration. Samples indicated that the non-woven fabric allowed more sediment to pass through the culvert maintainable drain than any of the woven fabrics. Over time however, all collected samples contained less sediment. At the 90-day periodic inspection, all samples taken were clear and did not appear to contain any sediment.

Jet Filters, through this demonstration, were proven to restore backfill drainage while retaining soil with the added benefit of being easily maintainable.

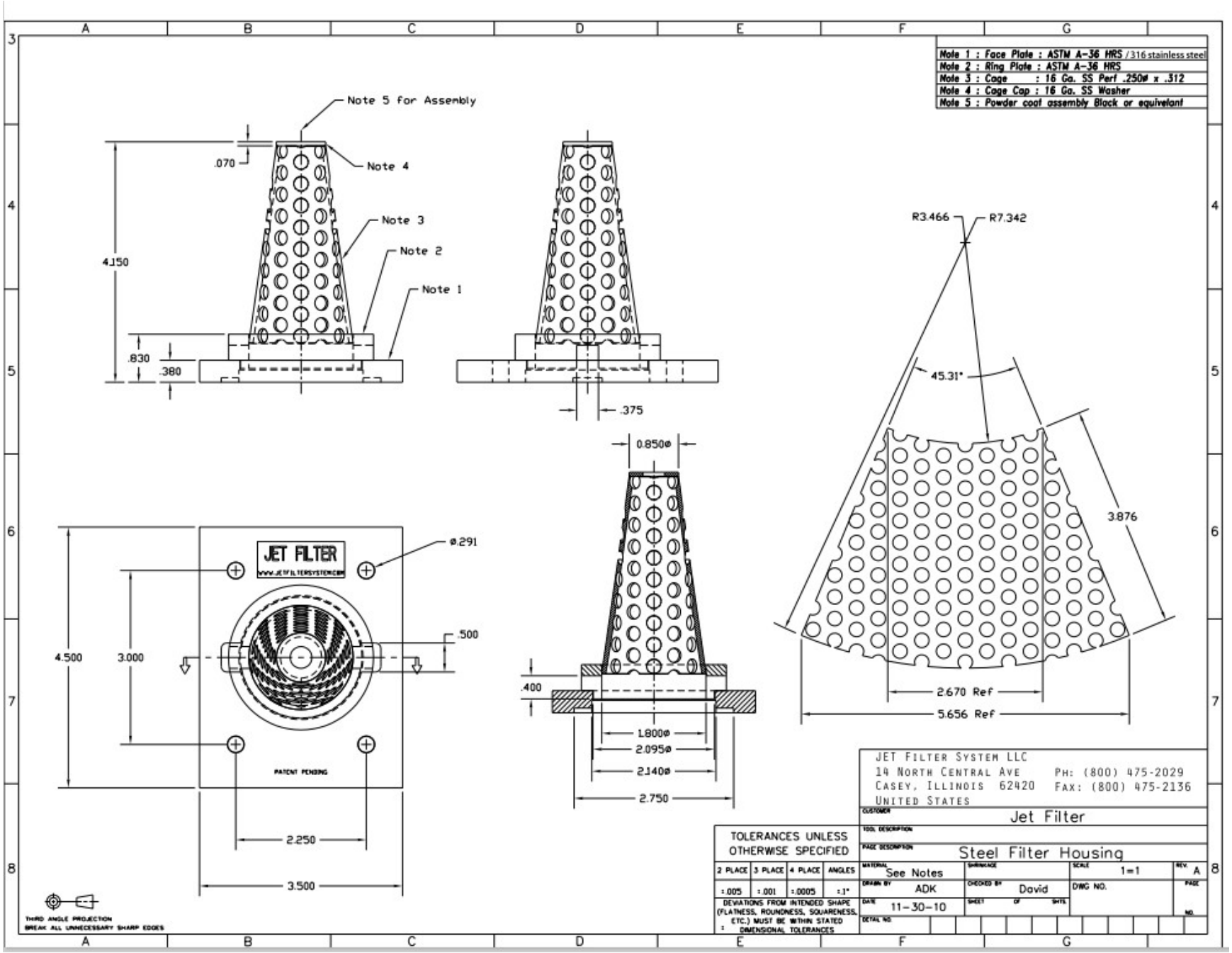
4.3. Michigan DOT Special Provision

As a result of this demonstration project, the Michigan DOT published a special provision to allow Jet Filter System's maintainable weep hole filters to be used in MDOT-let new construction projects, preservation projects, and maintenance of earth retaining structures.

