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Evaluation of ALDOT Ditch Check Practices using Large-Scale Testing Techniques

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EXECUTIVE SUMMARY

Linear construction typically uses drainage conveyances, such as roadside ditches, to convey stormwater runoff away from construction sites to receiving waters. This can expose these receiving waters to polluted runoff if channels are unstabilized giving way to erosive shear stresses in high velocity channelized flow. Therefore, best management practices, such as ditch checks, are used to help reduce channel erosion caused by high velocity flow while propagating sediment deposition within the channel.

The Auburn University Erosion and Sediment Control Testing Facility (AU-ESCTF) was used to evaluate and improve various ditch check practices' performance using large-scale, channelized flow techniques to assist the Alabama Department of Transportation (ALDOT) in better maximizing ditch check performance in the field. One control test and five different types of ditch check practices were evaluated. The five different ditch check practices were: (1) *wattles*, (2) *rip rap*, (3) *sand bags*, (4) *silt fence*, and (5) *stacked wattles*. Recommendations on installation modifications for each ditch check practice based upon testing results were made to better enhance the practices' capabilities.

A metric or limit is required to properly evaluate ditch check practices and manufactured products as a means for determining acceptable performance levels. Flow, geometry, and sediment conditions can vary and make comparative analyses difficult. Therefore, as part of this study, a hydraulic based performance metric was also devised. This hydraulic criteria is based on by the capabilities of a ditch check to slow flow velocity and create subcritical water depths. Using the ratio of water depth (y) to specific energy (E), the average hydraulic performance of the impoundment created by a ditch check can be measured and compared to other ditch check products and practices. When the Froude number is plotted against the y/E ratio for the same flow and channel conditions, a third order polynomial is created with an inflection that occurs at y/E of 0.75 which provides an objective threshold that may be used to determine ditch check performance and effectiveness.

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CHAPTER 1: INTRODUCTION & TESTING METHODOLOGY

1.1 INTRODUCTION

The construction of roadways typically consists of mass clearing and grading leaving many site areas unstable, lacking ground cover to protect against rainfall induced erosion. As linear roadway projects progress, unstabilized areas (i.e., roadbeds, cut and fill slopes, and other embankments) tend to be highly compacted thereby reducing infiltration. This may increase sediment-laden surface stormwater runoff from these unstabilized areas. Stormwater runoff from unstabilized grading operations on construction sites can yield sediment losses of 35 to 45 tons/acre (13 to 16.5 tonnes/hectare) per year (*1*). Eroded sediment from construction sites is one of the most harmful pollutants to the environment resulting in over 80 million tons (73 million tonnes) of sediment washing from construction sites into surface water bodies each year (*2*). In linear construction, stormwater runoff is typically diverted to a series of constructed stormwater conveyances (i.e., berms, swales, and ditches), which may also be unstabilized prior to vegetative establishment. Therefore, runoff control measures must be installed to minimize channel erosion, especially during peak periods of a storm event. Stormwater runoff control is the practice of managing concentrated flows and reducing peak runoff caused by modification of the site topography.

Ditch checks, which are runoff controls, are defined as either permanent or temporary structures constructed across runoff conveyances, intended to slow and impound stormwater runoff, reduce shear stresses that cause channel erosion, and create favorable conditions for sedimentation (*3*, *4*, *5*, *6*, & *7*). A wattle, which may be used as a ditch check or slope intercept device depending on site-specific requirements, is a manufactured, tubular device composed of natural or synthetic fillers (i.e., compost material, wheat straw, excelsior [wood shaving], coir, carpet fiber, or recycled rubber tires) encased in a natural fiber or synthetic netting. The advantages of using wattles as ditch checks, over other types of ditch checks (i.e., rock, hay bales, silt fence, etc.) include: (1) its biodegradability, (2) typically lightweight, (3) ease of installation using minimum resources, (4) economical, and (5) available in various dimensions making them adaptable to site specific constraints. Some limitations of using wattles as ditch checks include: (1) their elliptic shape may reduce surface area available for ground contact with the channel resulting in undermining and scour, and (2) the potential for lightweight wattles becoming buoyant, reducing adequate ground contact while subjected to concentrated flows.

Controlling erosion and sediment transport on construction sites has been deemed a top priority for environmental agencies such as the US Environmental Protection Agency (EPA) and the Alabama Department of Environmental Management (ADEM). Maximizing erosion and sediment control practices on construction sites has been the focus of this research study for the Alabama Department of Transportation (ALDOT). The use of ditch checks has been widely used on ALDOT construction sites and a need arose for determining the optimal practice and installation procedures for each ditch check.

Ditch checks are obstructions placed in paths of concentrated, channelized flows which impound water. This water impoundment creates subcritical, low velocity pools which reduce channel shear stress and channel erosion. In addition to impounding water and reducing erosion due to shear stresses, ditch check installations must also withstand hydrodynamic pressure force in the front face of the ditch check, uplift forces underneath a practice, while maintaining overall structural integrity without a major failure. Determining the most effective and feasible installation for various standard ditch check practice is the primary objective of these research.

The purpose of this final report is to summarize the results of performance testing conducted on various ditch check installations and provide recommendations for implementation and use on ALDOT projects. The various ditch checks tested include: (1) wattles, (2) rip rap, (3) sand bags, (4) silt fence, and (5) a stacked wattle installation. Each ditch check installation was tested using field-scale, replicable test protocols.

1.2 BACKGROUND

The spacing requirements for ditch checks is based upon the height of the ditch check and channel slope. Shallower channels will allow greater ditch check spacing while steeper channels require shorter spacing for ditch checks of the same height. Also, taller ditch checks will require longer spacing when compared to shorter ditch checks used for the same longitudinal slope. This concept is shown in Figure 1.1. ALDOT places a minimum ditch check spacing of 100 ft (*4*).

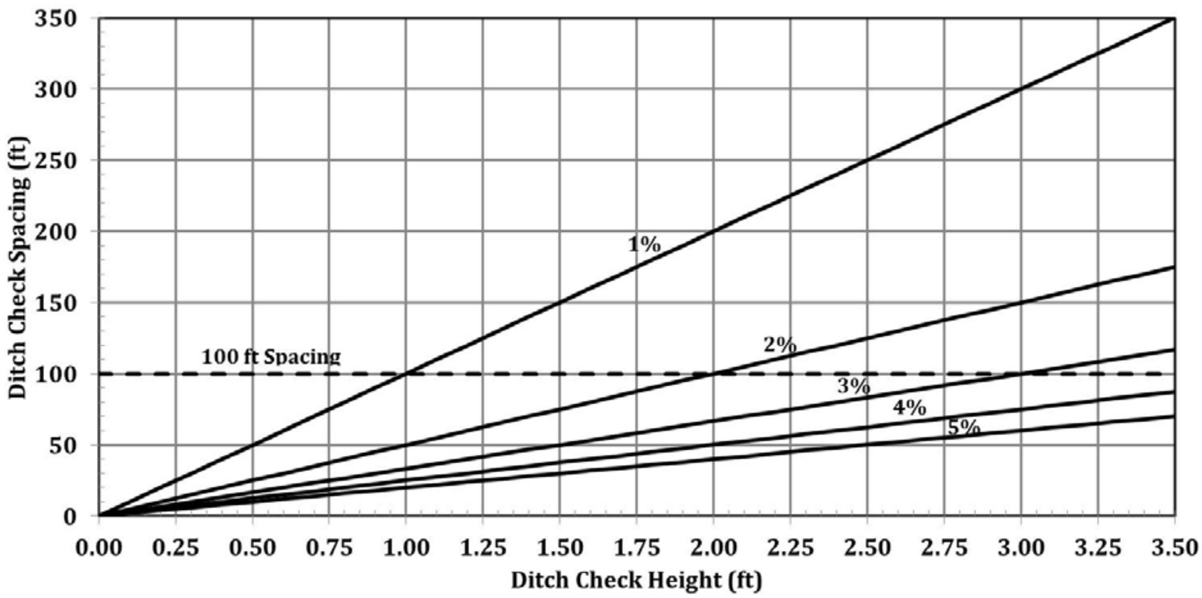


Figure 1.1: Ditch Check Spacing Based Upon % Long. Slope and Ditch Check Height

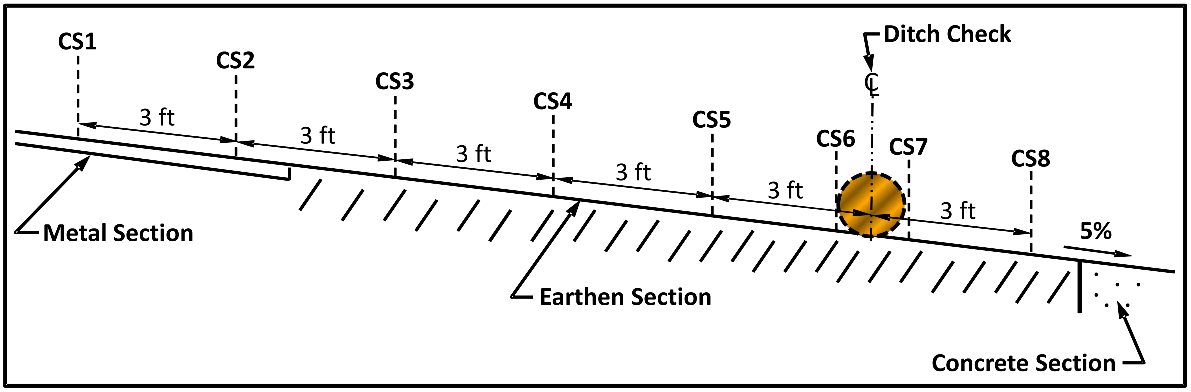
1.3 TESTING METHODOLOGY

All tests conducted as part of this research were performed at the Auburn University Erosion and Sediment Control Facility (AU-ESCTF) located at the National Center for Asphalt Technology (NCAT) in Opelika, AL. To properly evaluate the affect various installation configurations have on wattle performance, the same wheat straw wattle manufacturer and type were used for all tests performed.

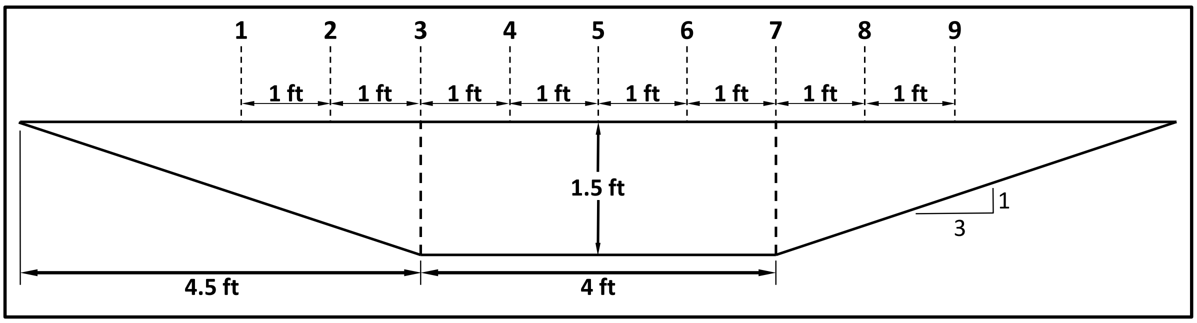
The standard test method referenced for the development of the testing methodology used in this study was ASTM D 7208-06: *Standard Test Method for Determination of Temporary Ditch Check Performance in Protecting Earthen Channels from Stormwater-Induced Erosion* (*7*).

1.3.1 Test Channel

The AU-ESCTF has a test channel dedicated to performance testing of ditch checks in concentrated flow applications and is shown in Figure 1.2(a) and (b).



(a) Elevation View



(b) Cross-Sectional View

Figure 1.2: Ditch Check Test Channel Dimensions and Configuration.

The ditch check testing channel has a trapezoidal cross section with a top width of 13 ft (4 m) and a bottom width of 4 ft (1.2m) with 3H:1V side slopes. The depth of the channel is 1.5 ft (0.5 m) and is 39.5 ft (12 m) long. The channel is divided into a galvanized steel plated section 24.5 ft (7.5 m) long and an earthen section 15 ft (4.6 m) long. The longitudinal slope of the channel is 5%. The earthen section allowed for field quality installations and performance observations of the ditch checks. The metal lined portioned allowed the ditch checks to be tested and evaluated regardless of channel performance.

1.3.1.1 Preparation of the Test Channel

Before each test, the 15 ft (4.6 m) earthen section is tilled using a rear tine tiller, hand raked, hand tamped, and then mechanically compacted using an upright rammer hammer with a compaction plate of 14 x 11.5 in. (36 x 29 cm), a blow count of 600 blows/minute and a compaction force of 2,700 lbs (1,225 kg). The soil within the earthen section was classified as a poorly graded sand using the USGS Soil Classification System. The maximum density of 123.8 lbs/ft^3 (19.44 kN/m^3) was determined by the method described in ASTM D698-07, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort* (*12*). In-place density samples were taken with a density drive hammer and thin walled Shelby tubes to verify that at least 95% +/- 2% compaction was achieved.

1.3.2 Constant Flow Test

The test for wattle installation evaluations for this study used a sustained, constant flow of 0.56 cfs (16 L/s) of clean water for a duration of 30 minutes. Prior to testing, eight level string lines were stretched across the channel at 8 cross-sectional (CS) locations (Figure 1.2(a): CS-1 to CS-8), six upstream and two downstream of the ditch check. The measurement points were spaced 1 ft (0.3 m) apart along each string line. These string lines were used to take water depth and velocity measurements at points 4, 5 and 6 in Figure 1.2(b) during each test.

1.3.3 Installation Evaluation Regime

A series of constant flow, large-scale ditch check experiments were performed to evaluate each installation configuration of the various types of ditch check practices. These were done to comparatively analyze the various ditch check installation configurations for: wattles, rip rap, sand bags, silt fence, and stacked wattle practices. For each installation configuration, including the control with no ditch check installed, three replicate tests were performed, totaling 74 large-scale experiments.

1.3.4 Data Collected

Once steady-state flow conditions were achieved, water depth and velocity measurements were taken at cross sectional measurement points 4, 5, and 6 for every cross section (CS1-CS8) shown in Figure 1.2(a) and (b). These points were averaged to determine the average water depth and average velocity for each cross section. The distance from the upstream face of the wattle to the hydraulic jump was also recorded once steady state conditions were achieved to determine subcritical flow length created by the installation's ability to impound water.

Using the collected data, the slope of the energy grade line (*EGL*) for the water profile was plotted as specified by ASTM D 7208-06. The EGL is defined by Equation 1.1 (*7*).

$$EGL = WSE + v^2/2g \qquad \text{(EQ. 1.1)}$$

where,

EGL = energy grade line (ft)
WSE = water surface elevation (ft)
v = average water velocity (ft/sec)
g = gravitational constant (32.2 ft/sec^2)

The slope of the EGL for long, unimpeded, continuous flow channels should closely mimic the channel slope. When the channel is impeded (e.g., by a ditch check), the slope of the EGL within the impoundment area becomes smaller than the channel slope as ponding depths increase towards the ditch check. The potential energy built up by the subcritical flow is returned to kinetic energy as the impounded water goes under, through and/or over the ditch check.

In addition, the specific energy was also determined from the velocity and water depth measurements. Specific energy is defined by Equation 1.2.

$$E = y + v^2/2g \qquad \text{(EQ. 1.2)}$$

where,

E = specific energy (ft)
y = water depth (ft)
v = average water velocity (ft/sec)
g = gravitational constant (32.2 ft/sec^2)

Previous product and practice evaluations have relied upon evaluating the length of impoundment pools and the slope of the energy grade line created by the flow interruption of the ditch checks. Though ASTM D 7208 requires plotting the slope of the energy grade line, there are no discussion or instructions for interpreting the fitted line. Therefore, AU-ESCTF has proposed a different evaluation tool for ditch checks. Using the water depth and specific energy, a ratio of y/E yields a metric that can be used to evaluate overall performance when this value is compared to the theoretical function of y/E vs the Froude number. The Froude number is shown in Equation 1.3.

$$Fr = \frac{v}{\sqrt{gD}} \qquad \text{(EQ. 1.3)}$$

where,

Fr = Froude number
v = average velocity measured for each cross section (ft/sec)
g = acceleration due to gravity (32.2 ft/sec^2)
D = hydraulic depth (ft)

The function created by y/E and Fr is a 3rd order polynomial with an inflection point that occurs at approximately y/E = 0.75. This inflection point designates the change in flow behavior of the channelized flow that is restricted by the ditch check. Measurements were taken at 3 ft intervals for 15 ft upstream of the ditch check to determine an average ratio of y/E. Using the location of the inflection point occurring in the function for the Froude number and y/E ratio, a minimum criteria of y/E equal to 0.75 was identified as the point at which the hydraulic behavior changes from velocity driven flow to depth dominated flow. Refer to '*Chapter 7: Performance Criteria'* for a more complete discussion and analysis of this criteria.

1.4 CONTROL TEST

A bare soil control test was performed that consisted of the channel being graded and compacted to experimental specifications without a ditch check installed. This test establishes a baseline for flow velocities and water depths under supercritical flow conditions (i.e., no impedance of flow) at each cross section (CS1-CS8) as shown in Figure 1.2(a).

1.5 ORGANIZATION OF FINAL REPORT

This final report is divided into seven chapters. *Chapter Two: Wattle Ditch Checks* examines large-scale ditch check testing used to evaluate the effects improving various wattle installation configurations have on wattle performance. *Chapter Three: Rip Rap Ditch Checks*, evaluates rock ditch checks, with and without chokers, to determine which installation will result in the greatest impoundment, and thereby protect the earthen channel from the greatest amount of stormwater induced erosion. *Chapter Four: Sand Bag Ditch Checks*, discusses and outlines the installation configuration modifications made to sand bag ditch checks to an effort to improve the performance and structural integrity of the practice. *Chapter Five: Silt Fence Ditch Checks* outlines the methods developed to improve the overall structural integrity of silt fence ditch checks while minimizing failure possibilities when used in channelized flow applications. *Chapter Six: Stacked Wattle Ditch Checks* focuses on using the newly adopted standard wattle ditch check installation, developed from wattle testing, to test and developed recommendations for a stacked wattle installation configuration. Chapters 2 through 6 focused on evaluating ALDOT's current ditch check installation practices, and developed enhancements for increasing the ditch checks performance capabilities. Recommendations based upon performance and feasibility are made for each ditch check practice evaluated. *Chapter Seven: Performance Criteria* provides a method for ALDOT to use when evaluating various ditch check practices and products for comparing overall performance and ability to function as a ditch check. The devised performance criteria will assist practitioners in developing approval/rejection criteria for products and practices submitted for consideration in the future.

CHAPTER 2: WATTLE DITCH CHECKS

2.1 INTRODUCTION

A literature review was performed to determine relevant studies focusing on various wattle ditch check applications and evaluations of overall performance. Several state highway agencies (SHAs) standard ditch check practices were investigated to determine various wattle installation practices. McEnroe and Treff (*8*) state that success or failure of ditch checks often relies upon location, placement, installation, and maintenance practices employed on construction sites. This is especially true for wattles since most are not manufactured with dedicated anchors to aid in securing them in place. Therefore installing wattles capable of impounding water, slowing runoff velocity, reducing channel erosion, and allowing for sedimentation to occur is important. Unfortunately there is a lack of relevant research published on the performance of wattles based upon installation practices. Many highway departments, municipalities, and manufacturers have installation details and recommendations, typically developed based on field evaluations and trial-and-error. However, McLaughlin et al. (*9*) states, "field testing of existing and new sediment and erosion control products or systems has been problematic when conducted on active construction sites. Uncertainty about runoff quantity and quality due to weather patterns and construction activities makes objective, replicated experiments very difficult." Therefore a need exists for evaluating the installation of ditch checks using large-scale experimental testing procedures to gain an understanding of performance while attempting to make improvements.

2.1.1 Field Evaluations of Ditch Check Performance

McEnroe and Treff (*8*) performed a qualitative study, based on field observations, investigating the effectiveness of Kansas Department of Transportation's (KDOT) temporary erosion and sediment control measures. The practices evaluated included silt fence and hay bales used as ditch checks, perimeter controls, and inlet protection devices. The qualitative performance of these measures was based on: preventing erosion, sediment capture, prevention of off-site sediment migration, observed failure modes, and whether improvements could be made making the controls more effective and less expensive. The majority of failures observed were caused by improper implementation with design and placement, use of substandard materials, and lack of attention to detail. Field personnel indicated that errors may be attributed to a basic misunderstanding of how erosion and sediment control practices are intended to perform. From this, the authors concluded that the success of these practices is largely dependent on installation and maintenance practices.

