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

Large-scale Channel Testing (ASTM D 7208 – modified) of Evaluation of Various Wattle Installation Configurations using a 20 in. Wheat Straw Wattle over Poorly Graded Sand

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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 neighboring water bodies. These may be unstabilized and highly susceptible to erosive shear stresses in high velocity runoff. Therefore, best management practices, such as wattle 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 wattle ditch check installation practice performance to help the Alabama Department of Transportation (ALDOT) better maximize wattle ditch check performance in the field. 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*.

Statistical analyses indicated that trenching, stapling, and a filter fabric underlay significantly affected 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.

This study concluded that ALDOT's current installation of only staking a wattle to an unstabilized channel can be improved. With the addition of a filter fabric (FF) underlay to protect the channel bottom at the installation area from scour and using sod staples in addition to teepee staking to secure the wattle in place while increasing ground contact, channel erosion and undercutting of the wattle can be reduced. Therefore, it is the recommendation of this study that the '*Teepee w/8 oz. FF + Staples*' installation be used to install 20 in. diameter wattles as ditch checks for maximum runoff control performance.

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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.

The purpose of this report is to examine and summarize the effects various wattle installation configurations have on a wattle's overall performance when used as a ditch check. Seven different wattle installation tests are compared to a control test (i.e., no wattle installation) to determine performance improvement based on velocity reduction, impoundment length, and structural integrity. Each ditch check installation was tested using field-scale, replicable test protocols.

2 BACKGROUND

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 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.

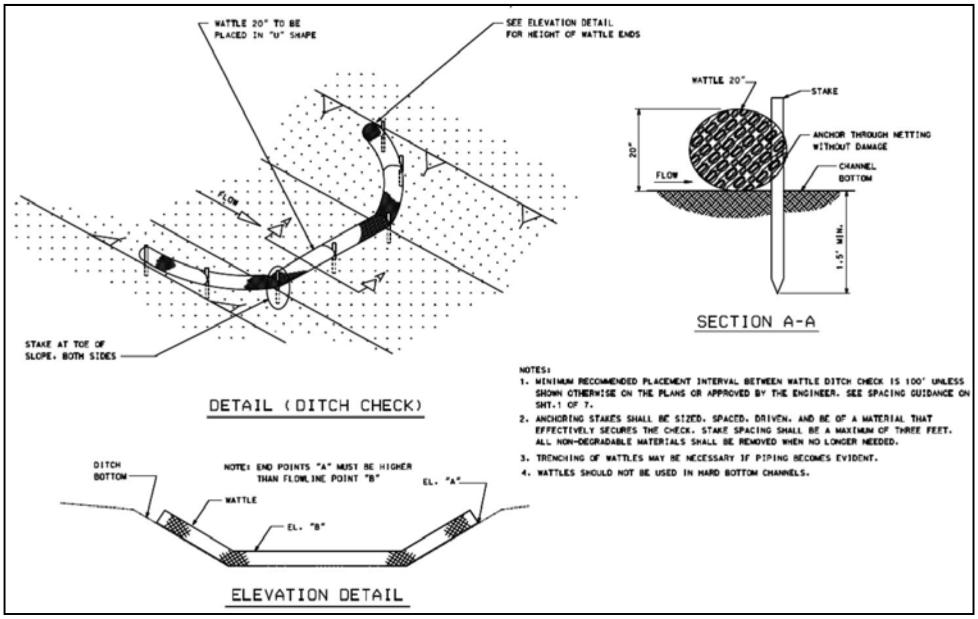
As a result of their research, McEnroe and Treff (*8*) implemented several new ditch check practices for field evaluation to compare against hay bale ditch checks including a Triangular Silt Dike™ (TSD), rock ditch checks, and bio-logs. A TSD is a triangular polyurethane foam insert wrapped in geotextile 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.