APPENDIX A – Jet Filter Dimensional and Material Specifications

2.5” Jet Filter – Stainless Steel Dimensional Details

Note: 2.5” SS has been replaced with 3” Jet Filter SS (pages A4-A7)



2.5” Jet Filter – Stainless Steel Product Specifications

Note: 2.5” Jet Filter has been replaced with 3” Jet Filter SS (pages A4-A7)

WEEP HOLE PRODUCT SPECIFICATION

2.5”dia. STEEL/SS

1.0 SCOPE

This Product Specification covers the performance requirements for earth retaining structures pertaining to weep holes and dewatering.

2.0 PRODUCT DESCRIPTION

2.1 Product Name and Part Number

Product Name	Part Number
JET FILTER STEEL; POWDER COATED BLACK	JF2.5PC
JET FILTER SS; 316 STAINLESS STEEL	JF2.5SS

3.0 MATERIALS

3.1 Flame Retardent Polycarbonate/ Acrylonitrile-Butadiene-Styrene (Filter Cartridge Only) U/V Resistance

3.2 Housing ASTM Hot Rolled Steel and 316 Stainless Steel

3.3 Filter Media

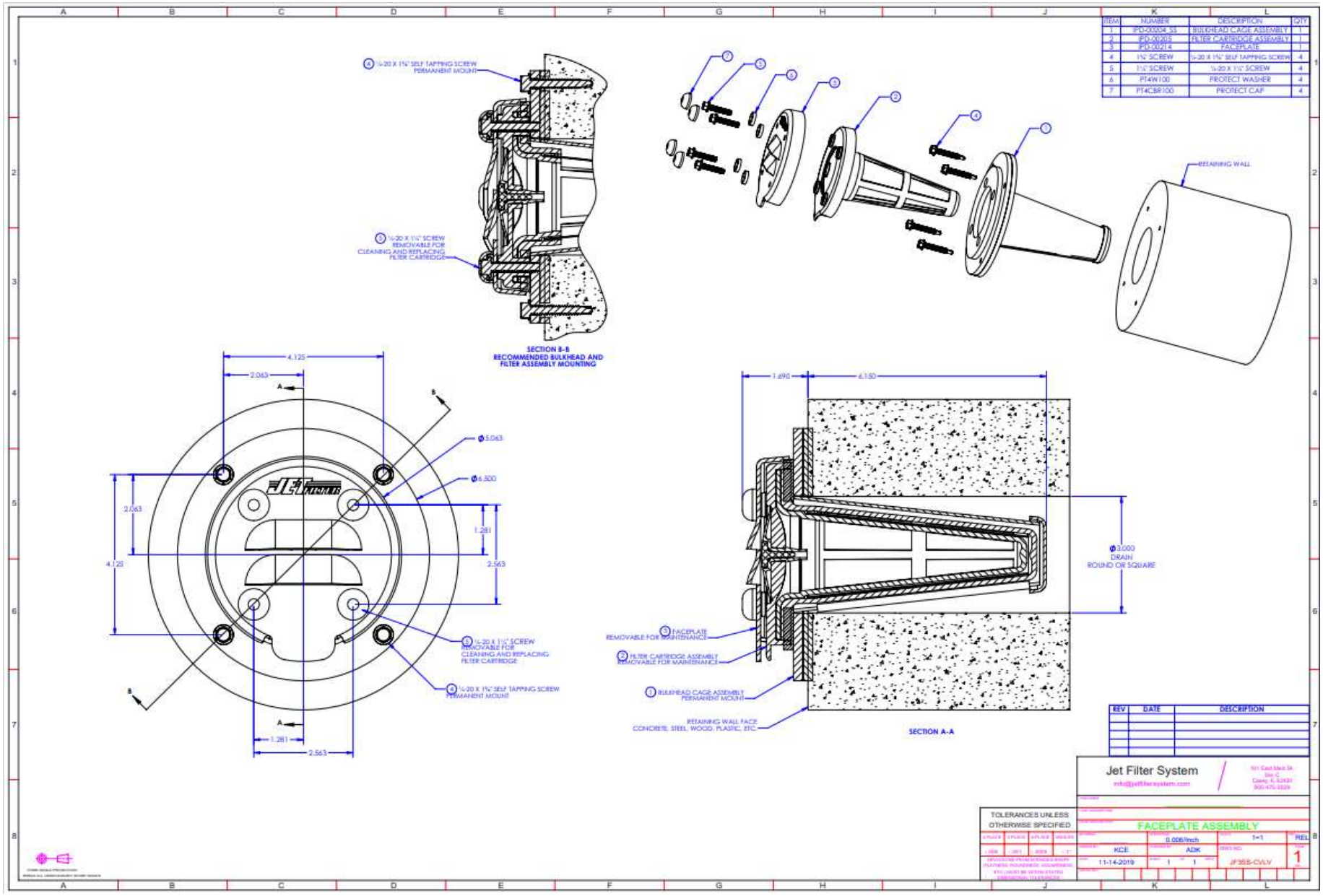
1.Mirafi® FW300 geotextile is composed of high-tenacity monofilament polypropylene yarns, which are woven into a stable network such that the yarns retain their relative position.

