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

**Large-scale Channel Testing
(ASTM D 7208 – modified)**

Performance Criteria Report

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EXECUTIVE SUMMARY

To properly evaluate ditch check practices and manufactured products, a metric or limit must be established to determine acceptable performance levels. Flow, geometry, and sediment conditions can vary and make comparative analyses difficult. Therefore, a criteria that can compare products and practices regardless of channel geometry and flow was determined by the researchers at the Auburn University–Erosion and Sediment Control Testing Facility (AU–ESCTF). This criteria is based solely on the hydraulic conditions created by 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. A minimum average y/E ratio of 0.75 (ft/ft) for one half the length between ditch checks spaced by geometry signifies the hydraulic point at which the behavior of the flow changes from velocity driven to depth dependent. As y/E approaches one, the kinetic energy developed by the flow is transforming into potential energy as velocity approaches zero in the impoundment pool created by a ditch check. When the Froude number is plotted against y/E for the same flow and channel conditions, a 3rd order polynomial is created with an inflection that occurs at y/E equal to 0.75. Though computing the Froude number requires knowledge of the channel geometry, the ratio y/E determined from depth and velocity measurements does not directly use geometry as input parameter; therefore, the plot of the Froude number versus y/E creates an optimum metric function for developing the acceptance criteria for ditch check product and practice performance evaluations.

As a result of this research effort, the research team recommends that the ALDOT accepts the performance criteria methodology described herein for evaluating all manufactured products submitted for use as a ditch check 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.

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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.

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 1.

$$A = (B + my)y \quad (\text{EQ. 1})$$

where,

- A = cross sectional area (ft²)
- 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 2.

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

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/sec²)

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 3.

$$Fr = \frac{v}{\sqrt{gD}} \quad (\text{EQ. 3})$$

where,

- Fr = Froude number
- v = average velocity measured for each cross section (ft/sec)
- g = acceleration due to gravity (32.2 ft/sec²)
- D = hydraulic depth (ft)

The hydraulic depth (D) in Equation 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 4.

$$T = B + 2my \quad (\text{EQ. 4})$$

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 5.

$$HGL = y + z \quad (\text{EQ. 5})$$

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 6 (ASTM 2006).

$$EGL = HGL + \frac{v^2}{2g} \quad (\text{EQ. 6})$$

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/sec²)

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. This theoretical curve is shown in Figure 1 with the data for each wattle tested. The performance criteria shown in Figure 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 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.

$$Q = vA \tag{EQ. 7}$$

where,

- Q = flow rate (ft³/s)
- v = average velocity (ft/s)
- A = cross sectional area of flow (ft²)

Figure 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 evaluate 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 1(a) and Figure 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 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.