As a result of their research, McEnroe and Treff (*8*) implemented several new ditch check practices for field evaluation to compare against hay bale ditch checks including a Triangular Silt Dike™ (TSD), rock ditch checks, and bio-logs. A TSD is a triangular polyurethane foam insert wrapped in geotextile fabric with a geotextile fabric apron sewn to the bottom. The apron protects the channel from scour upstream and downstream of the TSD. This device was deemed an improvement to current practice due to ease of installation and the aprons ability to protect the channel from scour at the ditch check. Rock ditch checks were also evaluated and recommended for steep sloped channels and/or channels that are conveying high flow rates due to their inherent structurally stability versus hay bale ditch checks. Bio-logs, erosion control blankets (ECBs) rolled up and placed across the ditch span, essentially a primitive type of wattle, were also field evaluated. Bio-logs were deemed ineffective due to extensive undermining.

McLaughlin et al. (*10*) performed a study to evaluate the effectiveness of wattles with and without the use of polyacrylamide (PAM), for reducing sediment and turbidity in runoff water on construction sites while comparing these practices to standard rock check dams. These sites employed small sediment traps constructed of rock ditch checks preceded by sumps and two different wattle types composed of two different materials, coir and wheat straw. One coir wattle was installed for every three wheat straw wattles because the coir wattles were larger, sturdier, and installed in case the wheat straw wattles failed. The coir logs were 12 in. (30 cm) in diameter and 10 ft (3 m) long. The straw wattles were 9 in. (23 cm) in diameter and 10 ft (3 m) long. Both wattles were installed using stakes and sod staples to secure in place. Gaps between the wattles and ground were filled with pieces of ECBs. Channels at site 1 were lined with ECBs due to channel steepness, while site 2 channels were unlined. Excelsior ECB underlays were installed for site 2 wattles, extending 3 ft (1 m) downstream of the wattles to prevent downstream scour.

Even though the primary focus of their research was sediment control performance of ditch check installations, some erosion control observations were noted. McLaughlin et al. (*10*) concluded that wattles performed better in low flow conditions than rock ditch checks while rock ditch checks typically had little to no pool in low flow conditions resulting in upstream channel erosion.

McLaughlin et al. (*10*) concluded that the ideal ditch check spacing has water impounding back up the slope, to the immediate downstream side of the preceding upstream ditch check. Therefore, the spacing is a function of ditch check height (or diameter) and channel slope. This creates a series of subcritical flowing pools that reduce shear force along the channel bottom, reducing channel erosion. Energy is transformed from potential energy (i.e., subcritical flow) back to kinetic energy (i.e., super critical flow) as water flows through, over, and/or under the ditch checks. Since the greatest energy transfers occur at the interface of the wattle and channel bottom, some type of channel armoring is recommended to dissipate energy and maintain channel integrity.

2.1.2 Standard SHA's Wattle Ditch Check Detail

ALDOT's standard wattle installation practice can be found on '*ESC-300 Ditch Check Structures, Typical Applications, and Details*' (*4*) and is shown in Figure 2.1(a) along with NCDOT's standard wattle installation detail in Figure 2.1(b) (*11*).

ALDOT's wattle installation specifies a 20 in. (51 cm) diameter wattle placed perpendicular to flow across a trapezoidal channel. The wattle is to be staked in place by anchoring the stake through the netting. The stakes are to be driven into the ground on the downstream side of the wattle a minimum of 1.5 ft (0.45 m) with a maximum stake spacing of 3 ft (1 m). The detail recommends trenching of wattles if piping under the wattle becomes evident. The main difference in the ALDOT and NCDOT details is the staking pattern and use of an underlay for channel protection. ALDOT's staking method pierces the downstream side of the wattle, making it a destructive staking practice. NCDOT's practice calls for stakes to be driven into the ground on the upstream and downstream side, angled towards the wattle in an A-shape or teepee configuration. This configuration does not pierce the wattle and is considered nondestructive.

Limited research has been conducted on controlled, large-scale testing of ditch checks in channelized applications. No studies were identified that focused on evaluating performance characteristics of various ditch check installations' ability to increase performance. As more temporary ditch check options become available within the industry, determining the most effective installation for each temporary ditch check, such as a wattle, has become increasingly important. The most effective wattle installation has the potential to maximize its ability to reduce channel erosion and create favorable conditions for sediment deposition to occur within the channel.

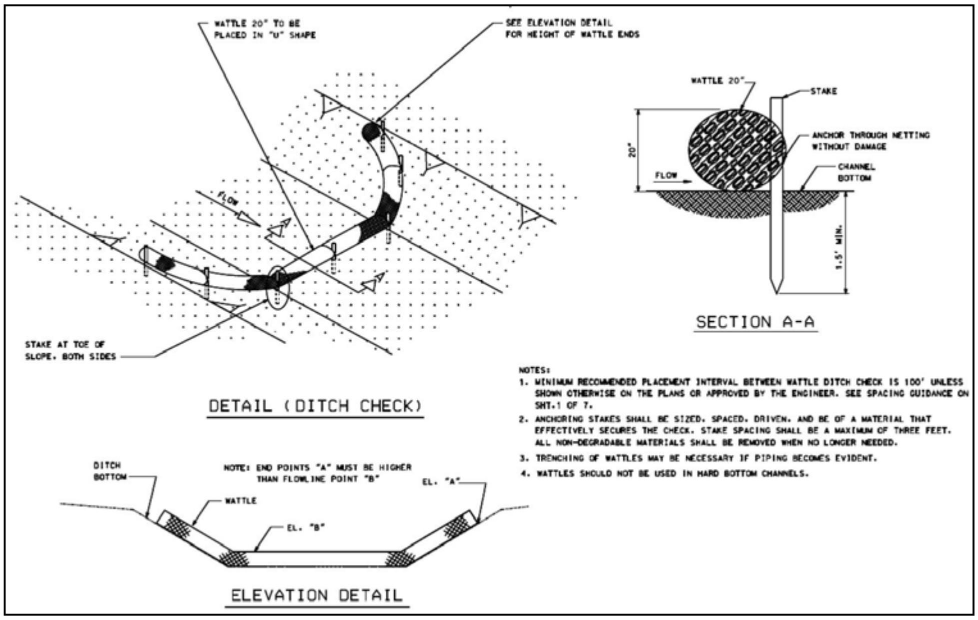
Based on the literature reviewed and a need to further understand wattle performance, field-scale ditch check testing was performed to evaluate the improvement effects various wattle installation configurations have on wattle performance.

2.2 MATERIALS FOR INSTALLATIONS

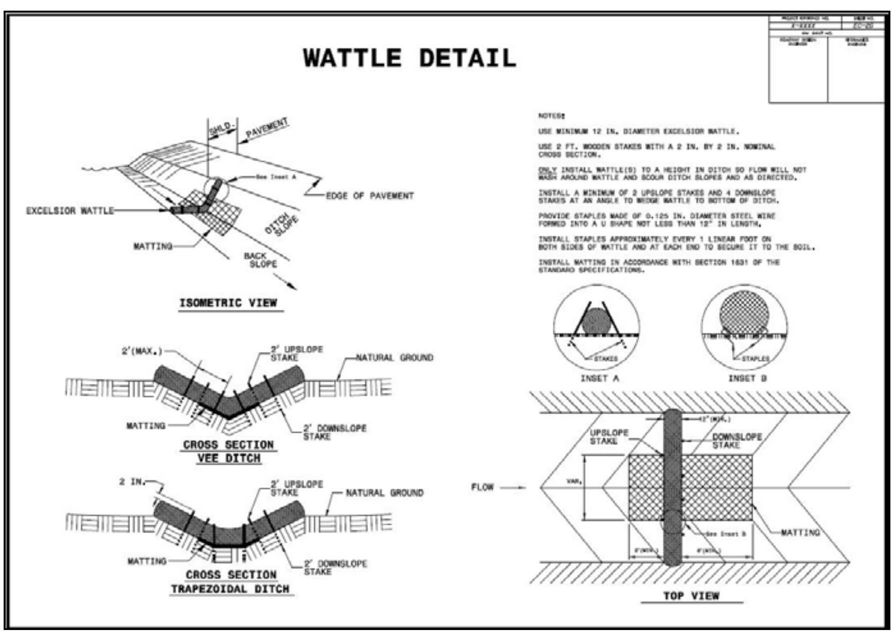
The following is a list of materials used for the various wattle installation configurations:

- <u>*wattle*</u>: 20 in. (50 cm) diameter, 20 ft (6 m) long wheat straw wattle with synthetic netting,
- <u>*wooden stakes*</u>: 1 in. x 2 in. x 3 ft (2.5 cm x 5 cm x 1 m), used to secure the wattle in place,

- *sod staples*: 11 gauge metal, 6 in. long x 1 in. (15 cm x 2.5 cm) wide U-shape staples, used to secure the filter fabric underlay and the wattle, and
- *filter fabric (FF) underlay*: 8 oz. (225 gram), nonwoven FF, 7.5 ft (2.3 m) long, 15 ft (4.6 m) wide. Extends 3 ft (1m) upstream from the upstream face of the wattle and keyed in a minimum of 5 in. (0.13 m) deep in a narrow trench. The fabric underlay extends 3 ft (1 m) downstream beyond the wattle. The trenched end of fabric was firmly tamped to ensure adequate compaction. The upstream and downstream edges of FF were secured with sod staples spaced 10 in. (25 cm) apart and longitudinally along each side and the centerline of the fabric spaced 1.5 ft (0.45 m).



(a) ALDOT Standard Wattle Detail (*4*)



(b) NCDOT Standard Wattle Detail (*11*)

Figure 2.1: Comparison of ALDOT and NCDOT Wattle Installation Practices.

2.3 WATTLE INSTALLATION TESTS

The channel was prepared to experimental specifications for all tests performed on the seven different wattle installation configurations so direct comparisons could be made with the control and various configurations. The following seven wattle installation configurations were tested:

(1) *Downstream Staking*: current ALDOT installation, wattle is placed across the channel in a U-shape, concave upstream, and secured with wooden stakes driven into the ground a minimum of 1.5 ft (0.45 m) and positioned every 2 ft (0.6 m) on the downstream side of the wattle piercing the netting.

(2) *Teepee Staking*: mimicked NCDOT staking practices (Figure 2.1(b)) creating a "teepee" or A-frame over the wattle by driving the stakes into the ground a minimum of 1.5 ft (0.45 m) next to the wattle without piercing the wattle or wattle netting. These stakes were driven in at an angle towards the wattle securing the wattle in place. A minimum of two stakes were installed upstream and a minimum of 5 stakes installed downstream with a maximum stake spacing of 2 ft. (0.6 m).

(3) *Downstream Staking w/8 oz. FF*: wattle was installed with an 8 oz. (225 gram) filter fabric underlay and secured in place using ALDOT staking practices.

(4) *Teepee Staking w/8 oz. FF*: wattle was installed with an 8 oz. (225 gram) filter fabric underlay and secured in place following NCDOT staking practices.

(5) *Downstream Staking w/Trenching*: entire width of the wattle was trenched into channel 2 in. (5.1 cm) deep, perpendicular to the flow of water and anchored using ALDOT staking practices.

(6) Teepee Staking w/8 oz. FF and Trenching: a 2 in. (5.1 cm) deep trench extending the entire width of the wattle was excavated and covered with an 8 oz. (225 gram) filter fabric underlay. The wattle was installed and secured using NCDOT staking practices.

(7) Teepee Staking w/8 oz. FF + Staples (*12*): wattle was installed exactly as described in configuration (4), also securing the bottom of the upstream and downstream face of the wattle to channel using sod staples along each side, spaced 12 in. (0.3 m) apart to improve contact with the channel bottom.

Figure 2.2 provides a photographic comparison of the control set-up and seven installation configurations prior to testing. Figure 2.2 shows the FF underlay that was used to prevent erosion within the channel (Figure 2.2(d), (e), (g), and (h)) and the two staking patterns.

2.4 STATISTICAL ANALYSIS

The statistical analysis method for this study uses a multiple linear regression model to determine the significance of the variables (i.e., wattle installation components). The multiple linear regression model independently evaluates the effect each variable has on increasing the length of impounded water (i.e., length of subcritical flow). The model develops partial regression coefficients that report how strongly that dependent variable (i.e., trenching, stapling, staking, or the underlay) affects the independent variable (i.e., subcritical flow length). The multiple linear regression model used for these analyses is shown in Equation 2.2.

$$f(x) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n \quad (2.2)$$

where,

$f(x)$ = dependent variable (e.g., subcritical flow length or impoundment length)
x_i = independent variables (e.g., trenching, stapling, staking, or the underlay)
β_i = the ordinary least squares coefficients

Using this model, the most effective means of increasing the subcritical flow length can be determined.

(a) Control

(b) Downstream Staking

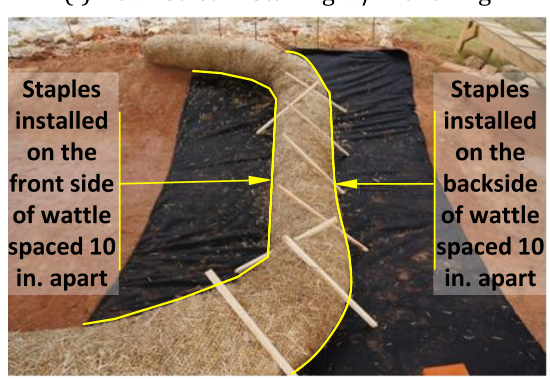
(c) Teepee Staking

(d) Downstream Staking w/8 oz. FF

(e) Teepee Staking w/8 oz. FF

(f) Downstream Staking w/Trenching

(g) Teepee Staking w/8 oz. FF + Trenching



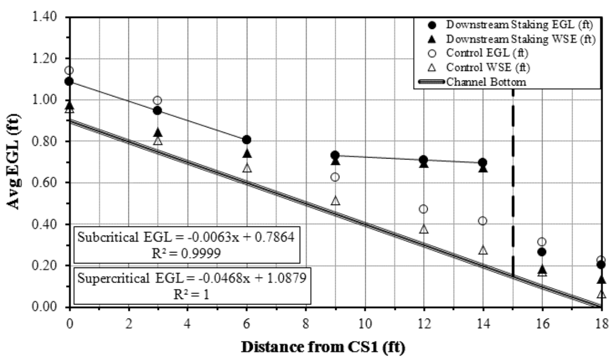
(h) Teepee Staking w/8 oz. FF + Staples

Figure 2.2: Control and All Wattle Installations Tested.

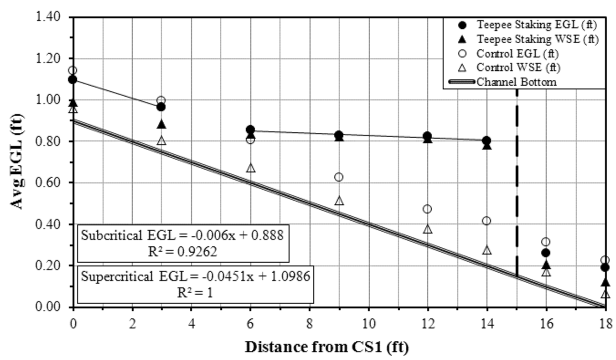
2.5 RESULTS AND DISCUSSION

The following section is a summary of the results and comparisons that were made from the experiments using a 0.56 cfs constant flow rate for all large-scale tests performed.

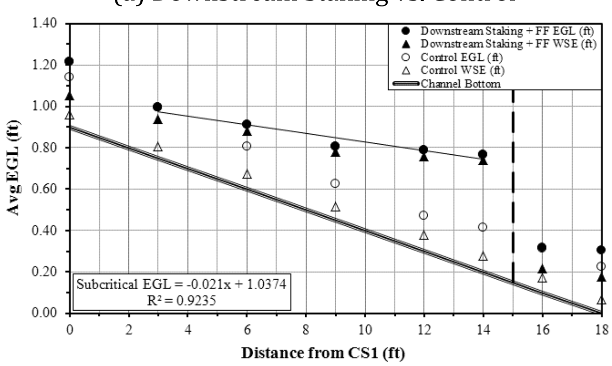
The current ALDOT installation practice, referred to as *Downstream Staking*, is considered a destructive installation practice because stakes pierce and potentially damaging the wattle netting. This staking pattern was tested and compared to the nondestructive *Teepee Staking* pattern. Data analysis determined that staking pattern had little effect on the average subcritical flow length when comparing the *Downstream Staking* pattern of 10.3 ft (3.1 m) to the *Teepee Staking* pattern of 10.7 ft (3.3 m). Visual documentation noted that during testing, for both staking patterns, a maximum impoundment length was achieved early, then receded to a shorter steady-state subcritical flow length as the test continued due to excessive undercutting and piping occurring at the interface of the wattle and channel bottom. To prevent the piping effect, the teepee and downstream staking were tested using an 8 oz. (225 gram) filter fabric (FF) underlay that was intended to protect the channel bottom at the wattle installation. The data collected shows that the *Teepee Staking w/8 oz. FF* installation increased subcritical flow length to 16.5 ft (5 m) in comparison to the previously discussed *Teepee Staking* installation. The *Downstream Staking w/8 oz. FF* installation also increased subcritical flow length to 15 ft (4.6 m) when compared to the *Downstream Staking* installation. Note however, that though the FF increased the subcritical flow length for both installations, both subcritical flow lengths were once again similar (i.e. 16.5 ft (5 m) for *Teepee Staking w/8 oz. FF* and 15 ft (4.6 m) for *Downstream Staking w/8 oz. FF*). These installations are each compared to the control (no wattle installation) as shown in Figure 2.3.



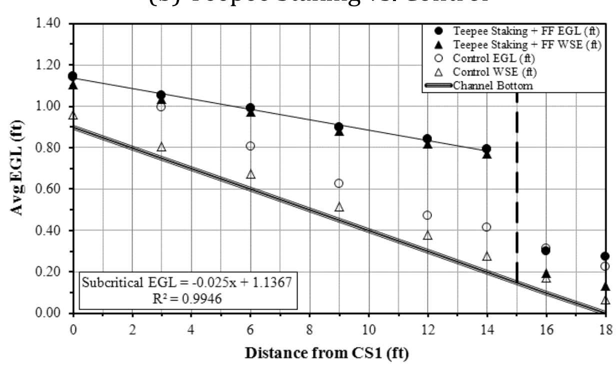
(a) Downstream Staking vs. Control



(b) Teepee Staking vs. Control



(c) Downstream Staking w/FF vs. Control



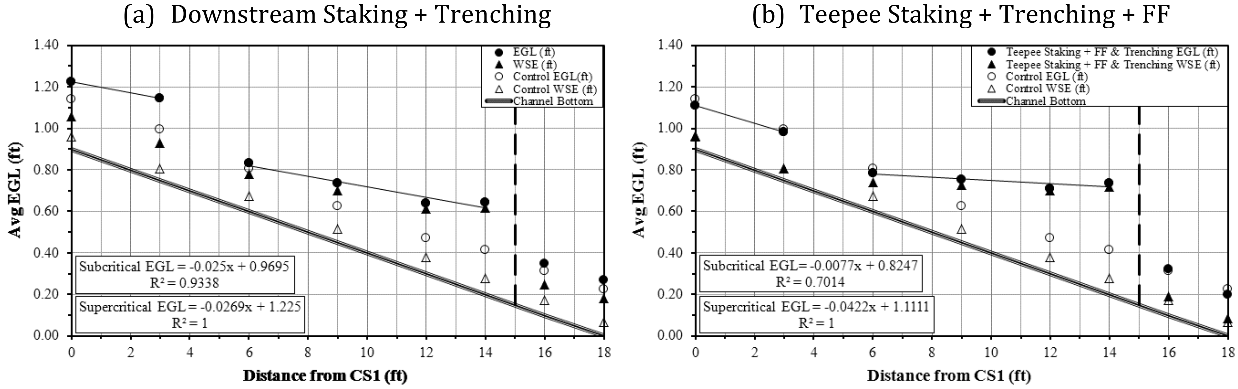
(d) Teepee Staking w/FF vs. Control

Figure 2.3: Comparisons of EGL and WSE for Various Installations.

The EGL and water surface elevation (WSE) are plotted for each. In Figure 2.3(a) and (b), there are two EGLs plotted for each installation. These two EGLs are a result of two different flow conditions (i.e. supercritical or subcritical) that fell within the measurement cross-sections. The upstream EGLs represent supercritical flow. These supercritical EGL points are above the WSE points and indicate higher kinetic energy from greater flow velocity. However, the downstream subcritical flow EGLs show less kinetic energy since the EGL points fall almost directly on top of the WSE points indicating impoundment of flow. This decrease in kinetic energy is the ideal circumstance for channel protection. This impoundment length of subcritical flow increases with the inclusion of the FF underlay.