CBR Puncture Strength	ASTM D6241	lbs (N)	1250 (5563)
Apparent Opening Size (AOS)1	ASTM D4751	U.S. Sieve (mm)	30 (0.60)
Percent Open Area	COE-02215	%	8
Permittivity	ASTM D4491	sec-1	1.5
Permeability	ASTM D4491	cm/sec	0.13
Flow Rate	ASTM D4491	(gal/min/ft2) l/min/m2	115 (4685)

US PAT #:		TITLE:	PART#:
7,615,148	JET FILTER SYSTEM LLC 101 EAST MAIN STREET CASEY ILLINOIS 62420 800-475-2029	2.5”DIA. ASTM/SS PRODUCT SPECIFICATION JET Filter components are 100% made in the USA and are compliant with the Buy American Clause.	JF2.5PC JF2.5SS

3” Jet Filter – Stainless Steel Closed-End Dimensional Details

Note: 2.5” Jet Filter (pages A2-A3) has been replaced with 3” Jet Filter Closed-End or Open-End SS unit



3” Jet Filter – Stainless Steel Closed-End Product Specifications

Note: 2.5” Jet Filter (pages A2-A3) has been replaced with 3” Jet Filter Closed-End or Open-End SS unit

WEEP HOLE PRODUCT SPECIFICATION

3”dia. One-Way Backflow Preventer

1.0 SCOPE

This Product Specification covers the performance requirements for earth retaining structures pertaining to weep holes and dewatering.

2.0 PRODUCT DESCRIPTION

2.1 Product Name and Part Number

Product Name	Part Number
JET FILTER BACKFLOW PREVENTER SS; w/SS LOUVERED VENT	JF3SSCVLV

3.0 MATERIALS

3.1 Flame Retardent Polycarbonate/ Acrylonitrile-Butadiene-Styrene (Filter Cartridge Only) U/V Resistance Themoplastic Sarlink Check Valve

3.2 Housing ASTM Hot Rolled Steel and 316 Stainless Steel

3.3 Filter Media

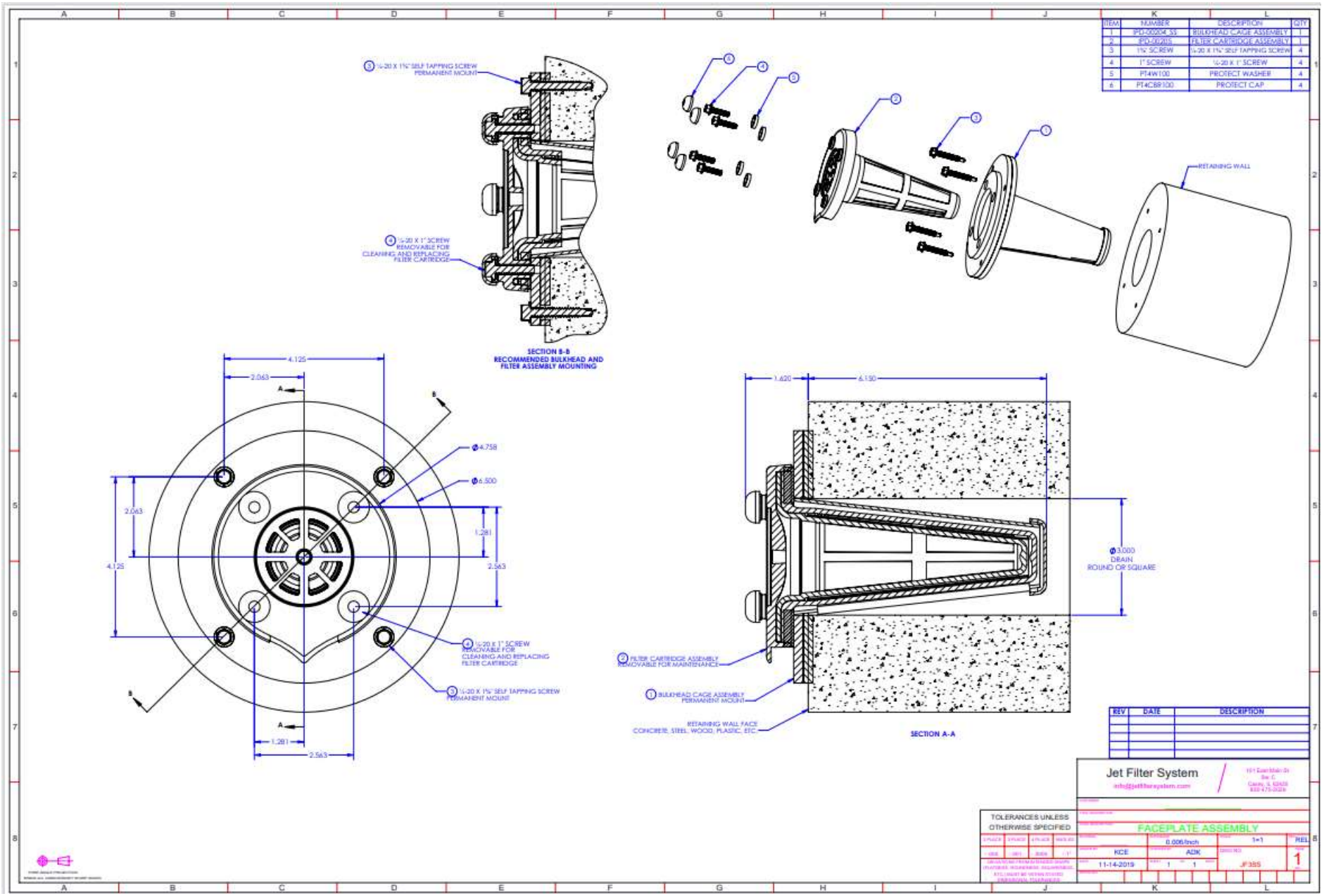
1.Mirafi® FW300 geotextile is composed of high-tenacity monofilament polypropylene yarns, which are woven into a stable network such that the yarns retain their relative position.