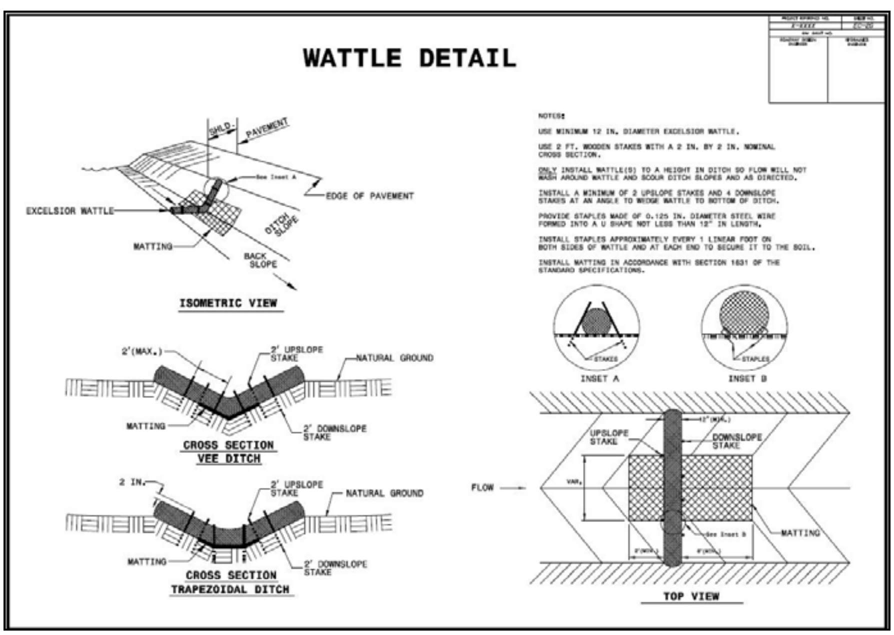
McLaughlin et al. (*10*) concluded that the ideal ditch check spacing has water impounding back up the slope, to the immediate downstream side of the preceding upstream ditch check. Therefore, the spacing is a function of ditch check height (or diameter) and channel slope. This creates a series of subcritical 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.

2.2 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 1(a) along with NCDOT's standard wattle installation detail in Figure 1(b) (*11*).



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



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

Figure 1: Comparison of ALDOT and NCDOT Wattle Installation Practices.

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, a field-scale ditch check testing methodology was developed and applied to evaluate the improvement effects various wattle installation configurations have on wattle performance.

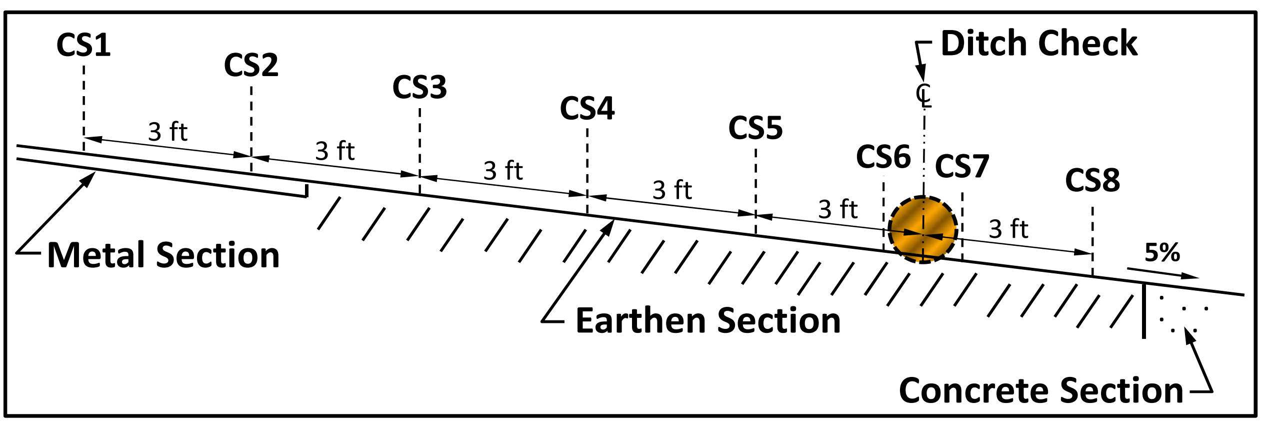
3 TESTING METHODOLOGY

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.