ALDOT and many manufacturers recommend trenching the wattle if piping becomes evident (*4, 13*). This installation was tested using the *Downstream Staking w/Trenching* installation and resulted in a decrease in impoundment length with an average subcritical flow length of 9 ft (2.7 m) which was 1.3 ft (0.4 m) shorter than the *Downstream Staking* installation alone. Visual documentation also observed piping and scour under the wattle, along with higher amounts of erosion occurring on the downstream side of the wattle due to the trench being washed out as shown in Figure 2.4(a). Anticipating better performance by once again using the FF underlay, the *Teepee Staking w/8 oz. FF and Trenching* was also tested and shown in Figure 2.4(b). However, trenching with FF did not increase performance; rather the average subcritical flow was reduced to 8 ft. (2.4 m) long compared to the *Teepee Staking w/8 oz. FF* impoundment of 16.5 ft (5 m) long. This seems to suggest that trenching reduces the wattle's ground contact with the channel bottom, allowing an easier path for water to flow under the wattle.

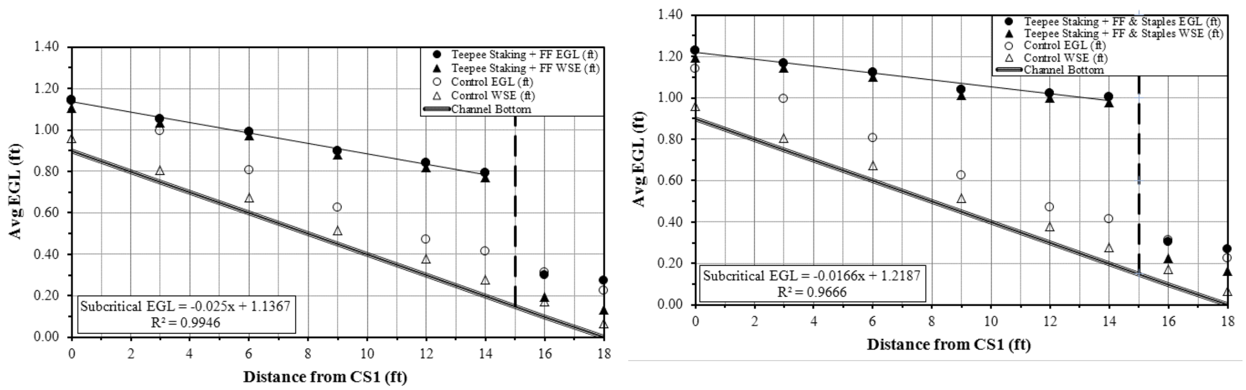
(a) Downstream Staking + Trenching (b) Teepee Staking + Trenching + FF



(c) Downstream Staking + Trenching vs. Control (d) Teepee staking + Trenching + FF vs. Control

Figure 2.4: Test Comparison of Trenched Wattle Configurations.

The final installation tested, *Teepee Staking w/8 oz. FF + Staples,* mimics the NCDOT's wattle detail (*11*). This installation uses a FF underlay, teepee staking, and 12 in. (30 cm) sod staples anchoring the wattle to the channel which is intended to improve ground contact and minimize undercutting. This installation resulted in an average subcritical flow length of 20.5 ft (6.2 m). Figure 2.5 shows the hydraulic results of this test compared to the *Teepee Staking w/8 oz. FF* installation. The inclusion of staples to increase ground contact appears to successfully improve wattle performance as evident by the increase of subcritical flow length and visual observations. Because the sod staples increased ground contact, undercutting was reduced and increased flow was visually noted as flowing through the wattle instead of under. This assumption was further verified by statistical analyses.



(a) Teepee Staking w/FF vs. Control (b) Teepee Staking w/FF + Staples vs. Control

Figure 2.5: Installation Comparison with and without Staples.

The impoundment lengths as well as the EGL slopes are tabulated in Table 2.1. ASTM D7208-06 says to determine the EGL by fitting a regression line through EGL elevation points determined at each cross section (*7*). No further guidance for interpreting or analyzing the data is given. This could be problematic if a hydraulic jump is within the measurement cross sections since steady-state supercritical EGL slopes typically closely match the channel slope while the subcritical EGL slope is flattened out by the impoundment caused by the wattle. Using a single trend-line to mimic the EGL slope across the hydraulic jump would make it inaccurate since the supercritical flow EGL is more affected by the water velocity while the subcritical flow EGL is most affected by WSE or water depth. The only installations that resulted in the hydraulic jump extending beyond the measurement threshold was *Teepee Staking w/8 oz. FF* and *Teepee Staking w/8 oz. FF +Staples (Fig. 6)*. The bare soil control is all supercritical flow. However, evaluating installations based on subcritical flows only can also be problematic because the shorter pool lengths typically have EGL slopes approaching zero (Fig. 4(a) and (b), Fig. 5 (d)). Longer-ponding EGL slopes tend to be steeper sloped which is evident when comparing longer subcritical flows to shorter subcritical flows as shown in Table 2.1. The EGL and WSE should mimic impoundments such as dammed reservoirs or sluices and should have small slopes along the flow direction; instead of the steeper impoundment slopes shown in Figure 2.5. This anomaly may be caused by the complex flows (e.g., three dimensional flow circulations observed during testing) created by undercutting and the wattles porous material. This should be further investigated in a future study.

Table 2.1: Comparative Results of Each Wattle Installation Configuration and the Control.

Treatment	Length of Subcritical Flow (Impoundment)		Energy Grade Line Slopes (ft/ft)	
	Length (ft)	Percent Difference(%)[a]	Based on ASTM D7208[b]	Subcritical Flows Only
Teepee w/8 oz. FF + Staples	20.5	99.0	-0.0166	-0.0166
Teepee w/8 oz. FF	16.5	60.2	-0.0250	-0.0250
Downstream w/8 oz. FF	15.0	45.6	-0.0302	-0.0210
Teepee	10.7	3.9	-0.0197	-0.0060
Downstream	10.3	--	-0.0277	-0.0063
Downstream w/Trenching	9.0	-12.6	-0.0457	-0.0250
Teepee w/8 oz. FF + Trenching	8.0	-22.3	-0.0275	-0.0077
Bare Soil Control	N/A	N/A	-0.0514	-0.0514

Notes: [a] Percent increase/decrease in comparison to the *Downstream Staking* installation;
[b] ASTM D7208-06 EGL slope was a single linear trend line through all EGL points upstream the wattle (including both supercritical and subcritical flow).

2.6 STATISTICAL ANALYSIS RESULTS

A multiple linear regression model was used to determine the effect of the different installation configurations on overall wattle performance. Each of the installations were classified by different combinations of the independent variables considered in the analysis: (1) trenching, (2) underlay, (3) downstream staking, (4) teepee staking, and (5) stapling. For the regression model, the downstream staking pattern was used as the analysis base, from which all other installation components are compared. This was selected because the current ALDOT practice is simply staking the wattle with downstream staking only. The results of this analysis along with corresponding p-values are shown in Table 2.2.

Table 2.2: Statistical Relationships of Installation Components

Installation Component		Statistical Significance	
		Coefficients	p-value[a]
Select 1 Staking Option:	Downstream Staking	Base	--
	Teepee Staking	-0.833	0.389
Select Any Treatments that Apply	Filter Fabric Underlay	3.500	0.002
	Trenching	-4.667	> 0.001
	Stapling	5.583	0.001

Notes: [a] a 99% confidence level was used to establish statistical significance

Using the model in Table 2.2, wattle performance can be determined by creating a representative model. Since teepee staking and downstream staking are not significantly different, either pattern may be used for installation. An installation that uses filter fabric underlay and stapling will see an increase in pool length of 9.083 ft (3.5 + 5.583) based upon the model in Table 2.2. However, including trenching in the installation would result in a reduction of 4.667 ft in pool length.

Based upon these results the following conclusions are made based on statistical significance of the model: (1) because the coefficient for staking is not statistically significant, we can conclude that the staking pattern does not significantly affect the performance of the installation for increasing subcritical flow length, (2) trenching the wattle has a significantly detrimental effect on performance, as evidenced by the negative coefficient, and (3) the underlay and stapling significantly improve performance by increasing the subcritical flow length.

2.7 CONCLUSIONS

As this study has shown, determining the most effective installation is difficult because opinions can vary based on manufacturer recommendations or SHA's standard practices. Reevaluating installation procedures in the field can be risky because installation failure often results in increased erosion along with greater sediment transport. Therefore evaluating wattle installation in a controlled environment helps alleviate risk while providing a more controlled and scientific platform to test various installation configurations.

Evaluating the installations requires determining the greatest mitigating factor that defines the wattles performance as a ditch check. The slope of the EGL is plotted to evaluate the energy reduction of the experimental flow, as kinetic energy (i.e., $v^2/2g$ of the supercritical flow) changes into potential energy (i.e., WSE of the subcritical flow) by the ditch check. However, recognizing that increased impoundment length means increased subcritical flow is also relevant for determining performance. For channelized flow, reducing the erosive forces caused by super critical flows in an earthen channel while also prompting sediment deposition in the subcritical flow area is the ideal scenario. This can be accomplished by maximizing the subcritical flow length, therefore minimizing highly erosive supercritical flows.

One control test and seven different installations were evaluated. The seven installations were: (1) *Downstream Staking*, (2) *Teepee Staking*, (3) *Downstream Staking w/Trenching*, (4) *Teepee Staking w/8 oz. FF and Trenching*, (5) *Downstream Staking w/FF*, (6) *Teepee Staking w/8 oz. FF* and (7) *Teepee Staking w/8 oz. FF + Staples*. Hydraulic evaluation of the tests' results showed that evaluating performance based solely on EGL slope reduction may lead to improper conclusions, especially if the EGL crosses the hydraulic jump. Perhaps a better method for performance evaluation would be to evaluate ditch checks performance based on subcritical flow length.

Using a multiple linear regression model to evaluate the most significant installation component for increasing subcritical flow length, five independent variables were identified and compared. These variables were: (1) trenching, (2) downstream staking, (3) teepee staking, (4) underlay, and (5) stapling. The model showed that the staking pattern did not significantly affect the wattles performance. The model did show that trenching, stapling, and underlay did significantly affect wattle performance with trenching being detrimental to performance and stapling and underlay improving performance. It should also be noted that trenching causes greater erosion downstream and may actually increase the effects of undercutting. Therefore taking the statistical significance into consideration while also looking at the largest increase in subcritical flow length, it is the recommendation of this study that the '*Teepee w/ 8 oz. FF + Staples*' installation be used to install 20 in. diameter wheat straw wattles as ditch checks for maximum stormwater control performance.

2.8 RECOMMENDATIONS FOR IMPLEMENTATION

As a result of this testing effort, the research team's first recommendation is to incorporate the '*Teepee w/ 8 oz. FF + Staples*' installation into the ALDOT Standard Drawings. Based upon the results of the testing, stapling the wattle increased the devices contact with the ground, resulting in a 99% increase in impoundment length in comparison to current standard installation of '*Downstream Staking*' only, and greatly reduced flow velocities upstream of the installation. Both the increased impoundment and a reduction of velocity will maintain the integrity of an earthen channel upstream of the installation which is a desirable outcome. However, during a working group meeting associated with the project, ALDOT representatives stated that it was unlikely that contractor's will include staples to fasten the wattle securely to the ground. The ALDOT representatives also believed it would increase overall inspection efforts of wattle ditch check installations. Therefore, the second recommendation of the research team is to incorporate the '*Teepee w/ 8 oz. FF*' installation into the standard drawings. The '*Teepee w/ 8 oz. FF*' installation resulted in a 60.2% increase in impoundment length in comparison to the current ALDOT standard installation of '*Downstream Staking*' only.

2.9 REFERENCES

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CHAPTER 3: ROCK DITCH CHECKS

3.1 INTRODUCTION

This chapter evaluates rock ditch checks, with and without chokers, to determine which installation will most efficiently create the greatest impoundment, and thereby protect the earthen channel from the greatest amount of stormwater induced erosion.

3.2 BACKGROUND

Rock ditch checks are typically comprised of one or more classifications of aggregate that must be large enough to withstand velocities of concentrated, channelized stormwater runoff while also impounding water. The Alabama Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Sites and Urban Areas, Volume 1, requires the use of ALDOT Class I Riprap with a geotextile underlay to protect the channel from undercutting and piping (*1*). The spacing of ditch checks if they are to be used to maximize performance and minimize erosion, such as riprap ditch checks, are to be no greater than the length of the ditch check's maximum pool length which protects the greatest amount of channel as shown in Figure 3.1.

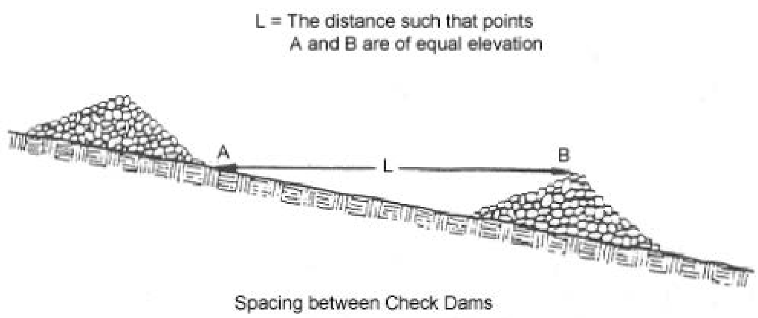


Figure 3.1: Alabama Handbook Recommended Ditch Check Spacing (*1*)

3.3 MATERIALS FOR INSTALLATIONS

The following is a list of materials used for the various riprap installation configurations:

- *ALDOT Class I Riprap*: consist of graded stones ranging from 10 to 100 pounds (5 to 50 kg) with not more than 10% having a weight (mass) over 100 pounds (50 kg) and at least 50% having a weight (mass) over 50 pounds (25 kg) and not over 10% having a weight (mass) under 10 pounds (5 kg) (*4*),
- *ALDOT No. 4 Coarse Aggregate*: consist of graded aggregate ranging from 1.5 in. to ⅜ in. (37.5 to 9.5 mm) with not more than 10 % greater than 1.5 in. (37.5 mm), at least 20-55% 1 in. (25 mm) and no more than 15% smaller than ¾ in. (9.5 mm) (*4*),
- *Sod Staples*: 11 gauge metal, 6 in. long x 1 in. (15 cm x 2.5 cm) wide U-shape staples or 11 gauge metal, 6 in. long x 1 3/8 in. (15 cm x 3.5 cm) round-top sod pin , used to secure the filter fabric underlay, and
- *Filter Fabric (FF) Underlay*: 8 oz. (225 gram), nonwoven FF, 12-20 ft (3.7-6 m) long depending on installation, 15 ft (4.6 m) wide. Extends 3 ft (1m) upstream from the upstream face of the riprap and pinned by two rows of sod staples spaced every 10 inches (25 cm) staggered on center. The fabric underlay extends 3 ft (1 m) downstream beyond the riprap. The

downstream edge of FF was secured with sod staples spaced 10 in. (25 cm) apart. Also pinned longitudinally along each side and the centerline of the fabric spaced 1.5 ft (0.45 m).

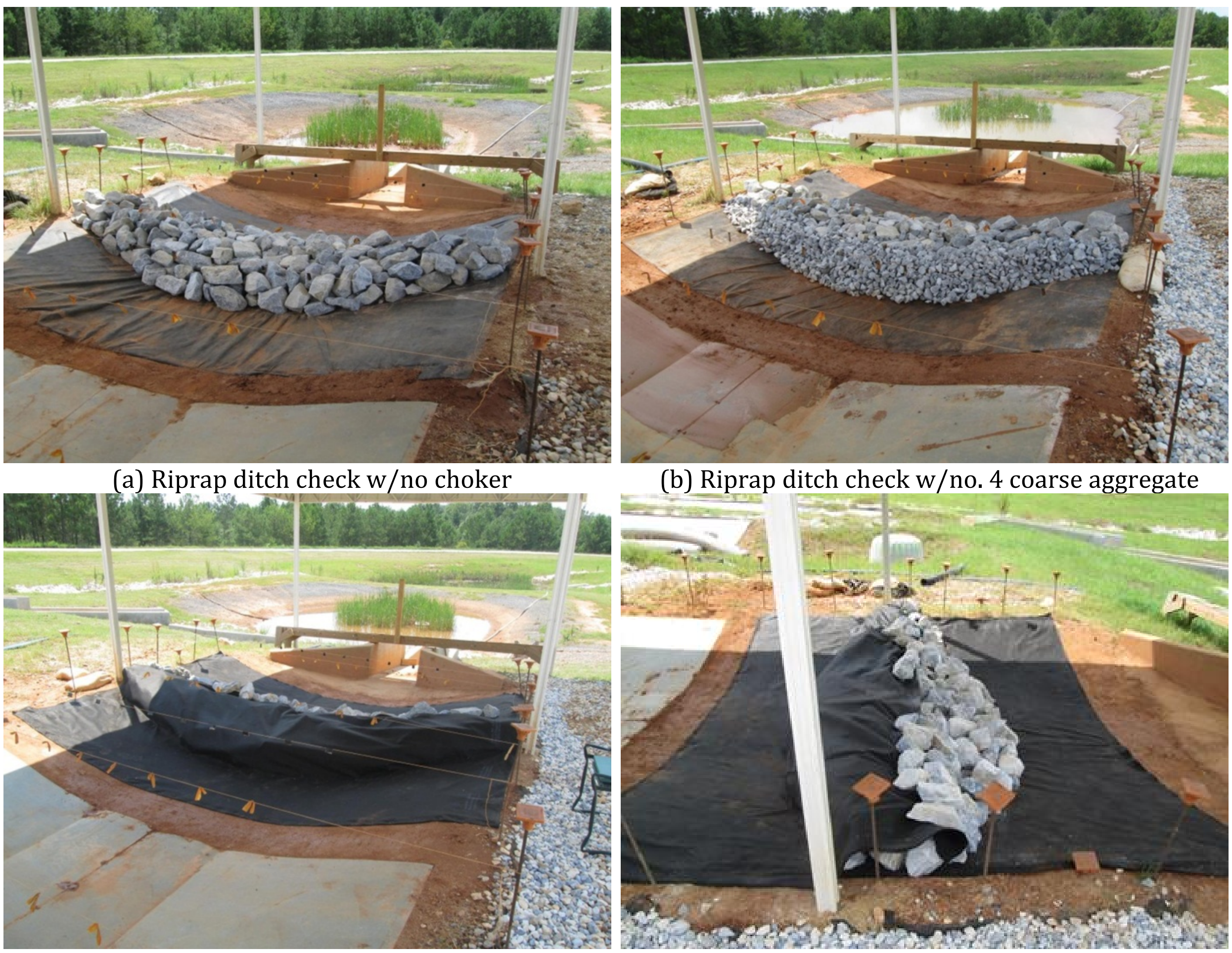
3.4 RIPRAP INSTALLATION TESTS

The channel was prepared to experimental specifications for all tests performed on the three different riprap ditch check installation configurations so direct comparisons could be made between each configuration. The following three riprap installation configurations were tested:

(1) _Riprap Ditch Check w/no Choker_: current ALDOT installation (Figure 3.2(a)), 8 oz. FF underlay extends beyond the toe of the rock slope 3 ft (1 m) upstream and downstream. The height of the ditch check is 18 in. (46 cm) and the base is 9 ft (2.7 m) from upstream to downstream toe of slope with rock slope being 3:1, (*5*)

(2) _Riprap Ditch Check w/ALDOT No. 4 Coarse Aggregate Choker_: installation mimics *Riprap Ditch Check w/no Choker*, however the upstream rock slope face is covered with a layer of ALDOT No. 4 coarse aggregate, as shown in Figure 3.2(b), and

(3) _Riprap Ditch Check w/8 oz. FF Choker_: installation uses an extra 8 ft of filter fabric. The fabric is extended 3 ft upstream of the toe of the slope, pinned and then pulled back downstream to drape over the upstream face of the riprap ditch check, where then riprap is used to secure the fabric in place as shown in Figure 3.2(c) and (d).