CBR Puncture Strength	ASTM D6241	lbs (N)	1250 (5563)
Apparent Opening Size (AOS)1	ASTM D4751	U.S. Sieve (mm)	30 (0.60)
Percent Open Area	COE-02215	%	8
Permittivity	ASTM D4491	sec-1	1.5
Permeability	ASTM D4491	cm/sec	0.13
Flow Rate	ASTM D4491	(gal/min/ft2) l/min/m2	115 (4685)

US PAT #:		TITLE:	PART#:
10,124,281	JET FILTER SYSTEM LLC 101 EAST MAIN STREET CASEY ILLINOIS 62420 800-475-2029	3"DIA.SS BACKFLOW PREVENTER PRODUCT SPECIFICATION JET Filter components are 100% made in the USA and are compliant with the Buy American Clause.	JF3SSCVLV

3” Jet Filter – Stainless Steel Open-End Dimensional Details

Note: 2.5” Jet Filter (pages A2-A3) has been replaced with 3” Jet Filter Closed-End or Open-End SS unit



3” Jet Filter – Stainless Steel Open-End Product Specification

Note: 2.5” Jet Filter (pages A2-A3) has been replaced with 3” Jet Filter Closed-End or Open-End SS unit

WEEP HOLE PRODUCT SPECIFICATION

3”dia. 316/SS

1.0 SCOPE

This Product Specification covers the performance requirements for earth retaining structures pertaining to weep holes and dewatering.