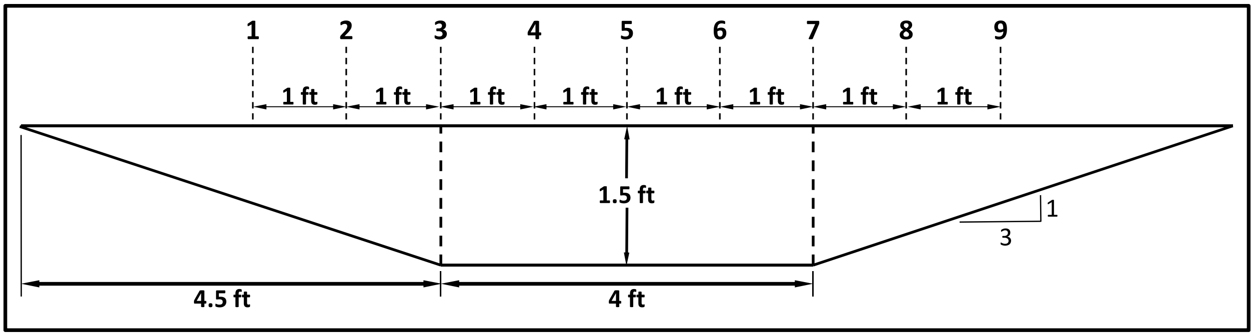
The standard test method referenced for the development of the testing methodology used in this study was ASTM D 7208-06: *Standard Test Method for Determination of Temporary Ditch Check Performance in Protecting Earthen Channels from Stormwater-Induced Erosion* (*7*).

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 2(a) and 2(b).



(a) Elevation View



(b) Cross-Sectional View

Figure 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 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.

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.

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 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 2(b) during each test.

3.3 Installation Evaluation Regime

A series of constant flow, large-scale ditch check experiments were performed to evaluate each installation configuration. These were done to comparatively analyze the seven different wattle ditch check installation configurations. For each installation configuration, including the control with no wattle installed, three replicate tests were performed, totaling 24 large-scale experiments.

3.3.1 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).

3.3.2 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 2(a).

3.3.3 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 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 3 provides a photographic comparison of the control set-up and seven installation configurations prior to testing. Figure 3 shows the FF underlay that was used to prevent erosion within the channel (Figures 3(d), (e), (g), and (h)) and the two staking patterns.

(a) Control

(b) Downstream Staking

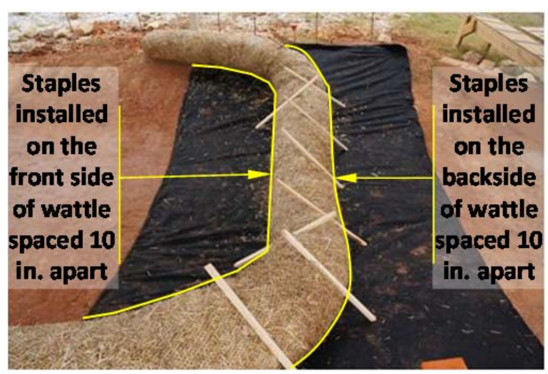
(c) Teepee Staking

(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 3: Control and All Wattle Installations Tested.

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 Figures 2(a) and 2(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 (*7*).

$$EGL = WSE + v^2/2g \tag{1}$$

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 wattle. 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 to impounding water and reducing erosion due to shear stresses, the installation must also withstand hydrodynamic pressure force in the front face of the wattle and possible lifting force underneath the wattle while simultaneously maintaining the integrity of the installation and ditch.