(a) Riprap ditch check w/no choker　(b) Riprap ditch check w/no. 4 coarse aggregate

(c) Riprap ditch check w/8 oz. FF choker　(d) 8 oz. FF choker secured w/riprap

Figure 3.2: Riprap Ditch Check Installation Configurations

3.5 RESULTS AND DISCUSSION

The following section is a summary of the results and comparisons that were made from the experiments using a 1.7 cfs (0.048 m^3/s) constants flow rate for all large-scale tests performed. Table 3.1 shows the comparative results of the various riprap installation configurations. Table 3.2, shown in the appendix of Chapter 3, summarizes the individual tests results of each test for the various installation types

Table 3.1: Comparative Results of Each Riprap Installation Configuration

Installation Type	Avg. Pool Length (ft)	% Difference(1)	% Efficiency(2)
Riprap w/No Choker	14.5	N/A	48.3%
Riprap w/No. 4 Coarse Aggregate	20.5	41.4%	68.3%
Riprap w/8 oz. FF Choker	29.1	100%	97.0%

(1) % difference w/respect to riprap w/no choker installation
(2) % efficiency refers % of spacing required for ditch check based on Figure 1.1 in comparison to average pool length

The Riprap w/no Choker installation (Figure 3.3(a)) allows flow to easily pass through the ditch check decreasing possible impoundment length when compared to the two ditch check installations with chokers. Adding ALDOT No. 4 coarse aggregate to the installation as shown in Figure 3.3(b) decreased the flow-through capabilities of the ditch check which therefore increased the impoundment length from 14.5 to 20.5 ft, an increase of 41.4%. Using the 8 oz. FF choker instead of the No. 4 coarse aggregate choker, as shown in Figure 3.3(c), further increased the pool length from 14.5 to 29.1 ft, an increase of 100%. A secondary benefit of using the filter fabric choker is that the fabric restricts flow through the ditch check and causes it to pass over and down the downstream slope of the ditch check as shown in Figure 3.3(d). The flow traveling through the filter fabric and/or over the downstream rock slope acts as further energy dissipation and reducing water velocity through the flow transition. This decreases the velocity of the water as it resumes down the ditch whereas water that flows through the ditch check finds the path of least resistance which are typically small passages which increase water velocity, creating a nozzle affect.

Another secondary benefit of the FF choker is when maintenance action is required as a result of sediment accumulation in front of the upstream face of the ditch check, the FF choker can be cut away from the underlay and replaced, increasing the longevity of the ditch check.

Referring back to Figure 1.1 and Table 3.1, it should be noted that the Riprap w/8 oz. FF Choker installation nearly reaches the expected ditch check impoundment length of 30 ft for an 18 in. (46 cm) tall ditch check in a 5% sloped channel. This means the ditch check was performing at nearly 100% efficiency for creating the greatest impoundment length.

(a) Riprap ditch check w/no choker

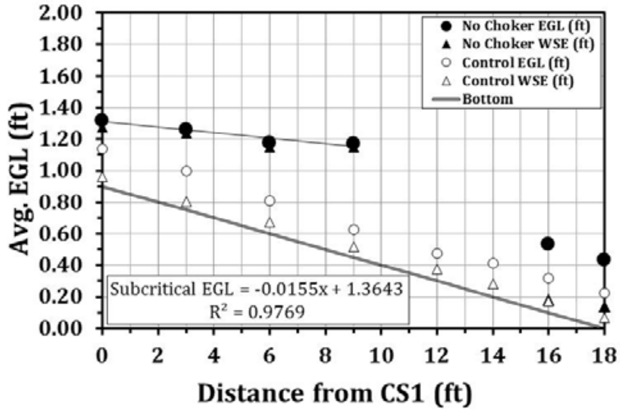
(b) Riprap ditch check w/no. 4 coarse aggregate choker

(c) Riprap ditch check w/8 oz. FF choker

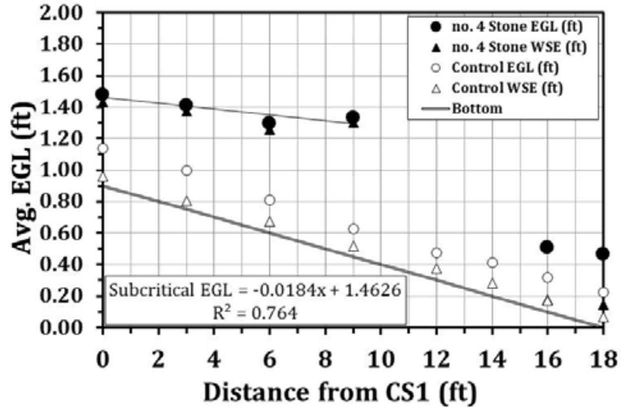
(d) Energy dissipation w/ 8 oz. FF choker

Figure 3.3: Average Performance of Each Riprap Ditch Check Installation

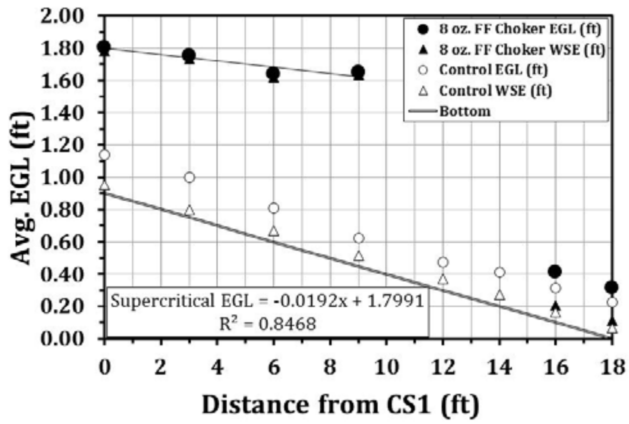
The slope of the EGLs for each installation is shown in Figure 3.4. The graphs depict the average EGL and WSE for all installation experimental replications. The slope of EGL will greatly decrease as flow is impounded and the transition occurs from supercritical to subcritical flow. Though this occurs for each installation, the degree of change varies based upon flow condition. Typically for shorter impoundments, flow is abruptly slowed, creating an EGL that flattens out very quickly near the upstream face of the ditch check. This flattening, in conjunction with a short impoundment length, often times creates an EGL that has a slightly smaller slope than the EGL slope of very long impoundments. Long impoundment lengths do not experience smaller EGL slopes in comparison to shorter impoundments because in these long-impoundment cases flow is affected by the slope of the channel as water flows over the structure instead of through it. When comparing the slope of the EGLs for the rip rap tests, a small increase in the slope of the EGL occurs as the impoundment pool increases for the various installations. These increases are small and still maintain a much smaller EGL slope than that of the unimpeded flow which has an EGL of approximately 0.05 slope which is the approximate slope of the channel. This trend is similar to wattle ditch check installation evaluations whereas the ditch check impoundment lengths increase, a slight increase in EGL slope was also noticed.



(a) Riprap ditch check w/no choker EGL and HGL



(b) Riprap ditch check w/no. 4 coarse aggregated choker EGL and HGL



(c) Riprap ditch check w/8 oz. FF choker EGL and HGL

Figure 3.4: Riprap Ditch Check Choker Comparisons

3.6 CONCLUSIONS

Riprap ditch checks are typically used in high flow, high velocity conditions due to their structural stability to withstand high velocity and flow forces. However, due to the large pores created by the aggregate shape, water has greater passages available for water to pass through the ditch check rather than over which results in decreased impoundment lengths. Choking these pore passages is a means to mitigate this issue and is recommended by ALDOT. ALDOT ESC 300 recommends choking with aggregate to decrease flow through. The AU-ESCTF tested both ALDOT No. 4 coarse aggregate and 8 oz. FF to determine which choker creates the longest impoundment length. The AU-ESCTF has determined that choking the ditch check with 8 oz. FF is a better means of flow impoundment and resulted in an impoundment length of 29.1 ft which was a 100% increase in flow length and a 97% impoundment efficiency in comparison to the riprap ditch check with no choker which impounded water14.5 ft at 48.3% impoundment efficiency. ALDOT No. 4 coarse aggregate impounded flow 20.5 ft which is a 50% increase in impoundment length at a 68.3% impoundment efficiency when also compared to the riprap ditch check with no choker installation.

3.7 RECOMMENDATIONS FOR IMPLEMENTATION

As a result of this testing effort, the research team's recommendation is to incorporate the 'Riprap Ditch Check w/8 oz. FF choker' installation into the ALDOT Standard Drawings. Based upon the results of the testing this installation resulting in a 100% increase in impoundment length in comparison to current standard installation of '*Riprap w/No Choker*', and greatly reduced flow velocities upstream of the installation. Both the increased impoundment and a reduction of velocity will maintain the integrity of an earthen channel upstream of the installation in high flow scenarios, which is a desirable outcome.

3.8 REFERENCES

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3. ASTM Standard D698, 2007, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort,* ASTM International, West Conshohocken, PA, 2007.
4. *Standard Specifications for Highway Construction*, Alabama Department of Transportation (ALDOT), Montgomery, AL, 2012, Sec. 801 & 814, pp. 561 & 577.
5. *ESC-300 Ditch Check Structures, Typical Applications and Details*, Alabama Department of Transportation (ALDOT), Montgomery, AL, 2012, sheets 1 & 6 of 7.

3.9 APPENDIX

Table 3.2: Comparative Results of All Riprap Tests

Installation	Avg Pool Length (ft)	% Difference(1)	% Efficiency(2)	EGL Slope (ft)
No Choker	14.5	N/A	48%	0.0141
	14.5	N/A	48%	0.0165
	14.5	N/A	48%	0.0176
#4 Choker	20.5	41%	68%	0.0192
	20.8	43%	69%	0.0181
	20.7	43%	69%	0.0174
FF Choker	29.2	101%	97%	0.0190
	29.2	101%	97%	0.0193
	29.0	100%	97%	0.0194

(1) % difference w/respect to riprap w/no choker installation
(2) % efficiency refers % of spacing required for ditch check based on Figure 1.1 in comparison to average pool length

CHAPTER 4: SAND BAG DITCH CHECKS

4.1 INTRODUCTION

Sand bag ditch checks are comprised of stacked rows of sand bags placed in channels to intercept flow and decrease runoff velocity. These ditch checks are not secured with stakes or staples, and therefore are ideal for hard bottom channels. Proper spacing of ditch checks within channels is critical to maximize their performance while minimizing the potential for channel erosion to occur. The spacing of ditch checks is to be no greater than the length of the ditch check's maximum pool length, which protects the greatest amount of channel as shown in Figure 4.1.

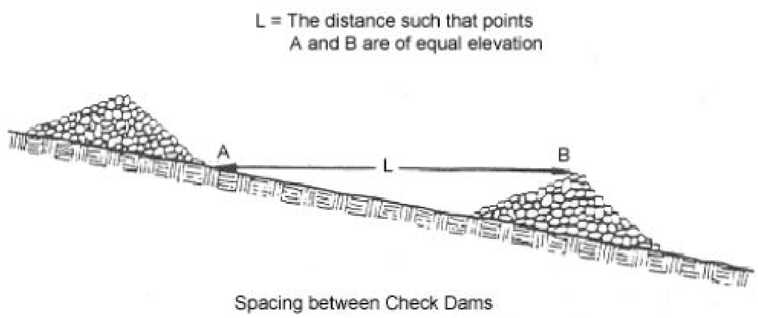


Figure 4.1: Alabama Handbook Recommended Ditch Check Spacing (*1*)

Sand bag ditch checks efficiently impound water at low flow rates due to very low flow through properties of the practice. However, due to the density and structure of the practice, traditional anchoring (i.e., the use of stakes, pins, or sod staples) to secure the practice in place is not practical. Therefore, sand bag ditch checks rely upon gravity and friction to remain in place. This can lead to structural failures when hydrostatic and hydrodynamic forces overcome the frictional force between bags causing bags to dislodge. Therefore, the focus of this testing was directed towards installation improvements for increasing structural stability instead of increasing impoundment lengths.

4.2 MATERIALS FOR INSTALLATIONS

The following is a list of materials used for the various sand bag installation configurations:

- *sand bags*: 19.5 x 12 x 4 in. (49.5 x 30.5 x 10 cm) woven polypropylene bags filled with a sandy soil, stacked in a three layer configuration, oriented dependent upon the particular installation.
- *sod staples and pins*: 11 gauge metal, 6 in. long x 1 in. (15 cm x 2.5 cm) wide U-shape staples or 11 gauge metal, 6 in. long x $1^3/_8$ in. (15 cm x 3.5 cm) round-top sod pin , used to secure the filter fabric, and
- *filter fabric (FF)*: 8 oz. (225 gram), nonwoven FF, 8 ft (2.4 m) long, 15 ft (4.6 m) wide. The edges of FF were secured with sod staples spaced 5 in. (12 cm) apart.

4.3 SAND BAG INSTALLATION TESTS

The channel was prepared to experimental specifications for all tests performed on the three different sand bag ditch check installation configurations so direct comparisons could be made between each configuration. The following three sand bag installation configurations were tested:

(4) *Standard Sand Bag Installation*: current ALDOT installation [Figure 4.2(a)] that consists of two rows of sand bags placed perpendicular to flow, with a second layer of sand bags, also consisting of two rows, stacked on top. A third layer of sand bags is placed in the seam of the sand bag rows. No stakes, pins, or staples are used to secure the bags in place (*5*).

(5) <u>*Sand Bag "Burrito"*</u>: sand bags are placed on a section of filter fabric approximately 8 ft by 15 ft (2.4 m x 4.6 m) using the same configuration as the "standard sand bag installation." The bags are wrapped with the fabric, tucking the edge under the bags on the downstream side as shown in Figure 4.2(b),

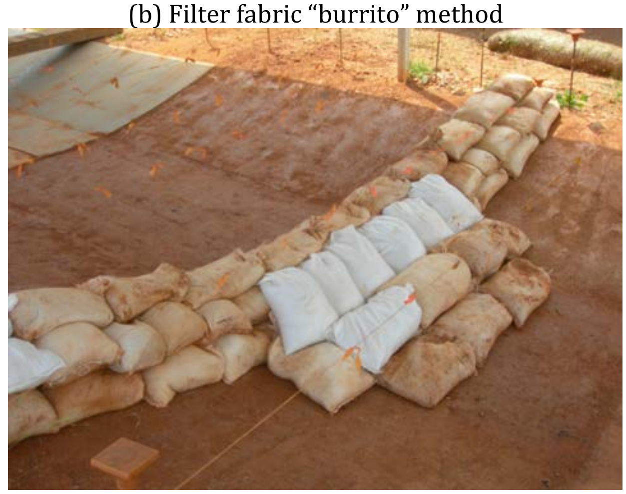
(6) <u>*Sand Bag Orientation Modification*</u>: installation modifies the "standard sand bag installation" by reorienting the middle layer of bags 90° as shown in Figure 4.2(c). Both rows of the middle layer of sand bags are reoriented into one row by placing the bags across the bottom layer of bags parallel with the flow while the bottom and top layers are oriented perpendicular to flow. Due to the impoundment capabilities of the sand bags, which minimized undercutting, the filter fabric underlay was removed from the installation to determine if it was necessary for this installation in an effort to minimize cost and installation time.

(7) <u>*Sand Bag Orientation Modification w/ Support Bags*</u>: installation modifies the "sand bag orientation modification" by adding support bags on the downstream side of the ditch check. Eighteen support bags are placed on the downstream side of the ditch check to reinforce the middle bags located along the 4 ft channel bottom as shown in Figure 4.2(d).

(a) ALDOT standard installation

(b) Filter fabric "burrito" method

(c) Reorientation of middle sand bag layer



(d) Addition of downstream support bags

Figure 4.2: Sand Bag Ditch Check Installation Configurations

4.4 RESULTS AND DISCUSSION

The following section is a summary of the results and comparisons that were made from the experiments using flows of 0.56, 1.12, and 1.68 cfs (0.016, 0.032, and 0.048 m^3/s). Table 4.1: Comparative Results of Each Sand Bag Installation Configuration shows the comparative results of the impoundments resulting from the various sand bag installation configurations. The burrito method produced the longest impoundment, which would be expected since the filter fabric would restrict flow-through, forcing the impoundment to overtop. Table 4.2, shown in the appendix of Chapter 4, summarizes the individual tests results of each test for the various installation types

Table 4.1: Comparative Results of Each Sand Bag Installation Configuration

Installation Type	Avg. Pool Length (ft)			Avg. % Efficiency(1)
	0.56 cfs	1.12 cfs	1.68 cfs	
Standard ALDOT	29.0	*failed*	*failed*	N/A
Burrito Method	32.7	33.2	33.5	109%
Orientation Modified	29.2	29.5	*failed*	98%
Support Bag Modified	29.0	29.5	30.8	99%

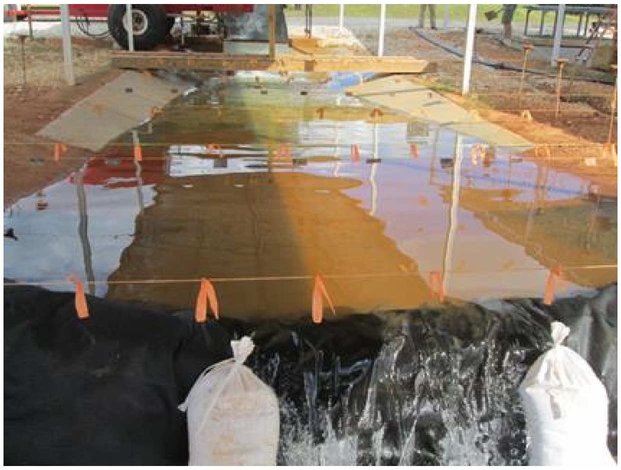
(1) Efficiency of impoundment was calculated against the spacing requirement (30 ft) for a 18 in. tall ditch check installed on a 5% slope

Since the sand bags restrict flow-through, maximizing the impoundment is not necessarily the main concern for optimizing the installation due to the sand bags ability to impound flow. However, as shown for the middle and highest flow tested for the "Standard ALDOT Sand Bag" installation, structural failure became a concern once flow was increased above 0.56 cfs (0.016 m^3/s). Structural stability of the bags is reliant upon gravitational and frictional forces to maintain the structural integrity of the ditch check. The result of structural failure for the "Standard ALDOT Sand Bag" installation is shown in Figure 4.3(a). ALDOT has used a modified installation to try to inhibit this structural failure by wrapping the sand bags in an 8 oz. (225 grams) nonwoven filter fabric as shown on an ALDOT project in Franklin County, AL in Figure 4.3(b). The sand bags were installed in the same manner as the ALDOT standard installation on top of a piece of filter fabric, and the extra fabric was wrapped over the sand bags and tucked under the bags on the downstream side. This method garnered some success in the field, and therefore warranted further investigation to compare to the original standard installation.

(a) standard installation configuration (b) sand bag burrito–Franklin Co, AL

Figure 4.3: Current ALDOT Sand Bag Practices.

This new installation was tested using the three tier flow regime. However, during the high flow condition of 1.68 (0.048 m3/s)cfs during the third replicate test, the sand bags dislodged at the center, within the filter fabric wrapping, causing partial dewatering of the impoundment, shown in Figure 4.4. A fourth replication was tested without failure occurring. Even though the addition of the filter fabric proved to increase the overall structural integrity of this installation when compared to the standard ALDOT installation, there was still concern about the stability of the sand bags.



(a) successful test

(b) failure at 1.68 cfs

Figure 4.4: Sand Bag Burrito Ditch Check Test.

Failure of both the standard installation and the burrito installation occurred when the sand bags in the middle layer within the primary flow path on the downstream side of the ditch check were finally pushed off the back by the force of the flowing water. The frictional forces holding the sand bags in place were in the direction across the width of the sand bags due to the orientation of the sand bags with regards to the direction of flow.

Therefore, a third installation was developed by changing the orientation of the middle row of sand bags. This reorientation made the resistance of frictional forces across the length of the bags by placing the middle row of sand bags parallel to the flow rather than perpendicular. This reorientation would also keep the bags from rolling off the back of the installation. The first modification to the new installation configuration was created by reorienting the bottom and middle layer to be parallel to the direction of flow. The filter fabric underlay was removed from the installation (Fig. 6) to determine if it was necessary for this installation in an effort to minimize cost and installation time. This installation performed better than the standard ditch check installation, however in the third flow tier, the sand bags in the middle of the channel were pushed downstream and spread apart, eventually causing structural failure. From this, it was determined that having the bottom layer oriented perpendicular to flow would help deter the bags from being pushed down stream by the flow. Therefore the second modification to the installation configuration shown in Figure 4.5 used sand bags that were oriented perpendicular to the flow in the bottom layer and parallel to the flow in the second layer. The single row third layer of sand bags was also oriented perpendicular to flow to minimize the number of sand bags required while still increasing the overall height of the ditch check.

The test shown in Figure 4.5 was successful in that the installation was structurally stable throughout the entire tier flow test. However, two subsequent replicate tests were unable to meet this performance stability and structural failure occurred for both tests during the highest flow tier phase. Though this would be an improved installation when compared to the standard ALDOT installation, however it did not perform as well as the sand bag burrito installation.

A final installation modification was performed to try to address this structural failure issue. Additional sand bags were placed on the downstream side of the ditch check to help reinforce the sand bags in the middle portion of the channel. This installation modification is shown in Figure 4.6.


(a) top sand bag layer perpendicular to flow (b) test during third flow tier of 1.68 cfs

Figure 4.5: Second Iteration of the Modified ALDOT Sand Bag Installation.