2.0 PRODUCT DESCRIPTION

2.1 Product Name and Part Number

Product Name	Part Number
JET FILTER SS; 316 STAINLESS STEEL	JF3SS

3.0 MATERIALS

3.1 Flame Retardent Polycarbonate/ Acrylonitrile-Butadiene-Styrene (Filter Cartridge Only) U/V Resistance

3.2 Housing ASTM Hot Rolled Steel and 316 Stainless Steel

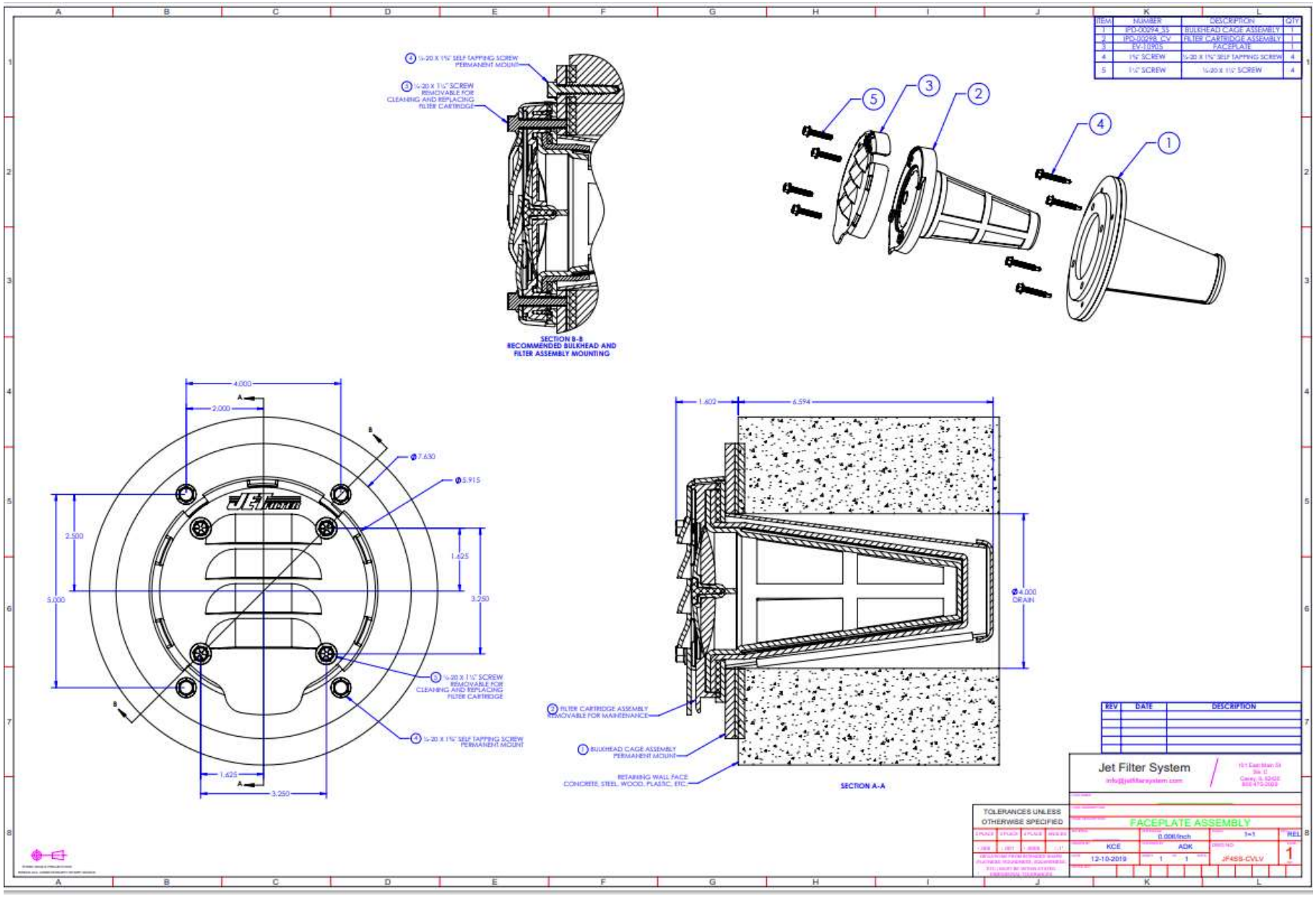
3.3 Filter Media

1.Mirafi® FW300 geotextile is composed of high-tenacity monofilament polypropylene yarns, which are woven into a stable network such that the yarns retain their relative position.

CBR Puncture Strength	ASTM D6241	lbs (N)	1250 (5563)
Apparent Opening Size (AOS)1	ASTM D4751	U.S. Sieve (mm)	30 (0.60)
Percent Open Area	COE-02215	%	8
Permittivity	ASTM D4491	sec-1	1.5
Permeability	ASTM D4491	cm/sec	0.13
Flow Rate	ASTM D4491	(gal/min/ft2) l/min/m2	115 (4685)

US PAT #:		TITLE:	PART#:
7,615,148	JET FILTER SYSTEM LLC 101 EAST MAIN STREET CASEY ILLINOIS 62420 800-475-2029	3"DIA. 316SS PRODUCT SPECIFICATION JET Filter components are 100% made in the USA and are compliant with the Buy American Clauses.	JF3SS

4” Jet Filter – Stainless Steel Closed-End Dimensional Details



4” Jet Filter – Stainless Steel Closed-End Product Specification

WEEP HOLE PRODUCT SPECIFICATION

4”dia. One-Way Backflow Preventer

1.0 SCOPE

This Product Specification covers the performance requirements for earth retaining structures pertaining to weep holes and dewatering.

2.0 PRODUCT DESCRIPTION

2.1 Product Name and Part Number

Product Name	Part Number
JET FILTER BACKFLOW PREVENTER SS, w/DEFLECTION CAP	JF4SSCVDC
JET FILTER BACKFLOW PREVENTER SS, w/SS LOUVERED VENT	JF4SSCVLV

3.0 MATERIALS

3.1 Flame Retardent Polycarbonate/ Acrylonitrile-Butadiene-Styrene (Filter Cartridge Only) U/V Resistance Themoplastic Sarlink Check Valve