3.5 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.

$$f(x) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n \tag{2}$$

where,

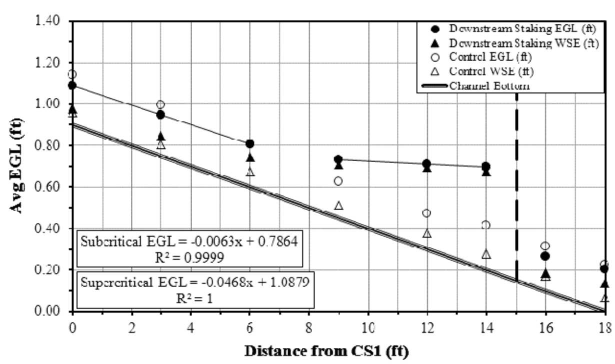
$f(x)$ = dependent variable (e.g., subcritical flow length or impoundment length)
x_i = independent variables (e.g., trenching, stapling, staking, or the underlay)
β_i = the ordinary least squares coefficients

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

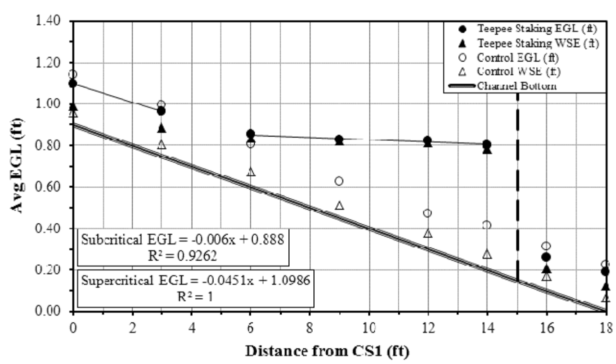
4 RESULTS AND DISCUSSION

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.

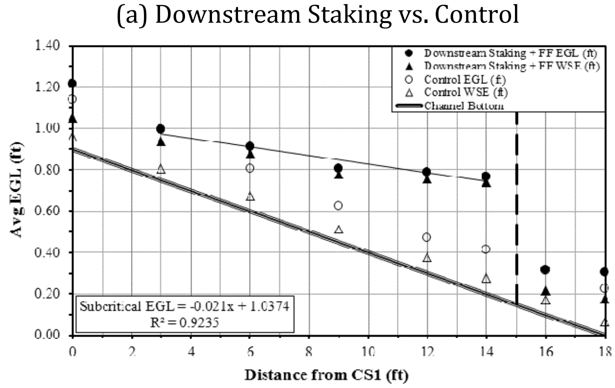
The current ALDOT installation practice, referred to as *Downstream Staking*, is considered a destructive installation practice because stakes pierce and potentially damaging the wattle netting. This staking pattern was tested and compared to the nondestructive *Teepee Staking* pattern. Data analysis 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 4. The EGL and water surface elevation (WSE) are plotted for each. In Figures 4(a) and 4(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.