This new modification reinforced the portion of the ditch check most susceptible to failure since the greatest amount of hydrostatic and hydrodynamic pressure force from flow is located in the middle portion of the channel. By adding this reinforcement and by reorienting the middle layer of the sand bags, the middle portion was stabilized, and the reinforcement bags actually act as a spillway and dissipate energy from the water flowing over the ditch check similar to the downstream side of the rip rap ditch check installation.


(a) downstream reinforcement sand bags (b) 1.68 cfs flow tier

Figure 4.6: Modified ALDOT Sand Bag Installation.

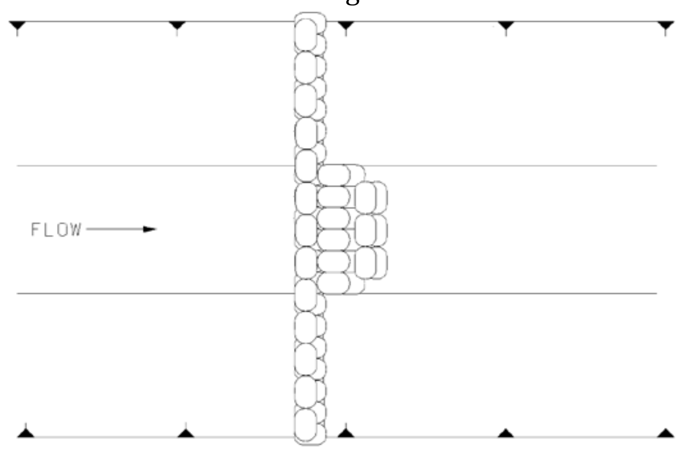
4.5 CONCLUSIONS

Sand bag ditch checks rely upon their weight and friction to hold the sand bags in place and resist dislodgment. Because of this, structural integrity was compromised for higher flow rates when all the sand bags were oriented perpendicular to the flow. Wrapping the ditch check in filter fabric provided extra stability, however the issue of sand bags being pushed off the downstream side from the middle layer was still an issue in one of the sand bag burrito installation replicate tests. Due to this, additional tests were performed on modified installations that reoriented bags in the middle layer parallel with the flow without using a filter fabric wrapping. This modification improved stability, but the center of the ditch check was unstable in high flow conditions of 1.68 cfs. Finally additional bags were added to the downstream side of the ditch check to reinforce the stability of the middle sand bags.

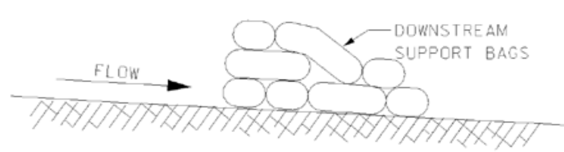
These installations were all capable of efficiently impounding water, as evident from Table 4.1. However, the sand bag burrito installation did outperform the installations that did not use a filter fabric wrapping from an impoundment standpoint. This is most likely due to the filter fabric reducing the flow-through rate of the installation as flow was unable to pass through the filter fabric and between the sand bags.

4.6 RECOMMENDATIONS FOR IMPLEMENTATION

As a result of this testing effort, the research team's recommendation is to incorporate the 'Sand Bag Orientation Modification w/Support Bags' installation into the ALDOT Standard Drawings. Based upon the results of the testing this installation resulted in a greatly improved installation structural stabilization. The reorientation of the bags increased the frictional resistance to dislodgment, while the support bags on the downstream side reinforced the middle section of sand bags most susceptible to dislodgement from the greatest amount of hydrostatic and hydrodynamic pressure. An optional variation to this installation could be to add a filter fabric choker similar to the rip rap ditch check installation, however this was not evaluated with the reorientation and support bag installation. The recommended installation variation is shown in Figure 4.7.



(a) plan view



(b) elevation view

Figure 4.7: Sand Bag Installation Modifications CADD Drawing.

4.7 REFERENCES

1. *Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas*, Alabama Soil and Water Conservation Committee, Montgomery, AL, 2009, Vol. 1, pp. 167 & 169.
2. ASTM Standard D7208, 2006, *Standard Test Method for Determination of Temporary Ditch Check Performance in Protecting Earthen Channels from Stormwater-Induced Erosion*, ASTM International, West Conshohocken, PA, 2007.
3. ASTM Standard D698, 2007, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort,* ASTM International, West Conshohocken, PA, 2007.

4. *Standard Specifications for Highway Construction*, Alabama Department of Transportation (ALDOT), Montgomery, AL, 2012, sec. 665, pp. 463 & 467.
5. *ESC-300 Ditch Check Structures, Typical Applications and Details*, Alabama Department of Transportation (ALDOT), Montgomery, AL, 2012, sheets 1 & 3 of 7.

4.8 APPENDIX

Table 4.2: Comparative Results of All Sand Bag Tests

Installation	Pool Length (ft)			% Efficiency			EGL Slope (ft/ft)		
Flow Rate (cfs)	**0.56**	**1.12**	**1.68**	**0.56**	**1.12**	**1.68**	**0.56**	**1.12**	**1.68**
Standard ALDOT	29.0	*fail*	*Fail*	97%	N/A	N/A	0.014	N/A	N/A
	29.0	*fail*	*Fail*	97%	N/A	N/A	0.015	N/A	N/A
	Did Not Perform the 3rd Replication Test Due to Previous Failures								
Burrito Method	32.0	33.0	33.5	106%	110%	112%	0.018	0.021	0.023
	33.0	33.2	33.5	110%	111%	112%	0.021	0.021	0.021
	33.0	33.3	*Fail*	110%	111%	N/A	0.021	0.021	N/A
	33.0	33.3	33.5	110%	111%	112%	0.020	0.020	0.020
Modified Orientation	29.1	29.4	*29.8*	97%	98%	99%	0.014	0.017	0.020
	29.2	29.7	*Fail*	97%	99%	N/A	0.016	0.019	N/A
	29.1	29.5	*Fail*	97%	98%	N/A	0.015	0.016	N/A
Modified w/ Support Bags	29.0	30.3	32.0	97%	101%	106%	0.014	0.016	0.014
	29.0	29.5	30.8	97%	98%	103%	0.013	0.013	0.012
	29.0	29.5	30.8	97%	98%	103%	0.015	0.016	0.013

CHAPTER 5: SILT FENCE DITCH CHECKS

5.1 INTRODUCTION

Silt fences are typically used as perimeter controls for construction sites. These are barriers installed down gradient of disturbed areas and are typically meant to intercept sheet flow. A properly functioning silt fence when used as a sheet flow interceptor is installed at the same grade across the gradient so that flow is evenly distributed across the width of the silt fence. The silt fence is trenched-in either by (1) digging a 6 in. by 6 in. (15 by 15 cm) trench and compacting soil on top of the trenched-in fabric or (2) using a silt fence installation machine that slices the ground open, pushes the fabric into the ground, and pushes the slice back together. If undercutting is prevented by properly installing the silt fence, then flow will impound up gradient.

As sediment deposits on silt fence, flow-through is restricted and the water level increases. This scenario could become problematic if a portion of the silt fence is installed down gradient of the rest of the fence, creating a low point and therefore a point of concentration. Often when a point of concentration occurs, the flow overtops at the low point once the fence reaches its volumetric capacity, creating a scour area on the down gradient side. Downstream scour combined with hydrostatic and hydrodynamic forces can cause the fence to fail and be pushed over, which releases impounded water and sediment deposited on the upstream side of the fence. Even though typical silt fence perimeter installations tend to have structural integrity problems when flows are concentrated to one point, silt fence can be used in drainage channels as a ditch check, exposing the barrier to the greatest flow concentrations created on the construction site. Silt fence ditch checks can also be pushed over in the same manner as silt fence perimeter controls used as flow interceptors if improperly installed and flow is concentrated to one point along the fence as shown in Figure 5.1.

Due to this failure concern, the structural integrity of silt fence ditch checks should be evaluated. Improving overall structural integrity and minimizing failure possibilities of silt fence installations should reduce the maintenance requirements and increase the longevity of the practice.

(a) perimeter control (b) ditch check under channelized flow

Figure 5.1: Silt Fence Structural Failures.

5.2 MATERIALS FOR INSTALLATIONS

The following is a list of materials used for the various silt fence installation configurations:

- *silt fence fabric*: 3.5 oz. (100 g), nonwoven filter fabric (FF), 45 in. (114 cm) wide. The fabric is attached to wire backing with c-ring staples. The fabric is trenched in a 6 by 6 in. (15 by 15 cm) trench or stapled to the channel bottom on top of a FF underlay using two rows of sod pins, staggered and spaced 10 in. apart (25.4 cm),

- *FF underlay*: 8 oz. (226 g), nonwoven FF, 12.5 ft (3.8 m) long that extends the length of both of the V sides of the 45 degree ditch check installation. Each section is 3 ft (1 m) wide and extends 1 ft (0.3 m) upstream of the silt fence and 2 ft (0.6 m) downstream of the silt fence when the pinned silt fence installation is used. The underlay is pinned to the channel bottom with sod pins spaced 10 in. (25.4 cm) on center,
- *sod pins*: 11 gauge metal, 6 in. (15 cm) long by 1 in. (2.5 cm) diameter round top pins, used to secure the filter fence and the filter fabric underlay to the channel bottom,
- *wire mesh backing*: 14 gauge steel wire mesh with a minimum 6 in. by 6 in. (15 by 15 cm) vertical and horizontal spacing of the wire mesh,
- *c-ring staples*: 11/16 in. (1.7 cm), 16 gauge, galvanized steel. The c-ring staples are used to attach the filter fabric to the top wire of the wire backing,
- *studded t-post*: 5 ft (1.5 m) studded steel t-post, driven into the ground 24 in. (60 cm) spaced 3 ft (1 m) apart on center,
- *wire ties*: 6.5 in (16.5 cm), 11 gauge, aluminum fence tie wires. These wire ties are used to secure the wire backing to the t-posts,
- *hay bale*: 3 ft (1 m) long bound straw bale with a weight of approximately 35 lbs (16 kg),
- *modified no. 4 coarse aggregate:* consist of graded aggregate ranging from 4 in. to ¾ in. (10 to 2 cm) with not more than 10 % greater than 4 in. (10 cm), at least 20% to 55% 1 in. (2.5 cm) and no more than 15% smaller than ¾ in.(2 cm), and
- *ALDOT Class I riprap:* graded stones ranging from 10 to 100 lbs (4.5 to 45 kg) with not more than 10% having a weight over 100 pounds (45 kg) and at least 50% having a weight over 50 lbs (23 kg) and not over 10% having a weight under 10 lbs (4.5kg) (*4*).

5.3 SILT FENCE INSTALLATION TESTS

The channel was prepared to experimental specifications for all tests performed on the five different silt fence ditch check installation configurations so direct comparisons could be made between each configuration. The following five silt fence installation configurations [Figure 5.2(a)–(e)] were tested:

(1) *Standard ALDOT V Installation [*Figure 5.2*(a)]*: center post placed in the channel centerline, posts are spaced 2.5 ft (76 cm) on center in a V pattern. Fabric and wire backing is trenched in a 6 in. by 6 in. (15 by 15 cm) trench. Overall fence height is 32 in. (81.3 cm)

(2) *Standard ALDOT V Installation w/Hay Bale Dissipater [*Figure 5.2*(b)]*: installed in the same manner as the *Standard ALDOT V installation*, however hay bales were placed downstream, abutted to the fence in an attempt to dissipate energy and reduce downstream scour next to the fence.

(3) *Standard ALDOT V Installation w/Modified No. 4 Stone Dissipater [*Figure 5.2*(c)]*: installed in the same manner as the *Standard ALDOT V Installation*, however modified no. 4 stone is placed downstream, in an attempt to dissipate energy and reduce downstream scour next to the fence.

(4) *TDOT Enhanced Silt Fence Check Installation [*Figure 5.2*(d)]*: installed in the same manner as the *Standard ALDOT V Installation*, however an 18 in. (45.7 cm) tall weir is cut into the fabric that extends across the width of the channel bottom. Directly downstream of the weir, a 2 ft (60.9 cm) wide 8 oz. (226 g) FF splash apron over the length of the weir is installed and covered with ALDOT Class I riprap to dissipate energy of the water overtopping the weir.

(5) *Enhanced ALDOT Pinned Installation [*Figure 5.2*(e)]*: the *Standard ALDOT V Installation* w/Pinning is installed, however a weir is cut into the fabric in the same manner as the *TDOT Enhanced Silt Fence* Installation.

(a) std. ALDOT V installation

(b) std. ALDOT V install. w/hay bale dissipater

(c) std. ALDOT V install. w/mod. #4 dissipater

(d) TDOT enhanced install. w/rip rap dissipater

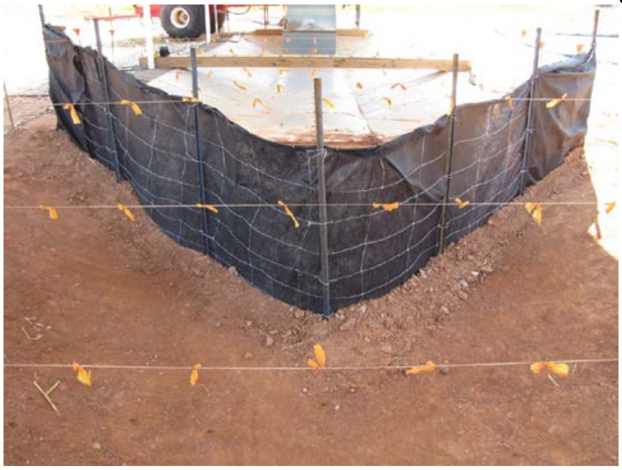
(e) enhanced ALDOT pinned installation

Figure 5.2: Silt Fence Ditch Check Installation Configurations.

5.4 RESULTS AND DISCUSSION

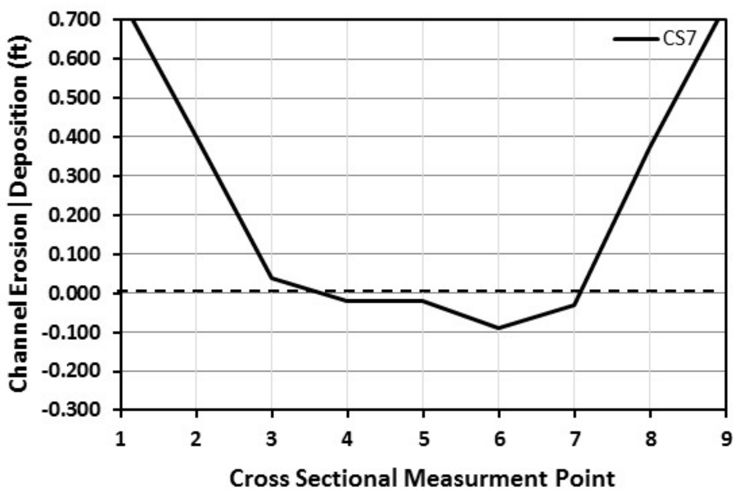
The following section is a summary of the results and comparisons that were made from the silt fence ditch check experiments. Due to the height of the silt fence ditch check, impoundment lengths will not be reported because when tested using the full height of the silt fence, the impoundment overtopped the channel banks and impounded water the entire length of the test channel. Had the channel been longer, a longer impoundment length would have been measured. Therefore, this report will focus on erosion and deposition, impoundment depths, and EGL.

Since structural failure is the major concern for the silt fence ditch check, evaluation of the "V" installation required investigation. This installation was tested to determine possible structural failure modes. Silt fence installations typically degrade over time as water passes through or over the filter fabric and creates scour points directly downstream. These scour points can erode around the middle t-post reducing the structural integrity of the installation and cause the fence to eventually fail by falling over. These scour patterns became evident after testing the standard ALDOT installation under low flow conditions of 0.56 cfs (0.016 m^3/s). This is shown in Figure 5.3.



(a) pre-test

(b) post-test



(c) downstream erosion pattern

Figure 5.3: Erosion Pattern of Standard ALDOT Silt Fence Installation.

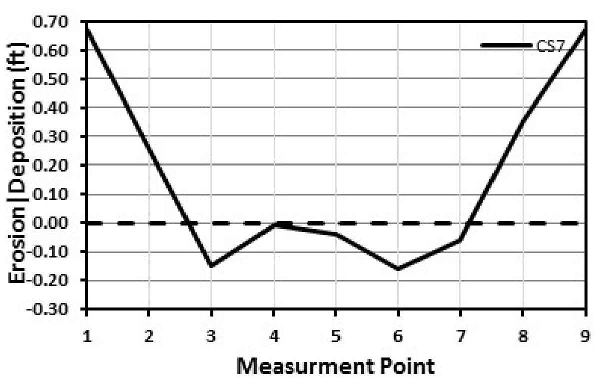
Figure 5.3(c) shows that up to 0.1 ft (3 cm) of erosion occurred directly downstream of the ditch check after one, 30 minute test at 0.56 cfs (0.016 m^3/s). Due to this, an installation modification directed towards reducing this downstream scour was tested. The proposed modifications included using rock or hay bales positioned directly downstream of the silt fence, to be used as flow dissipation and channel protection. These modifications are shown in Figure 5.4.

(a) hay bale dissipater pretest

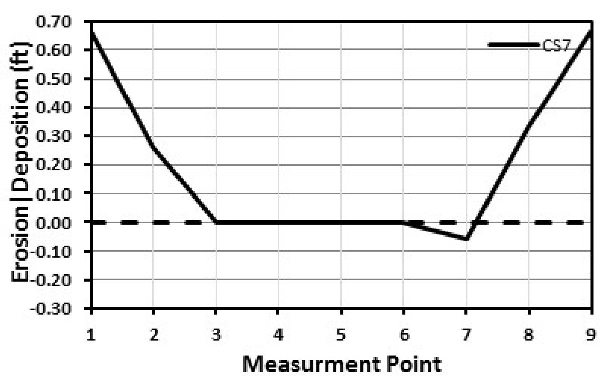
(b) modified no. 4 dissipater pretest

(c) hay bale dissipater posttest

(d) modified no. 4 stone dissipater post test



(e) hay bale dissipater erosion pattern

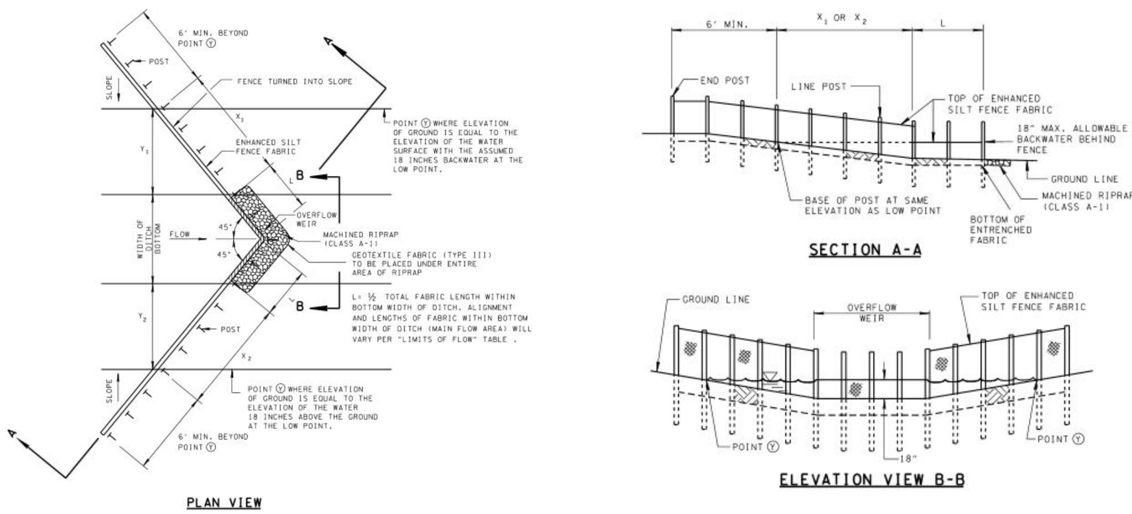


(f) modified no. 4 erosion pattern

Figure 5.4: Downstream Modifications for V-Installation Silt Fence and Erosion Patterns.

The inclusion of downstream dissipation measures (i.e., hay bales, modified no. 4 stone) did not improve the erosion patterns for the channel. However, the modified no. 4 stone dissipater did manage to move the erosion away from the downstream side of the fence as shown in Figure 5.4. Once beyond the dissipaters, the flow is able to resume supercritical flow velocities causing downstream erosion. Erosion occurred beneath the hay bales, but the rock reduced the erosion directly downstream of the fence. It should be noted that using a rock dissipation method may not be cost effective and would create a need to remove the rock once construction is complete, thereby increasing the overall cost of the practice.

The Tennessee Department of Transportation (TDOT) enhanced silt fence ditch check installation was also evaluated. This installation uses a weir cut horizontally across the fabric the width of the channel bottom. This weir is approximately 18 in. high and uses a splash pad downstream of the weir. This splash pad is comprised of a geotextile fabric and riprap. This installation detail is shown in Figure 5.5.