3.2 Housing ASTM Hot Rolled Steel and 316 Stainless Steel

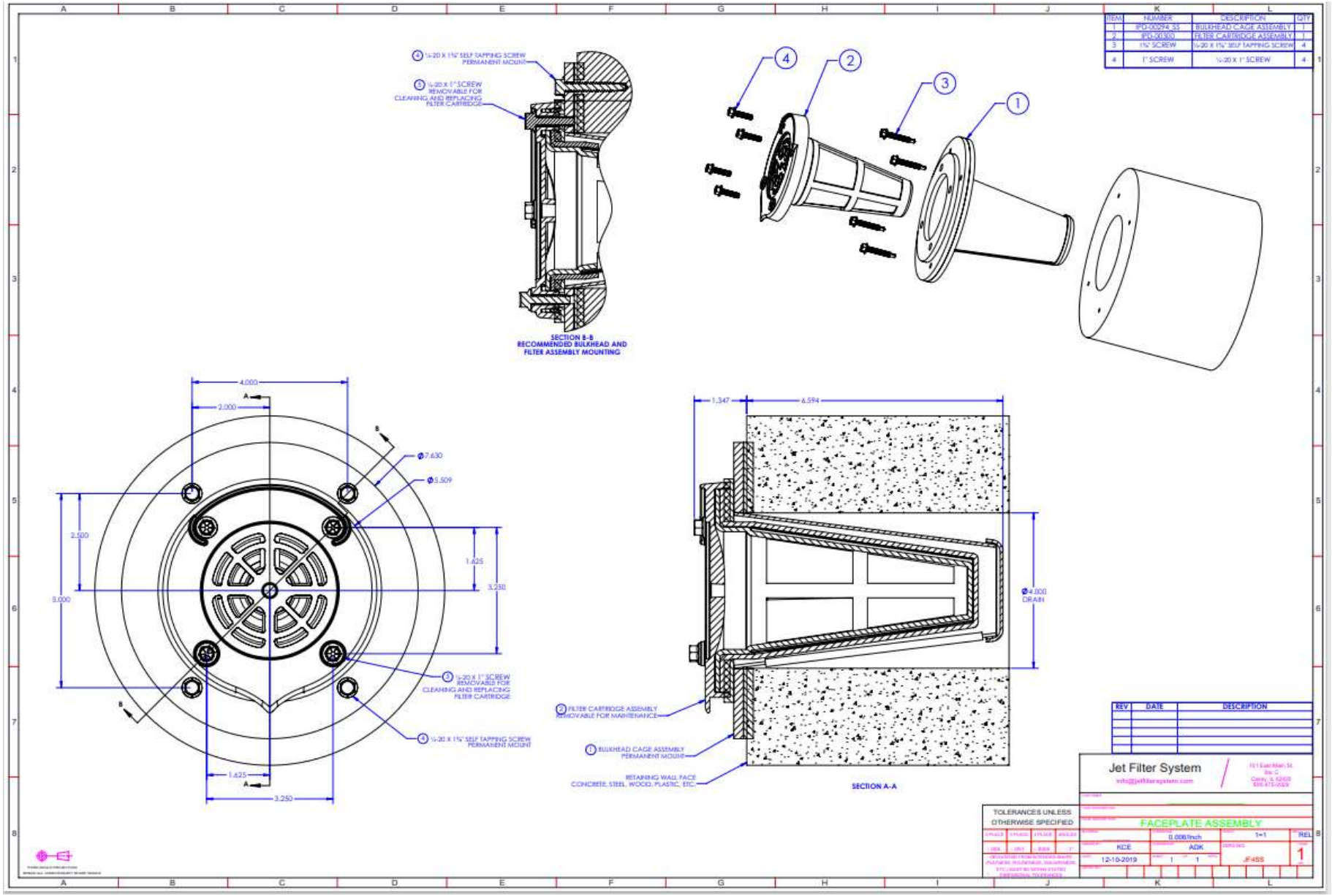
3.3 Filter Media

1.Mirafi® FW300 geotextile is composed of high-tenacity monofilament polypropylene yarns, which are woven into a stable network such that the yarns retain their relative position.

CBR Puncture Strength	ASTM D6241	lbs (N)	1250 (5563)
Apparent Opening Size (AOS)1	ASTM D4751	U.S. Sieve (mm)	30 (0.60)
Percent Open Area	COE-02215	%	8
Permittivity	ASTM D4491	sec-1	1.5
Permeability	ASTM D4491	cm/sec	0.13
Flow Rate	ASTM D4491	(gal/min/ft2) l/min/m2	115 (4685)

US PAT #:		TITLE:	PART#:
10,124,281	JET FILTER SYSTEM LLC 101 EAST MAIN STREET CASEY ILLINOIS 62420 800-475-2029	4"DIA.SS BACKFLOW PREVENTER PRODUCT SPECIFICATION JET Filter components are 100% made in the USA and are compliant with the Buy American Clause.	JF4SSCVDC JF4SSCVLV

4” Jet Filter – Stainless Steel Closed-End Dimensional Details



4” Jet Filter – Stainless Steel Closed-End Product Specification

WEEP HOLE PRODUCT SPECIFICATION

4”dia. STEEL/SS

1.0 SCOPE

This Product Specification covers the performance requirements for earth retaining structures pertaining to weep holes and dewatering.