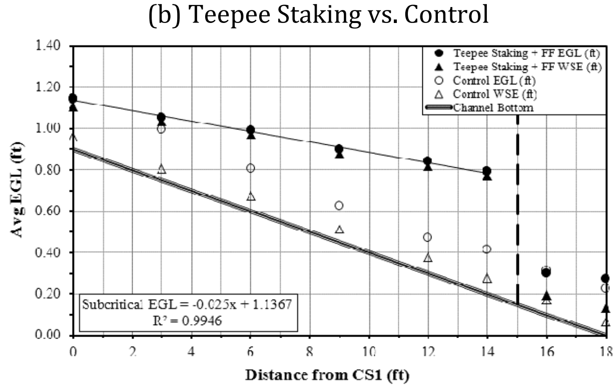
(a) Downstream Staking vs. Control



(b) Teepee Staking vs. Control



(c) Downstream Staking w/FF vs. Control



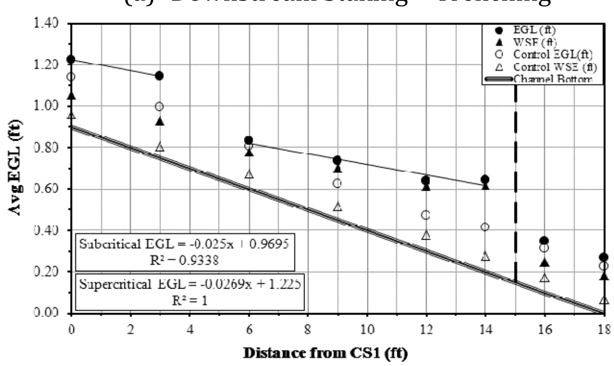
(d) Teepee Staking w/FF vs. Control

Figure 4: Comparisons of EGL and WSE for Various Installations.

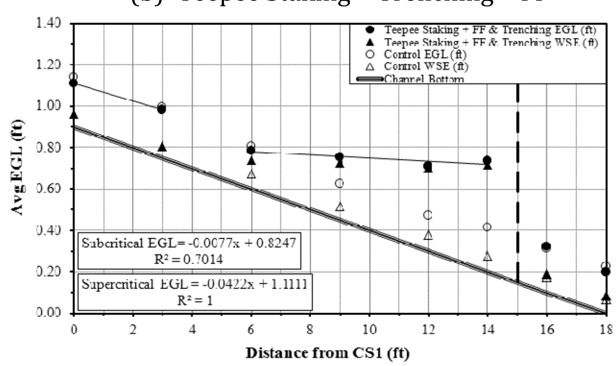
ALDOT and many manufacturers recommend trenching the wattle if piping becomes evident (*4, 13*). This installation was tested using the *Downstream Staking w/Trenching* installation and resulted in a decrease in impoundment length with an average subcritical flow length of 9 ft (2.7 m) which was 1.3 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 5(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 5(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



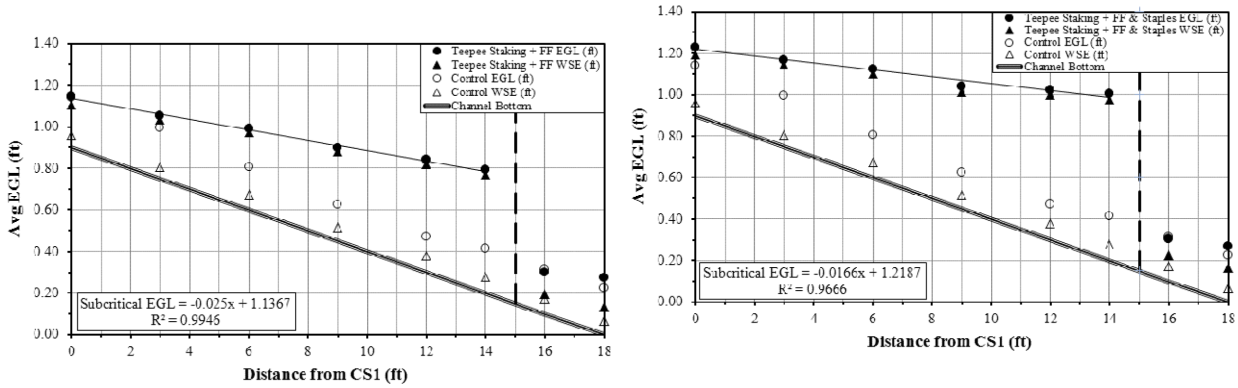
(c) Downstream Staking + Trenching vs. Control



(d) Teepee staking + Trenching + FF vs. Control

Figure 5: 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 6 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 6: Installation Comparison with and without Staples.

The impoundment lengths as well as the EGL slopes are tabulated in Table 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 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 6. 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 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).

4.1 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.

Table 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, 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. 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.

5 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.

6 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.

7 ACKNOWLEDGEMENTS

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