(a) plan view (b) elevation and cross-sectional views

Figure 5.5: TDOT Enhanced Silt Fence Installation (TDOT 2012).

The purpose of this installation is to minimize the amount of impoundment upstream of the silt fence in an attempt to reduce the hydrostatic and hydrodynamic pressure placed on the device. This method reduces the amount of silt fence that needs to be installed outside of the channel, if the depth of the ditch is less than the height of the fence. This installation is shown in Figure 5.6.

The weir allowed flow to impound the entire length of the channel, creating 30 ft (10 m) of subcritical flow. This is the optimum condition for earthen channels whereas flow is impounded the maximum impoundment length and the ditch check is not subjected to adverse conditions created by a much larger impoundment. Testing this method showed that a splash pad was an effective means of controlling scour directly downstream of the ditch check. This is evident in Figure 5.6(d).

Integration of a downstream splash pad appeared to be the optimum choice. However, proper implementation of this enhancement was crucial to the success of the practice. Installing the splash pad after the silt fence is installed could create gaps between the splash pad and the fence. These gaps could allow water to undercut the splash pad. The ideal scenario is to install the underlay first, then the silt fence on top, however, this creates issues with trenching the fence into the channel. Therefore, a new installation was developed that includes an underlay, which extends 2 ft (0.6 m) downstream and 1 ft (0.3 m) upstream and does not involve trenching the fence into the channel. Instead, the extra fabric is pinned to the channel bottom as shown in Figure 5.7(a).


(a) pre-test


(b) 18 in. weir


(c) post-test

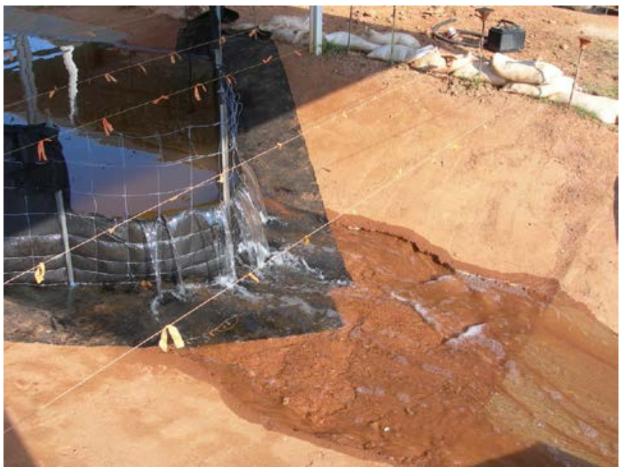

(d) effect of underlay

Figure 5.6: TDOT Enhanced Silt Fence Ditch Check Test.

The downstream splash pad provided protection immediately downstream of the ditch check however, downstream erosion is still a concern for this and all ditch check practices. Figure 5.7(d) demonstrates how properly spacing the ditch check would create a subcritical pool directly downstream of each ditch check that results in less channel scour from supercritical flow.

The use of a weir to minimize impoundment pressure on the silt fence installation appears to be an ideal scenario. As shown in Figure 5.8, the impoundment of the full height ditch check is much greater than the weir ditch check. The full height ditch check requires the silt fence to be run up gradient of the channel far enough so that flow cannot bypass the silt fence. This increases the installation materials for the ditch check and also exposes the top of the banks to flow as water passes through the silt fence material that is out of the channel further exposing more areas to erosive runoff. The weir installation decreases the impoundment height and can be adjusted to ensure that the height of the center of ditch check is lower than the full depth of the channel. This will prevent the need for running silt fence out of the channel and up the sides, possibly disturbing more areas.


(a) FF underlay and pinning of fence (b) resulting impoundment pool




(c) resulting downstream erosion (d) demonstration of downstream subcritical pool

Figure 5.7: Pinned Silt Fence Installation Test.

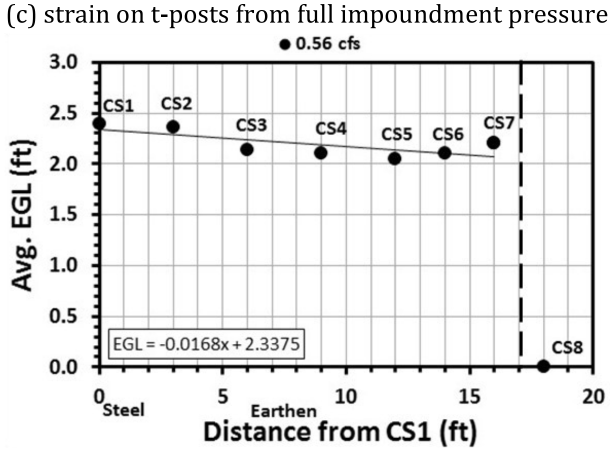
The EGLs for two installations show in Figure 5.8(e) and (f) vary due to the large differences in impoundment depth and flow through conditions for each installation. The weir installation allows flow to pass freely over the top of the silt fence, creating a more uniform flow condition. The full height installation forces water through the filter fabric, creating less uniform conditions as flow attempts to reach steady state conditions with the flow through of the filter fabric. Typically when comparing two installations, if one of the installations causes overtopping and one does not, the installation that does not overtop will have a shallower EGL. This result is due to the flattening of the EGL that occurs near to the upstream side of the ditch check, which is similar to the hydraulic conditions of dams. This is especially true for EGLs with very short impoundments. The full height silt fence installation does not over top, and therefore has that flattening trend at the cross sections nearest the ditch check. However, the EGL is still larger due to the greater impoundment depths. When comparing the EGLs of the two installations, it should also be noted that the typical flattening of the EGL does not occur for the weir installation since the flow is a free overflow condition. This does also produce a very uniform EGL similar to what is observed for gradually varied flow conditions because of the free overflow and the low flow rate of 0.56 cfs.

(a) full height silt fence ditch check impoundment

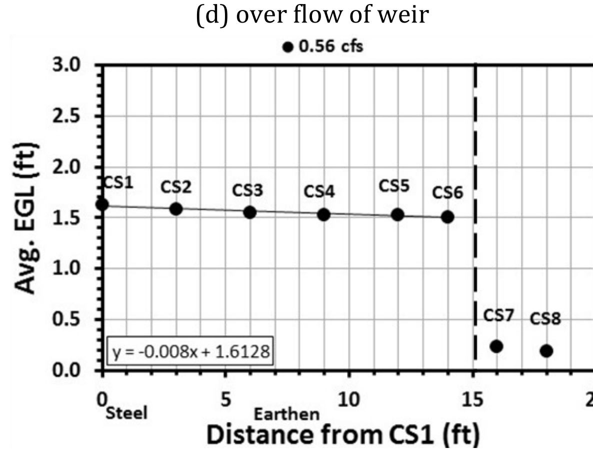
(b) silt fence ditch check w/ weir impoundment

(c) strain on t-posts from full impoundment pressure

(d) over flow of weir



(e) EGL of full height silt fence



(f) EGL of silt fence ditch check w/ weir

Figure 5.8: Comparison of Hydraulic Performance of Full Height vs Weir Installation.

The pinned installation appeared to enable impoundment to occur without undercutting the practice, which is also prevented by the trenched silt fence. However, it was uncertain if the pinned practice would be able to maintain this impoundment capability over a longer period of time. If repeated storm events eventually caused undercutting, the ditch check could be rendered useless over time. Therefore a longevity test was performed to determine the effectiveness of the ditch check over time. Six tests were performed over a two month period on the same pinned silt fence installation. During the entirety of this longevity test, 41.9 ft^3 (1.2 m^3) of sediment was added to the test flow to further mimic field-like conditions. This test is shown in Figure 5.9.

(a) introduction of sediment-laden water
(b) ditch check impoundment
(c) sediment retention after first three tests
(d) sediment retention after one week w/out testing
(e) large particles deposited at channel head
(f) sediment deposition post longevity test

Figure 5.9: Sediment-Laden Silt Fence Longevity Test.

A robotic total station was used to survey the pre-test and post-test elevations of the channel to determine sediment retention and downstream scour after the longevity test was completed. The survey concluded that approximately 38.2 ft^3 (1.1 m^3) of sediment was retained upstream of the ditch check resulting in 91.2% sediment retention. However, 6.2 ft^3 (0.18 m^3) of sediment loss occurred due to erosion measured downstream as shown in Figure 5.10.

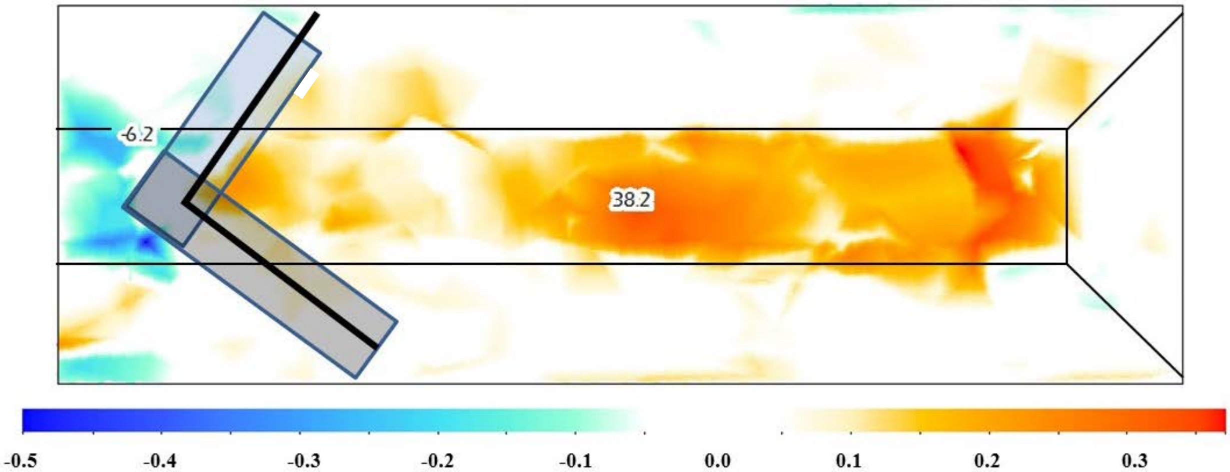


Figure 5.10: Final Erosion and Deposition Patterns of Silt Fence Longevity Test.

Figure 5.10 shows the deposition pattern upstream of the silt fence installation and erosion patterns caused by the downstream flow. The greatest concentration of sediment deposition occurred just downstream of the sediment and water introduction trough as denoted by the dark orange area. Approximately 0.4 ft (12 cm) thick layer of sediment was deposited. This sediment consisted of the larger sandy particles that fell out of suspension quickly due to a low velocity condition caused by the impoundment. Sediment deposition decreased closer to the ditch check. This is due to the larger sediment depositing upstream and smaller particles depositing further downstream as more time is required for the smaller particles to settle out. The sediment not retained by the silt fence most likely requires longer impoundment times or flocculation to settle out of suspension.

5.5 CONCLUSIONS

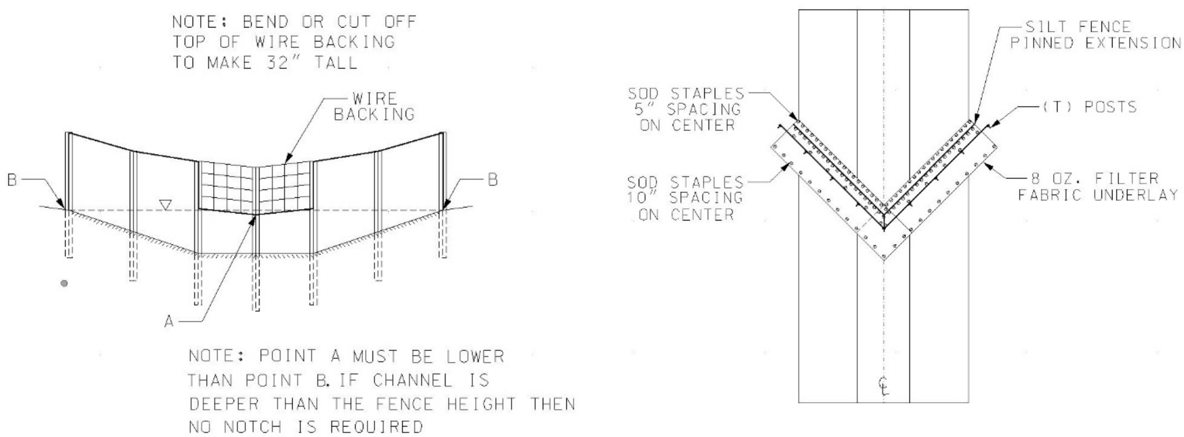
When silt fence is used as a ditch check, massive impoundments will be created due to the height of the silt fence when compared to other, shorter ditch check practices. The strain created by the large impoundment accompanied with downstream scour can cause structural failure of the ditch check. If structural failure occurs during a full impoundment condition, the resulting mass release of impounded water would most likely cause additional practice failures downstream, especially if the downstream practices are also experiencing structural strain. Therefore, creating a silt fence ditch check installation that minimizes these conditions is important. The inclusion of a weir creates a more manageable impoundment area for the silt fence installation to endure.

Including a splash pad downstream also helps with downstream scour issues that could also cause structural failure. Finally, pinning the silt fence to the channel rather than trenching it allows an underlay to be installed that extends upstream and downstream of the ditch check, further armoring the ditch check and channel interface. It should be noted that the channel should have a smooth area for the underlay and silt fence to be installed. Rocky and bumpy channels could create issues for the underlay to maintain full ground contact. If full ground contact does not occur, undermining could occur decreasing the performance of the silt fence ditch check.

5.6 RECOMMENDATIONS FOR IMPLEMENTATION

As a result of this testing effort, the research team's recommendation is to incorporate the weir option for the silt fence installation as well as the pinning option shown in Figure 5.11. The weir height can be adjusted based upon the maximum channel depth to minimize the flow over the channel bank. The recommended minimum and maximum weir heights are 15 in. and 20 in., respectively, in order for a silt fence ditch check to be as effective as other ditch checks (i.e., wattles, sandbags, and rock), which are typically 15 to 20 in. in height. Since channel depths may be less than the 15 to 20 in. weir height, the typical 45° V angle from the centerline for silt fence ditch checks may not be applicable. Therefore, when channel depths are less than the weir height, the angle of the fence should be reduced so that the end of the silt fence extends out of the channel at a location so that the top bank of the channel is at the same elevation as the top of the weir. Figure 5.12, in the Appendix of Chapter 5, provides a schematic of this situation for the silt fence ditch check installations. Table 5.1(a) – (f), also in the Appendix, will aid designers and installers on the recommended installation lengths of the silt fence ditch check practice.

The inclusion of a splash pad on the downstream side of the installation is crucial and also recommended to minimize scour and possible damage of the silt fence installation. The pinned installation garnered success and is recommended for further consideration as an in-field installation. This installation option may not be suitable for all scenarios whereas a smooth channel bottom is required to maintain ground contact. However, this may be most suitable when trenching equipment is unable to be used for the installation.



(a) weir detail (b) pinning detail

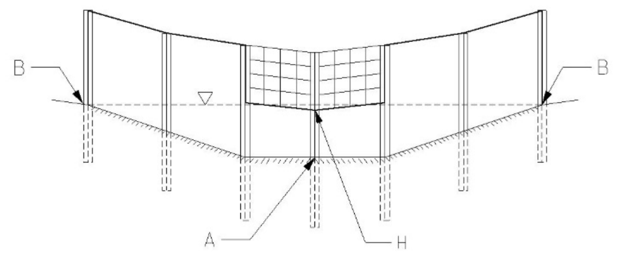
Figure 5.11: Recommended Silt Fence Ditch Check Detailed Drawings.

5.7 REFERENCES

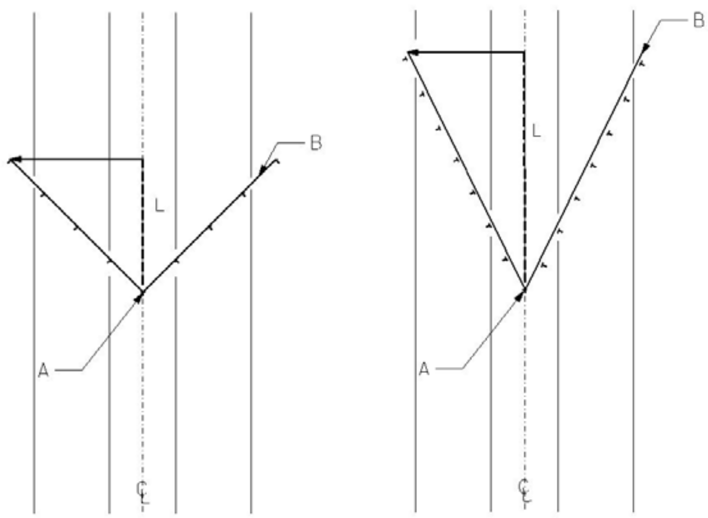
1. *Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas*, Alabama Soil and Water Conservation Committee, Montgomery, AL, 2009, Vol. 1, pp. 167 & 169.
2. ASTM Standard D7208, 2006, *Standard Test Method for Determination of Temporary Ditch Check Performance in Protecting Earthen Channels from Stormwater-Induced Erosion*, ASTM International, West Conshohocken, PA, 2007.
3. ASTM Standard D698, 2007, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort,* ASTM International, West Conshohocken, PA, 2007.
4. *Standard Specifications for Highway Construction*, Alabama Department of Transportation (ALDOT), Montgomery, AL, 2012, sec. 801 & 814, pp. 561 & 577.
5. *ESC-300 Ditch Check Structures, Typical Applications and Details*, Alabama Department of Transportation (ALDOT), Montgomery, AL, 2012, sheets 1 - 2 of 7.

5.8 APPENDIX: GUIDANCE TABLES FOR DETERMINING LENGTH OF SILT FENCE

To keep impounded flow from overtopping the banks when the depth of the channel is less than the height of the weir, the silt fence should be installed so that the end of the fence (B) is at an elevation greater than the height of the weir (H). In order to assure this, the silt fence must be extended longitudinally upstream a minimum length (L) as shown in Figure 5.12. The angle of the silt fence installation can vary accordingly in order to achieve the minimum length to satisfy the minimum weir height while preventing the ditch bank overtopping condition.



(a) location and elevation of weir vs. channel depth



(b) examples of varying silt fence V angle required to satisfy depth and weir height

Figure 5.12: Variation of Silt Fence Angle and Required Length of Silt Fence.

Table 5.1 below provides selection charts to determine silt fence lengths for various channel depths and slopes, in order to satisfy the minimum weir height requirements. These silt fence lengths will ensure that the silt fence ditch check is installed properly to maximize impoundments while preventing water from flowing over the channel banks and around the ditch check.

Table 5.1: Req. Silt Fence Lengths to Contain Impounded Water for Various Channel Depths.

(a) Channel Depth = 0.25 ft (3 in.)

Weir Height (in.)	Longitudinal Channel Slope (ft/ft)									
	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
15	100.0	50.0	33.3	25.0	20.0	16.7	14.3	12.5	11.2	10.0
16	108.3	54.2	36.1	27.1	21.7	18.1	15.5	13.6	12.1	10.9
17	116.7	58.3	38.9	29.2	23.4	19.5	16.7	14.6	13.0	11.7
18	125.0	62.5	41.7	31.3	25.0	20.9	17.9	15.7	13.9	12.6
19	133.3	66.7	44.5	33.4	26.7	22.3	19.1	16.7	14.9	13.4
20	141.7	70.8	47.2	35.4	28.4	23.7	20.3	17.8	15.8	14.2
	Minimum length (L_{min}) required to contain impounded water in channel (ft)									

(b) Channel Depth = 0.5 ft (6 in.)

Weir Height (in.)	Longitudinal Channel Slope (ft/ft)									
	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
15	75.0	37.5	25.0	18.8	15.0	12.5	10.7	9.4	8.4	7.5
16	83.3	41.7	27.8	20.8	16.7	13.9	11.9	10.4	9.3	8.4
17	91.7	45.8	30.6	22.9	18.4	15.3	13.1	11.5	10.2	9.2
18	100.0	50.0	33.3	25.0	20.0	16.7	14.3	12.5	11.2	10.0
19	108.3	54.2	36.1	27.1	21.7	18.1	15.5	13.6	12.1	10.9
20	116.7	58.3	38.9	29.2	23.4	19.5	16.7	14.6	13.0	11.7
	Minimum length (L_{min}) required to contain impounded water in channel (ft)									

(c) Channel Depth = 0.75 ft (9 in.)