2.0 PRODUCT DESCRIPTION

2.1 Product Name and Part Number

Product Name	Part Number
JET FILTER STEEL; POWDER COATED BLACK	JF4PC
JET FILTER SS; 316 STAINLESS STEEL	JF4SS

3.0 MATERIALS

3.1 Flame Retardent Polycarbonate/ Acrylonitrile-Butadiene-Styrene (Filter Cartridge Only) U/V Resistance

3.2 Housing ASTM Hot Rolled Steel and 316 Stainless Steel

3.3 Filter Media

1.Mirafi® FW300 geotextile is composed of high-tenacity monofilament polypropylene yarns, which are woven into a stable network such that the yarns retain their relative position.

CBR Puncture Strength	ASTM D6241	lbs (N)	1250 (5563)
Apparent Opening Size (AOS)1	ASTM D4751	U.S. Sieve (mm)	30 (0.60)
Percent Open Area	COE-02215	%	8
Permittivity	ASTM D4491	sec-1	1.5
Permeability	ASTM D4491	cm/sec	0.13
Flow Rate	ASTM D4491	(gal/min/ft2) l/min/m2	115 (4685)

US PAT #:		TITLE:	PART#:
7,615,148	JET FILTER SYSTEM LLC 14 N CENTRAL AVE CASEY ILLINOIS 62420 800-475-2029	4”DIA. ASTM/SS PRODUCT SPECIFICATION JET Filter components are 100% made in the USA and are compliant with the Buy American Clause.	JF4PC JF4SS

Appendix B TenCate Mirafi Geotextile Filter Data Sheets

A. TenCate FW300 woven

TENCATE Mirafi®

TENCATE GEOSYNTHETICS
Americas

Mirafi® FW300

Mirafi® FW300 geotextile composed of polypropylene yarns, which are woven into a stable network such that the yarns retain their relative position. Mirafi® FW300 geotextile is inert to biological degradation and resists naturally encountered chemicals, alkalis, and acids

TenCate Geosynthetics Americas Laboratories are accredited by Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP).

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
			MD	CD
Grab Tensile Strength	ASTM D4632	lbs (N)	400 (1780)	335 (1491)
Grab Tensile Elongation	ASTM D4632	%	20	15
Trapezoid Tear Strength	ASTM D4533	lbs (N)	145 (645)	125 (556)
CBR Puncture Strength	ASTM D6241	lbs (N)	1250 (5563)	
			Minimum Roll Value	
Percent Open Area	COE-02215	%	8	
Permittivity	ASTM D4491	sec^{-1}	1.5	
Flow Rate	ASTM D4491	gal/min/ft² (l/min/m²)	115 (4685)	
			Maximum Opening Size	
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	30 (0.60)	
			Minimum Test Value	
UV Resistance (at 500 hours)	ASTM D4355	% strength retained	90	

Physical Properties	Unit	Roll Size
Roll Dimensions (width x length)	ft (m)	12.5 x 300 (3.8 x 91)
Roll Area	yd² (m²)	417 (348)

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FGS000021
ETQR20

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B. TenCate FW402 woven

TENCATE Mirafi

TENCATE GEOSYNTHETICS
Americas

Mirafi® FW402

Mirafi® FW402 is composed of high-tenacity monofilament polypropylene yarns, which are woven into a stable network such that the yarns retain their relative position. Mirafi® FW402 geotextile is inert to biological degradation and resists naturally encountered chemicals, alkalis, and acids

TenCate Geosynthetics Americas Laboratories are accredited by Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP). NTPEP Listed

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
			MD	CD
Grab Tensile Strength	ASTM D4632	lbs (N)	365 (1624)	200 (890)
Grab Tensile Elongation	ASTM D4632	%	24	10
Trapezoid Tear Strength	ASTM D4533	lbs (N)	115 (512)	75 (334)
CBR Puncture Strength	ASTM D6241	lbs (N)	675 (3004)	
			Minimum Roll Value	
Percent Open Area	COE-02215	%	10	
Permittivity	ASTM D4491	sec^{-1}	2.1	
Flow Rate	ASTM D4491	gal/min/ft² (l/min/m²)	145 (5907)	
			Maximum Opening Size	
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	40 (0.425)	
			Minimum Test Value	
UV Resistance (at 500 hours)	ASTM D4355	% strength retained	90	

Physical Properties	Unit	Roll Size
Roll Dimensions (width x length)	ft (m)	12.5 x 300 (3.8 x 91)
Roll Area	yd² (m²)	417 (348)

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C. TenCate FW404 woven

TENCATE Mirafi®

TENCATE GEOSYNTHETICS
Americas

Mirafi® FW404

Mirafi® FW404 is composed of high-tenacity monofilament polypropylene yarns, which are woven into a stable network such that the yarns retain their relative position. Mirafi® FW404 geotextile is inert to biological degradation and resists naturally encountered chemicals, alkalis, and acids

TenCate Geosynthetics Americas Laboratories are accredited by Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP). NTPEP Listed

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
			MD	CD
Grab Tensile Strength	ASTM D4632	lbs (N)	400 (1780)	315 (1402)
Grab Tensile Elongation	ASTM D4632	%	15	15
Trapezoid Tear Strength	ASTM D4533	lbs (N)	150 (668)	165 (734)
CBR Puncture Strength	ASTM D6241	lbs (N)	1150 (5118)	
			Minimum Roll Value	
Percent Open Area	COE-02215	%	1.0	
Permittivity	ASTM D4491	sec^{-1}	0.9	
Flow Rate	ASTM D4491	gal/min/ft^2 (l/min/m^2)	70 (2852)	
			Maximum Opening Size	
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	40 (0.425)	
			Minimum Test Value	
UV Resistance (at 500 hours)	ASTM D4355	% strength retained	90	

Physical Properties	Unit	Roll Size
Roll Dimensions (width x length)	ft (m)	15 x 300 (4.57 x 91.4)
Roll Area	yd^2 (m^2)	500 (418)

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D. TenCate FW700 woven

TENCATE
Mirafi®

TENCATE GEOSYNTHETICS
Americas

Mirafi® FW700

Mirafi® FW700 geotextile is composed of high-tenacity monofilament polypropylene yarns, which are woven into a stable network such that the yarns retain their relative position. Mirafi® FW700 geotextile is inert to biological degradation and resists naturally encountered chemicals, alkalis, and acids.

TenCate Geosynthetics Americas Laboratories are accredited by Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP). NTPEP Listed

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
			MD	CD
Grab Tensile Strength	ASTM D4632	lbs (N)	370 (1647)	250 (1113)
Grab Tensile Elongation	ASTM D4632	%	15	15
Trapezoid Tear Strength	ASTM D4533	lbs (N)	100 (445)	60 (267)
CBR Puncture Strength	ASTM D6241	lbs (N)	950 (4228)	
			Minimum Roll Value	
Percent Open Area	COE-02215	%	4	
Permittivity	ASTM D4491	sec^{-1}	0.28	
Flow Rate	ASTM D4491	$gal/min/ft^2$ ($l/min/m^2$)	18 (733)	
			Maximum Opening Size	
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	70 (0.212)	
			Minimum Test Value	
UV Resistance (at 500 hours)	ASTM D4355	% strength retained	90	

Physical Properties	Unit	Roll Size
Roll Dimensions (width x length)	ft (m)	12 x 300 (3.7 x 91)
Roll Area	yd^2 (m^2)	400 (334)

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E. TenCate 160N non-woven

TENCATE Mirafi®

TENCATE GEOSYNTHETICS
Americas

Mirafi® 160N

Mirafi® 160N is a nonwoven geotextile composed of polypropylene fibers, which are formed into a stable network such that the fibers retain their relative position. Mirafi® 160N is inert to biological degradation and resists naturally encountered chemicals, alkalis, and acids. Mirafi® 160N meets AASHTO M288 Class 2 for Elongation > 50%.

TenCate Geosynthetics Americas Laboratories are accredited by Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP). NTPEP Listed

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
			MD	CD
Grab Tensile Strength	ASTM D4632	lbs (N)	160 (712)	160 (712)
Grab Tensile Elongation	ASTM D4632	%	50	50
Trapezoid Tear Strength	ASTM D4533	lbs (N)	60 (267)	60 (267)
CBR Puncture Strength	ASTM D6241	lbs (N)	410 (1825)	
			Maximum Opening Size	
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	70 (0.212)	
			Minimum Roll Value	
Permittivity	ASTM D4491	sec^{-1}	1.5	
Flow Rate	ASTM D4491	$gal/min/ft^2$ ($l/min/m^2$)	110 (4481)	
			Minimum Test Value	
UV Resistance (at 500 hours)	ASTM D4355	% strength retained	70	

Physical Properties	Unit	Roll Size
Roll Dimensions (width x length)	ft (m)	15 x 300 (4.5 x 91)
Roll Area	yd^2 (m^2)	500 (418)

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