Weir Height (in.)	Longitudinal Channel Slope (ft/ft)									
	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
15	50.0	25.0	16.7	12.5	10.0	8.3	7.2	6.3	5.6	5.0
16	58.3	29.2	19.5	14.6	11.7	9.7	8.4	7.3	6.5	5.9
17	66.7	33.3	22.2	16.7	13.3	11.1	9.5	8.4	7.4	6.7
18	75.0	37.5	25.0	18.8	15.0	12.5	10.7	9.4	8.4	7.5
19	83.3	41.7	27.8	20.8	16.7	13.9	11.9	10.4	9.3	8.4
20	91.7	45.8	30.6	22.9	18.4	15.3	13.1	11.5	10.2	9.2
	Minimum length (L_{min}) required to contain impounded water in channel (ft)									

(d) Channel Depth = 1.0 ft (12 in.)

Weir Height (in.)	Longitudinal Channel Slope (ft/ft)									
	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
15	25.0	12.5	8.3	6.3	5.0	4.2	3.6	3.1	2.8	2.5
16	33.3	16.7	11.1	8.3	6.7	5.6	4.8	4.2	3.7	3.3
17	41.7	20.8	13.9	10.4	8.3	7.0	6.0	5.2	4.6	4.2
18	50.0	25.0	16.7	12.5	10.0	8.3	7.2	6.3	5.6	5.0
19	58.3	29.2	19.5	14.6	11.7	9.7	8.4	7.3	6.5	5.9
20	66.7	33.3	22.2	16.7	13.3	11.1	9.5	8.4	7.4	6.7
	Minimum length (L_{min}) required to contain impounded water in channel (ft)									

(e) Channel Depth = 1.25 ft (15 in.)

Weir Height (in.)	Longitudinal Channel Slope (ft/ft)									
	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
15	0	0	0	0	0	0	0	0	0	0
16	8.3	4.2	2.8	2.1	1.7	1.4	1.2	1.0	0.9	0.8
17	16.7	8.3	5.6	4.2	3.3	2.8	2.4	2.1	1.9	1.7
18	25.0	12.5	8.3	6.3	5.0	4.2	3.6	3.1	2.8	2.5
19	33.3	16.7	11.1	8.3	6.7	5.6	4.8	4.2	3.7	3.3
20	41.7	20.8	13.9	10.4	8.3	7.0	6.0	5.2	4.6	4.2
	Minimum length (L_{min}) required to contain impounded water in channel (ft)									

(f) Channel Depth = 1.5 ft (18 in.)

Weir Height (in.)	Longitudinal Channel Slope (ft/ft)									
	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	8.3	4.2	2.8	2.1	1.7	1.4	1.2	1.0	0.9	0.8
20	16.7	8.3	5.6	4.2	3.3	2.8	2.4	2.1	1.9	1.7
	Minimum length (L_{min}) required to contain impounded water in channel (ft)									

Note: If $L_{min} = 0$, the resultant angle of the silt fence V=90°. If the $L_{min} > 0$ the resultant angle of the silt fence V is less than 90°

CHAPTER 6: STACKED WATTLE DITCH CHECK

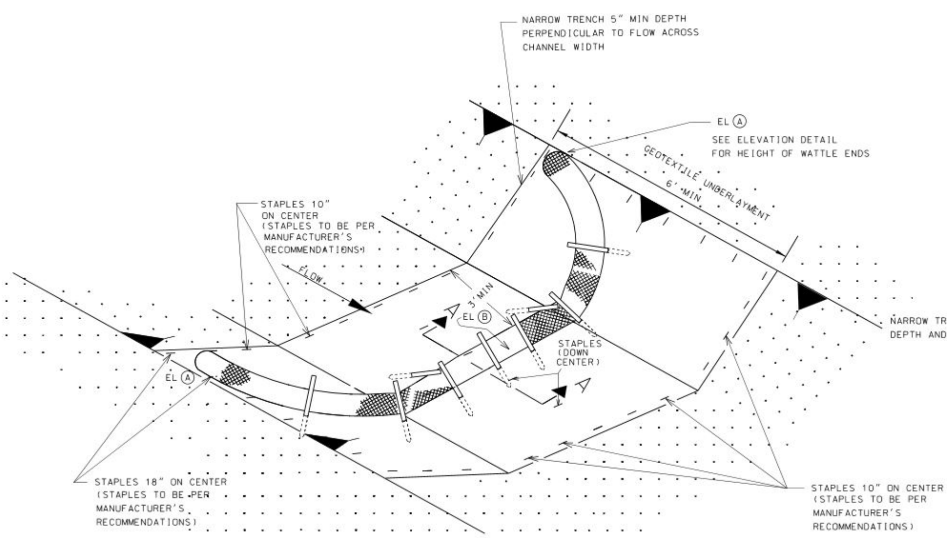
6.1 INTRODUCTION

A series of constant flow, large-scale ditch check experiments were performed to evaluate the stacked wattle installation configuration on two different wattle products. The Erosion Eel™ and Filtrexx Filter Soxx™ were each evaluated by 3 clean water tests and 1 sediment-laden test for a total of 8 tests. New product was used for each installation test performed, for a total of 24 wattles used during this testing effort.

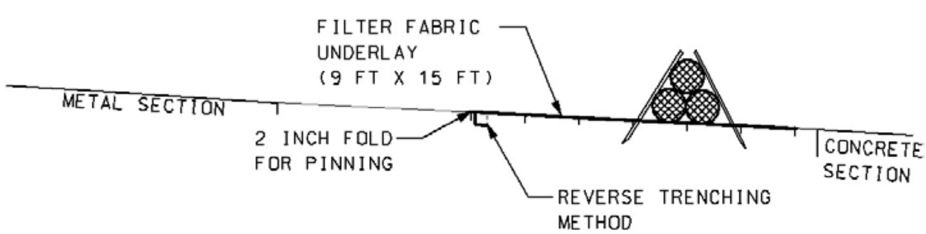
The tests for the proposed stacked wattle installation evaluations used a two tiered flow rate of 0.56 cfs (0.016 m^3/s) and 1.12 cfs (0.032 m^3/s) for 15 minutes each for a total duration of 30 minutes. Installation Evaluation Regime

6.2 WATTLE INSTALLATION

ALDOT's newly adopted standard wattle ditch check installation can be found on '*ESC-300 Ditch Check Structures, Typical Applications, and Details*' (*4*) and is shown in Figure 6.1(a). The adopted standard wattle ditch check installation was used to develop the proposed stacked wattle ditch check installation as detailed in Figure 6.1(b).



(a) ALDOT New Standard Wattle Detail (*4*)



(b) Proposed Stacked Wattle Installation

Figure 6.1: Comparison of ALDOT Std. and Proposed Stacked Wattle Installation Practices.

ALDOT's new wattle installation specifies a 20 in. (51 cm) diameter wattle placed perpendicular to flow across a trapezoidal channel. An 8 oz. nonwoven filter fabric underlay 9 ft by 15 ft (2.7 m by 4.6 m) is placed in the channel to protect the wattle/channel bottom interface from erosion and undercutting. The filter fabric is trenched a minimum of 4 in. in using a reverse trenching method as shown in Figure 6.1(b). A two inch fold should be used to secure the upstream edge of the filter fabric. The two inch fold consists of pulling fabric upstream two inches once the fabric has been secured in the trench. This fold is pinned to the channel to avoid pinning the filter fabric through the trench which may be looser the upstream, undisturbed portion of the channel. The wattles are to be staked in place using a teepee or A-frame method that is nondestructive and secures the wattles in place allowing the practice to intercept channelized flow.

6.3 MATERIALS FOR INSTALLATIONS

The following is a list of materials used for the various wattle installation configurations:

- *wattle*: 9 to 12 in. (23 to 30 cm) diameter, 10 ft (3 m) long wattles (Note: dimensions nominal),
- *wooden stakes*: 1 in. x 2 in. x 3 ft (2.5 cm x 5 cm x 1 m), used to secure the wattles in place,
- *sod pins*: 11 gauge metal, 6 in. long x 1 in. (15 cm x 2.5 cm) round top pins, used to secure the filter fabric underlay, and
- *filter fabric (FF) underlay*: 8 oz. (225 gram), nonwoven FF, 9 ft (3 m) long, 15 ft (4.6 m) wide. Extends 3 ft (1m) upstream from the upstream face of the wattles and keyed in a minimum of 5 in. (0.13 m) deep in a trench. The fabric underlay extends 3 ft (1 m) downstream beyond the wattles. The trenched end of fabric uses a reverse trenching method which is recommended for rolled erosion control products by American Excelsior Company® as shown in Figure 6.2 (*9*). The upstream and downstream edges of FF were secured with sod staples spaced 10 in. (25 cm) apart and longitudinally along each side and the centerline of the fabric spaced 1.5 ft (0.45 m).

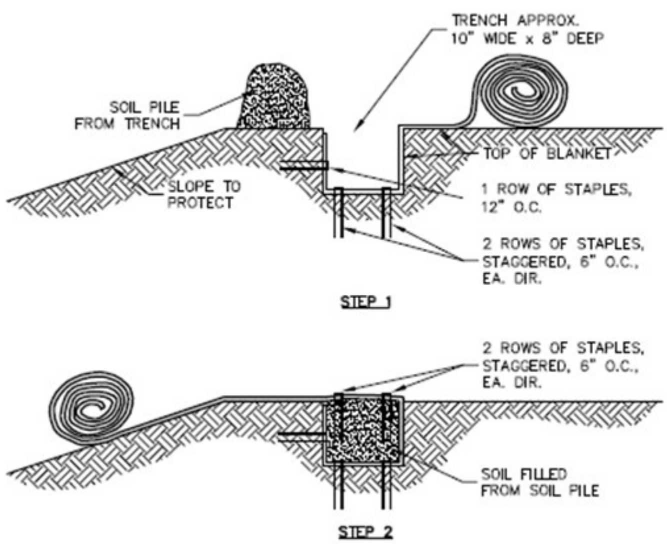


Figure 6.2: American Excelsior Erosion Control Blanket Trenching Method (*9*)

6.4 STACKED WATTLE INSTALLATION TESTS

The channel was prepared to experimental specifications for all tests performed on the stacked wattle installation configurations so direct comparisons could be made with the 20 in. wattle tests. Figure 6.3 provides a photographic comparison of the two products (Erosion Eel and Filtrexx Filter Soxx) used for the stacked wattle installation tests using clean water flow. Figure 6.4 exhibits that deposition patterns created by the stacked installations at the conclusion of the sediment-laden performance tests.

(a) Erosion Eel stacked installation

(b) Filtrexx Filter Soxx stacked installation

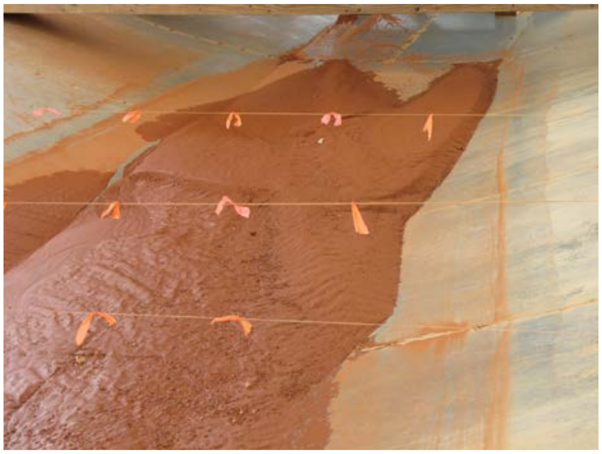
(c) Erosion Eel clean water at 0.56 cfs

(d) Filtrexx clean water at 0.56 cfs

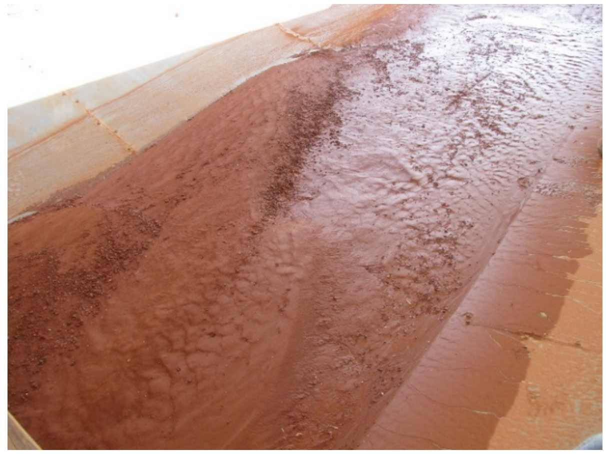
(e) Erosion Eel clean water at 1.12 cfs

(f) Filtrexx clean water at 1.12 cfs

Figure 6.3: Stacked Wattle Installation Performance Tests.



(a) Erosion Eel sediment-laden test deposition



(b) Filtrexx sediment-laden test deposition

Figure 6.4: Sediment-laden Performance Test Results on Stacked Wattle Installations.

6.5 RESULTS AND DISCUSSION

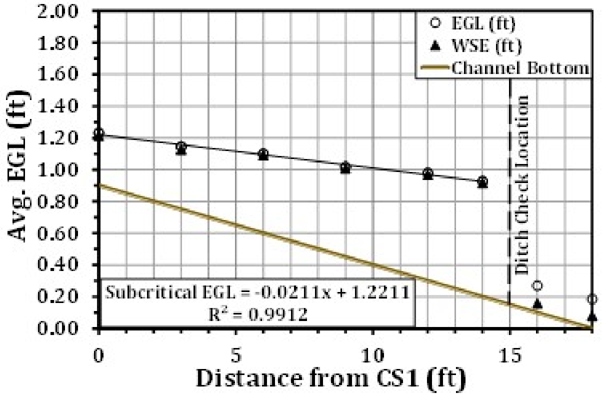
The following section is a summary of the results and comparisons that were made from the experiments using a two tier flow regime of 0.56 and 1.12 cfs for 15 minutes each for a total test duration of 30 minutes.

The stacked wattle installation evaluation was performed using the two products with diameters smaller than the 20 in. nominal diameter requirement currently approved by ALDOT: (1) Erosion Eel and (2) Filtrexx. Each installation was comprised of three wattles setup in a stacked formation with two wattles as the base and one wattle as the top forming a pyramidal shape to create a taller ditch check installation. Both products were installed using the same adaptation of the newly adopted standard ALDOT wattle ditch check installation.

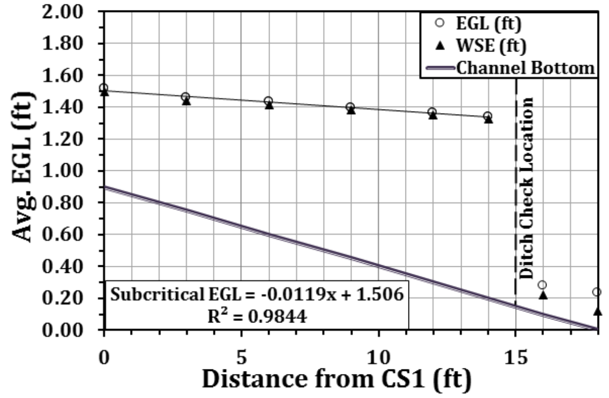
As Figure 6.5(e) and (f) show, the average stacked wattle installation performs slightly better than the average performance for all seven 20 in. wattles tested during this research effort. It should be noted that as shown in Table 6.1, the Erosion Eel and Filtrexx Filter Soxx products are heavier and denser than any of the 20 in. diameter wattles, having an average density of 2.8 lbs/ft^3. Since these products are much denser than the 20 in. wattles, the stacked wattle installations were able to impound water to a degree similar to the heaviest and most dense 20 in. wattles.

Table 6.1: Average Measured Product Dimensions

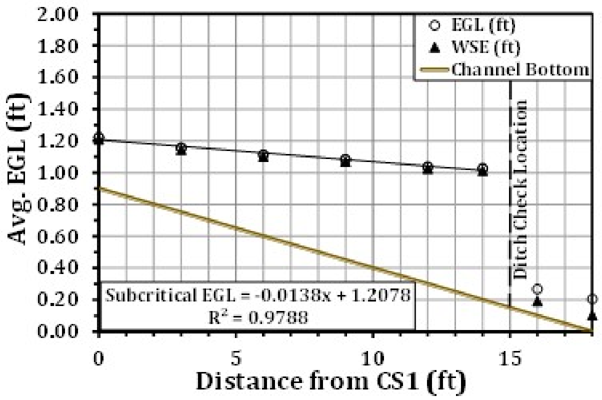
Product	Avg. Length (ft)	Avg. Diameter (in.)	Avg. Weight (lbs)	Avg. Density (lbs/ft^3)
Erosion Eel	9.5	9.4	137.1	30.2
Filtrexx Filter Soxx	10.6	10.4	92.0	14.9



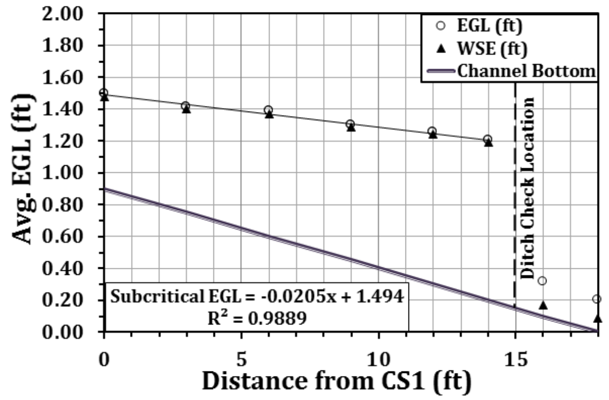
(a) Erosion Eel Average EGL (0.56 cfs)



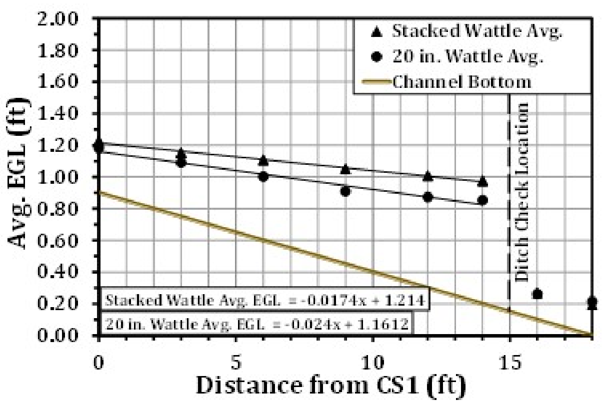
(b) Erosion Eel Average EGL (1.12 cfs)



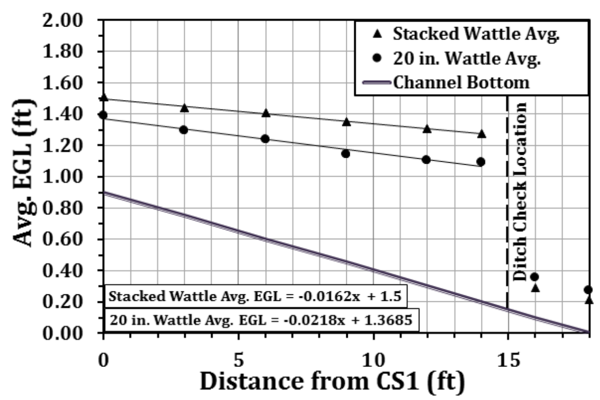
(c) Filtrexx Filter Soxx Average EGL (0.56 cfs)



(d) Filtrexx Filter Soxx Average EGL (1.12 cfs)



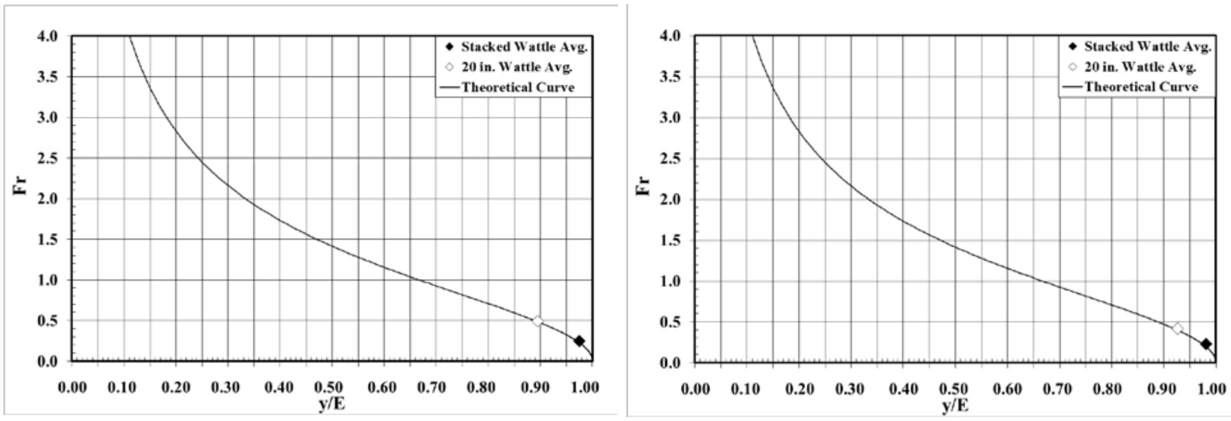
(e) Stacked vs. 20 in. wattle average EGLs (0.56 cfs)



(f) Stacked vs. 20 in. wattle average EGLs (1.12 cfs)

Figure 6.5: Comparisons of Average EGLs for Various Product Installations.

Using the performance criteria of *y/E*, the average performance of the 20 in. diameter wattle installation was compared to the average performance of the stacked installation for both flow tiers, as shown in Figure 6.6. The average *y/E* for the stacked wattle installation was 0.97 and 0.98 for low and medium flow, respectively. The *y/E* for the 20 in. wattle installation was determined to be 0.89 and 0.93 also for low and medium flow, respectively. The *y/E* of the 20 in. wattles is skewed by the excelsior wattles that are high flow through and create much lower *y/E* ratios even at higher flow rates.



(a) 0.56 cfs (low flow) (b) 1.12 cfs (high flow)

Figure 6.6: Performance Criteria for Avg. 20 in. and Stacked Wattle Installations.

6.6 CONCLUSIONS

As this study has shown, the stacked wattle installation is capable of creating favorable conditions for impounding water, reducing flow velocity, and increasing water depth. These conditions help protect earthen channels from erosive forces and create conditions favorable for sedimentation to occur. The stacked installation resulted in a y/E ratio of 0.98. Each product used for this installation study also resulted in a y/E ratio of 0.98 for flows at 1.12 cfs. Both of these y/E ratios are closer to 1 than the average y/E for the standard 20 in. wattle installation. This is most likely due to the density of the products used, rather than the installation. However, the installation does allow the products to perform as intended and therefore is effective as a stacked wattle ditch check practice.

6.7 RECOMMENDATIONS FOR IMPLEMENTATION

As a result of this testing effort, the research team recommends a stacked installation using smaller diameter wattles that employs the same installation practices used for the standard 20 in. wattle installation. This installation practice includes using the teepee, nondestructive staking pattern and an 8 oz. filter fabric underlay to minimize undercutting and protect the channel | wattle interface from erosion. The recommended installation will consist of three smaller diameter wattles using a stacked installation comprised of two wattles lined up perpendicular to flow and one wattle placed on top of the seam generated by the bottom two wattles creating a pyramid shaped, stacked installation. From this study, it is apparent that this installation practice will yield similar hydraulic performance as the standard 20 in. wattle installation and will keep installation practices simple and not require separate installations for the 20 in. and stacked installation.

6.8 REFERENCES

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CHAPTER 7: PERFORMANCE CRITERIA

7.1 INTRODUCTION

Determining a performance criteria for ditch checks requires determining a metric to comparatively evaluate various practices and manufactured products. A properly performing ditch check slows runoff, creating impoundment pools of water with velocity approaching zero and water depths increasing above critical depth creating subcritical flow. These pools of low velocity impoundments will reduce channel erosion and create conditions favorable for sedimentation to occur. The performance of a ditch check could be evaluated and compared based on pool length of the impoundment, however the pool length is affected by many factors (e.g., channel geometry and slope, ditch height, etc.). These factors create difficulty in selecting a fixed pool length as acceptance criteria for the performance of various ditch checks. Therefore, as part of this research effort, an in-depth hydraulics study of open channel flows and data analyses were performed to propose an objective performance criteria for evaluating ditch check performance.

During this research effort, each wattle on ALDOT List II-24 was tested using a tier flow test regime of 0.56 cfs, 1.12 cfs, and 1.68 cfs for ten minutes each for a total test duration of 30 minutes. Through testing, it was determined that structural stability was compromised for denser wattle products at flow rates of 1.68 cfs. As a result of these failures, wattle products tested in the future will be evaluated based upon low and medium flow rates of 0.625 and 1.25 cfs, respectively. These flows represent the average flow rates for the peak 90 minutes of the 2-year, 24 hour runoff hydrographs for a 0.5 and 1.0 acre drainage basin that mimics an Alabama highway median. The test channels used for product evaluation will be 5% longitudinally sloped with 4 ft wide bottoms and 3:1 side slopes.

7.2 CRITERIA DATA COLLECTION AND CALCULATIONS

To determine a performance criteria for ditch check practices and products being tested, water depth (y) and water velocity (v) were measured at six cross sections spaced 3 ft apart spanning 15 ft upstream of the ditch check. The average water depth was used to calculate the cross sectional area of flow for each cross section. The cross sectional area can be calculated by using Equation 7.1.

$$A = (B + my)y \qquad \text{(EQ. 7.1)}$$

where,

A = cross sectional area (ft^2)
B = channel bottom width (ft)
m = side slope of the channel (horizontal to vertical H:V)
y = flow depth for a specific cross section (ft)

The specific energy (E) was calculated using Equation 7.2.

$$E = y + \frac{v^2}{2g} \qquad \text{(EQ. 7.2)}$$

where,

E = specific energy (ft)
y = flow depth for a specific cross section (ft)
v = average velocity measured for each cross section (ft/sec)
g = acceleration due to gravity (32.2 ft/sec^2)

The Froude number is used in open channel flow to express the ratio of inertial forces (kinetic energy) to gravity forces (*Crowe et al., 2001*). For open channel flow, the Froude number is defined in Equation 7.3.

$$Fr = \frac{v}{\sqrt{gD}} \quad \text{(EQ. 7.3)}$$

where,

Fr = Froude number
v = average velocity measured for each cross section (ft/sec)
g = acceleration due to gravity (32.2 ft/sec^2)
D = hydraulic depth (ft)

The hydraulic depth (D) in Equation 7.3 is the cross sectional area (A) divided by the top width (T) of the flow at each cross section. The top width of flow for a trapezoidal channel is defined in Equation 7.4.

$$T = B + 2my \quad \text{(EQ. 7.4)}$$

where,

T = top width of flow (ft)
B = bottom width of the channel (ft)
m = side slope of the channel (H:V)
y = flow depth for the cross section (ft)

The hydraulic grade line (HGL) is defined by Equation 7.5.

$$HGL = y + z \quad \text{(EQ. 7.5)}$$

where,

HGL = hydraulic grade line which equals the water surface elevation (ft)
y = water depth (ft)
z = elevation of the channel bottom measured from a datum (ft)

The energy grade line (EGL) is defined by Equation 7.6 (*ASTM 2006*).

$$EGL = HGL + \frac{v^2}{2g} \quad \text{(EQ. 7.6)}$$

where,

EGL = energy grade line that equals HGL plus the velocity head (ft)
HGL = hydraulic grade line that equals the water surface elevation (ft)
v = average water velocity in the cross section (ft/sec)
g = gravitational constant (32.2 ft/sec^2)

When the *HGL:EGL* ratio is calculated, a relationship that shows the interaction of flow depth and flow velocity is created. The ratio *HGL:EGL* approaches 1 when velocity is approaching zero and the *EGL* is dominantly dependent upon water depth. As the ratio decreases from 1, the velocity head becomes more dominant. However, the channel bottom elevation (z) used in calculating both the *HGL* and *EGL* increases or decreases the effect of water depth y and velocity head on the *HGL:EGL* ratio depending on the scale used for z (i.e., the datum used to determine z). Therefore, if z is eliminated from *HGL* and *EGL*, the ratio becomes y/E, where $E = y + v^2/2g$ is specific energy (*Akan, 2006*). Basically, if the datum is set at the channel bottom for one to compute *HGL* and *EGL*, then $HGL/EGL = y/E$. Therefore, specific energy (E) interprets the total flow energy relative to the channel bottom (*Akan, 2006*).

The Froude number determines proportions of inertial forces to gravitational forces of flow. An open channel flow is typically controlled by two domain forces: (1) gravitational force (driving force) and (2) fluid frictional forces due to fluid viscosity and channel roughness. The inertial forces or kinetic forces are forces associated with fluid motion (*Crowe et al., 2001*) when gravitational forces overcome fluid frictional forces. The Froude number basically describes which force is stronger; the gravitational force, which its component along the channel slope is in the direction of flow, or the frictional force, which is acting against the gravitational force. For Froude numbers greater than one, the flow has higher velocity and shallower water depth. However, for Froude numbers less than one, the flow has lower velocity and high water depth, creating less erosive force within the channel. The Froude number requires the calculation of hydraulic depth, thereby requiring knowledge of the channel geometry.

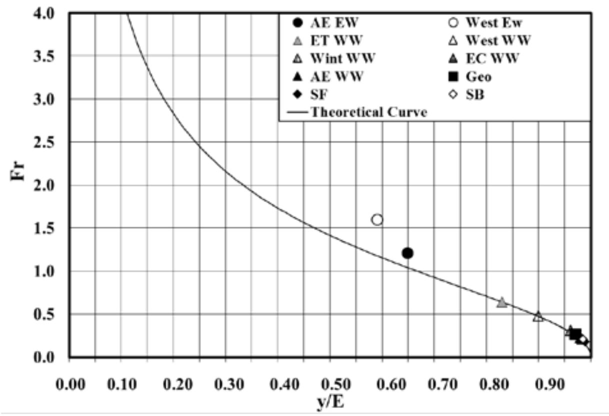
This is important since the y/E function does not directly take into consideration channel geometry when the velocity measurements are taken within the testing channel. When the Froude number is plotted against the y/E ratio, a 3rd order polynomial function is created. This function has an inflection point that designates the change in flow behavior of the channelized flow restricted by a ditch check. A consistent inflection point from data created by different flow conditions and different channel geometries would allow data to be compared between tests performed on channels of different dimensions using various flow rates. Theoretical data were generated to determine if this relationship could be further understood. A theoretical curve was developed from incremental depth of 0.0001 using a specified flow rate and calculating the cross sectional area and resulting velocity using Equation 7.7. This theoretical curve is shown in Figure 7.1 with the data for each wattle tested. The performance criteria shown in Figure 7.1 is based on two flow rated parameters: y/E as the x-axis and Froude number (Fr) as the y-axis. Both parameters are directly linked to the flow velocity. Higher velocity in the impoundment pool of a ditch check results in a smaller y/E and larger Fr. Therefore, the lower right corner of Figure 7.1 is associated with lower velocity in the impoundment pool that has lower erosive forces in the channel, which means the ditch check performs better.

$$Q = vA \tag{EQ. 7.7}$$

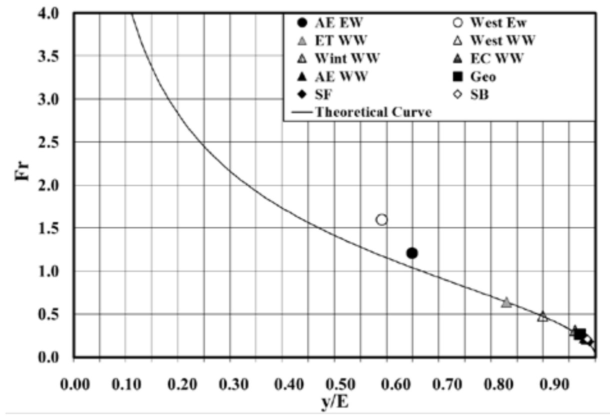
where,

Q = flow rate (ft^3/s)
v = average velocity (ft/s)
A = cross sectional area of flow (ft^2)

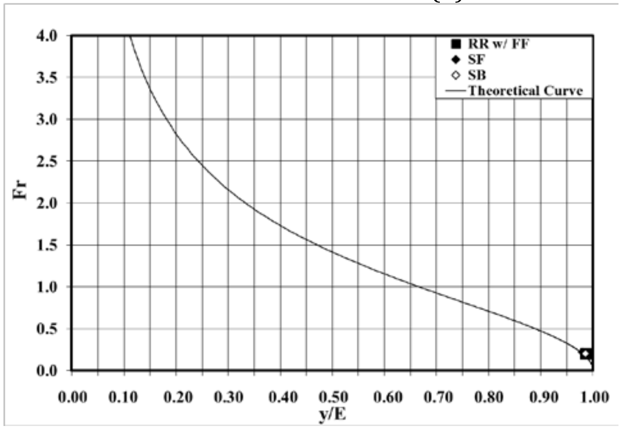
Figure 7.1 shows the performance based criteria and the actual performance of various ditch check practices (i.e., wattles, silt fence, sand bags, and rock) under low (0.56 cfs), medium (1.12 cfs), and high flow conditions (1.68 cfs). From testing, the flow rates for which wattle ditch checks were analyzed are 0.56 cfs and 1.12 cfs. The 0.56 cfs, low flow condition allows ditch checks to be evaluated based upon the protection they provide within the earthen channel during low flow conditions, typically resulting in a shorter impoundment length. The 1.12 cfs flow rate was used to evaluate the maximum impoundment pool created by a ditch check and to ensure the structural integrity of the installation is maintained under medium flow conditions. Therefore, performance criteria used to evaluated wattle ditch check practices at the AU-ESCTF should be based upon the data from these two flow rates and specified channel geometry. However, it is also important to realize that other channel geometries and other flow rates may also be used to test products, and knowing if a performance criteria can be developed from these conditions is also of interest. Figure 7.1(a) and Figure 7.1(b) show the results of the enhanced silt fence (SF), sand bag (SB), and 20 in. nominal diameter wattle ditch checks under the low to medium flow conditions. Figure 7.1(c) shows the results of the enhanced traditional SF, SB, and riprap with filter fabric choker (RR w/FF) ditch checks under high flow conditions. Each enhanced traditional ditch check practice resulted in a y/E ratio of 0.98 or above at all flow rates tested.



(a) ditch checks tested at 0.56 cfs



(b) Ditch checks tested at 1.12 cfs



(c) ditch checks tested at 1.68 cfs

Figure 7.1: Performance Criteria Based Upon Avg. Performance and Theoretical Data.

The incremental, theoretical data generated from Equation 7.7 allows the specific energy equation (E) and Froude number to be determined from the incremental water depth as each depth is related to flow rate, channel bottom width, and side slopes. The data set can be analyzed using a numerical method to take the first and second derivatives of the function created by the data set. The first derivative identifies the locations of minima and maxima using Equation 7.8, and the second derivative identifies points of inflection using Equation 7.9. The dependent variable (Y) is the Froude number, whereas the independent variable (X) is the ratio y/E. Therefore, Equation 7.8 represents the relationship of the change in Froude number with respect to the change in y/E.

$$\frac{dY}{dX} = \frac{\Delta Fr}{\Delta(\frac{y}{E})} \qquad \text{(EQ. 7.8)}$$

where,

$\frac{dY}{dX}$ = first derivative of the Fr vs. y/E relationship

ΔFr = change of Fr ($Fr_i - Fr_{i+1}$) on the theoretical cure of Fr vs. y/E (Fig. 1)

$\Delta(\frac{y}{E})$ = change of y/E ($y/E_i - y/E_{i+1}$) on the theoretical cure of Fr vs. y/E (Fig. 1)

The first derivative will show the approximate location of the inflection point, however, taking the second derivative will better pinpoint the location within the data set. The second derivative can also be estimated numerically as shown in Equation 7.9.

$$\frac{d^2Y}{dX^2} = \frac{\Delta[\frac{\Delta Fr}{\Delta(\frac{y}{E})}]}{\Delta(\frac{y}{E})} \quad \text{(EQ. 7.9)}$$

where,

$\frac{d^2Y}{dX^2}$ = second derivative of the Fr vs. y/E relationship

$\Delta[\frac{\Delta Fr}{\Delta(\frac{y}{E})}]$ = change of the first derivative of Fr vs. y/E relationship $(\frac{\Delta Fr}{\Delta(\frac{y}{E})}^{i} - \frac{\Delta Fr}{\Delta(\frac{y}{E})}^{i+1})$

$\Delta(\frac{y}{E})$ = change of y/E $(y/E_{i} - y/E_{i+1})$

Using the theoretical data calculated from the incremental depth, five different scenarios (Table 7.1) were evaluated to determine the effect of flow rate and channel geometry has on the location of the inflection point on the Fr versus y/E function. Table 7.1 tabulates these scenarios and shows the resultant location of the inflection point with respect to the y/E relationship. These scenarios are the AU-ESCTF ditch channel geometry and three test flow rates, a small scale lab test channel at Auburn Hydraulics Laboratory, and the test channel described by ASTM D7208.

Table 7.1: Location of Inflection for Different Ditch Check Testing Scenarios

Scenario	Flow Rate (cfs)	Bottom Width (ft)	Side Slope (m:1)	Location of Inflection (y/E)
AU-ESCTF	0.56	4	3	0.75
AU-ESCTF	1.12	4	3	0.75
AU-ESCTF	1.68	4	3	0.75
Lab Channel	0.25	1	0	0.75
ASTM D 7208	3	2	2	0.74

Table 7.1 shows the location of the inflection point is approximately located at y/E equals 0.75. This is important because the inflection point signifies a change in behavior. For this function, the change in behavior occurs as a result of the specific energy becoming depth dominate as velocity nears zero and the ratio y/E moves closer to equaling 1.

Upstream cross-sections 1 through 6 represent 15 ft upstream of the ditch check. If the ditch checks were spaced based upon geometry, then the required spacing for a 1.5 ft (18 in.) tall ditch check on a 5% slope channel would be 30 ft. Based upon this spacing, if the average Fr versus average y/E falls within the criteria of y/E equal to or greater than 0.75, then this signifies that at least half the channel between two ditch checks is protected by a low velocity impoundment that will help protect the channel from erosion while also creating conditions favorable for sedimentation to occur. This criteria is shown in Figure 7.1 with the average performance data for each product for the flow rates of 0.56 and 1.12 cfs. From Figure 7.1 it can be seen that the American Excelsior's excelsior (AE EW) wattle does not satisfy the $y/E \geq 0.75$ criteria for both the low and medium flow rates tested. The average y/E for the Western Excelsior's excelsior wattle (West EW) also did not meet the minimum acceptance criteria for the low flow condition. For the medium flow condition, West EW produced a y/E ratio of 0.77, which just satisfies the minimum y/E criteria of 0.75 for the medium flow condition.

The excelsior wattles do not fall on the theoretical line because the Fr to y/E relationship is not a linear line and the resultant Froude numbers for two upstream cross sections (CS1 and CS2) were very high, skewing the average off the theoretical line.

The Fr versus y/E relationship has provided a criteria for which ALDOT and possibly other state highway agencies can use to communicate with manufacturers the minimum performance criteria products must satisfy to be included on qualified product lists as a ditch check practice. This relationship may also allow researchers to normalize the data so that direct comparison of performance data from ditch check tests performed at different facilities using different flow rates and channel dimensions can be made by comparing the actual data to the theoretical curve.

7.3 CONCLUSIONS

A performance criteria was developed to determine if a ditch check product or practice is affecting the runoff adequately to protect earthen channels from erosive shear stresses caused by high velocity flows and creating conditions favorable for sedimentation to occur. A metric to compare this hydraulic performance was determined using the ratio of water depth to the specific energy. Measurements were taken at 3 ft intervals for 15 ft upstream of the ditch check to determine an average ratio of y/E. Using the location of the inflection point occurring in the function for the Froude number and y/E ratio, a minimum criteria of y/E equal to 0.75 was identified as the point at which the hydraulic behavior changes from velocity driven flow to depth dominated flow. All ditch check products or practices to be used on ALDOT highway construction sites must satisfy this minimum criteria in order to ensure that the product or practice will perform adequately to protect earthen channels from erosion.

7.4 RECOMMENDATIONS FOR IMPLEMENTATION

As a result of this research effort, the research team recommends that the ALDOT accepts the performance criteria methodology described above for evaluating all manufactured ditch check products submitted to the ALDOT Product Evaluation Board (PEB) for approval and inclusion on ALDOT List II-24. The researchers also recommend that the ALDOT accepts the minimum performance threshold of y/E = 0.75 for the acceptance of manufactured products being considered for use as ditch checks on ALDOT construction projects. It is recommended that all future testing of wattles used as ditch checks be tested at a low and medium flow rates of 0.625 cfs and 1.25 cfs, respectively. Lastly we recommend that all other ditch checks (e.g., silt fence, rock, manufactured systems) be tested at flow rates (i.e., 0.625, 1.25, and 1.875 cfs) resembling low, medium, and high flow conditions, respectively. The selected flow rate shall be based on the intended purpose of the practices or at the discretion of the product manufacturer seeking product/system approval, in order to determine the maximum capabilities of the product/system. These flow rates represent the average flow rate for the peak 90 minutes of the 2-year, 24 hour runoff hydrograph for a 0.5 and 1.0 acre drainage basin that mimics an Alabama highway median. The test channels used for product evaluation will be 5% longitudinally sloped with 4 ft wide bottoms and 3:1 side slopes.

7.5 REFERENCES

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