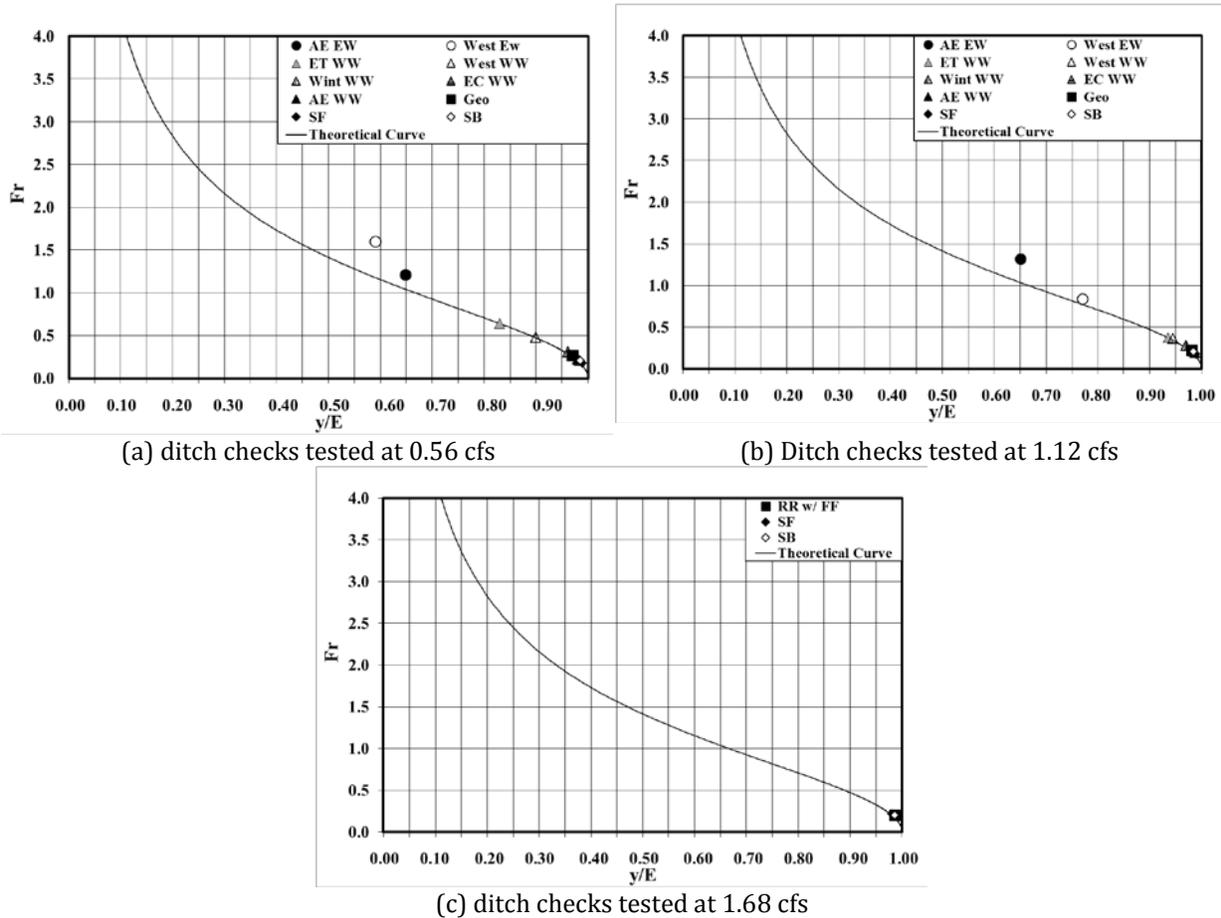


Figure 1: Performance Criteria Based Upon Avg. Performance and Theoretical Data.

The incremental, theoretical data generated from Equation 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 8, and the second derivative identifies points of inflection using Equation 9. The dependent variable (Y) is the Froude number, whereas the independent variable (X) is the ratio y/E . Therefore, Equation 8 represents the relationship of the change in Froude number with respect to the change in y/E .

$$\frac{dY}{dX} = \frac{\Delta Fr}{\Delta(\frac{y}{E})} \quad (\text{EQ. 8})$$

where,

$$\begin{aligned} \frac{dY}{dX} &= \text{first derivative of the } Fr \text{ vs. } y/E \text{ relationship} \\ \Delta Fr &= \text{change of } Fr (Fr_i - Fr_{i+1}) \text{ on the theoretical cure of } Fr \text{ vs. } y/E \text{ (Fig. 1)} \\ \Delta(\frac{y}{E}) &= \text{change of } y/E (y/E_i - y/E_{i+1}) \text{ on the theoretical cure of } Fr \text{ vs. } y/E \text{ (Fig. 1)} \end{aligned}$$

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 9.

$$\frac{d^2Y}{dX^2} = \frac{\Delta[\frac{\Delta Fr}{\Delta(\frac{y}{E})}]}{\Delta(\frac{y}{E})} \quad (\text{EQ. 9})$$

where,

$$\begin{aligned} \frac{d^2Y}{dX^2} &= \text{second derivative of the } Fr \text{ vs. } y/E \text{ relationship} \\ \Delta[\frac{\Delta Fr}{\Delta(\frac{y}{E})}] &= \text{change of the first derivative of } Fr \text{ vs. } y/E \text{ relationship} \\ &= \left(\frac{\Delta Fr}{\Delta(\frac{y}{E})^i} - \frac{\Delta Fr}{\Delta(\frac{y}{E})^{i+1}} \right) \\ \Delta(\frac{y}{E}) &= \text{change of } y/E \text{ (} y/E_i - y/E_{i+1} \text{)} \end{aligned}$$

Using the theoretical data calculated from the incremental depth, five different scenarios (Table 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 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 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 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 1 with the average performance data for each product for the flow rates of 0.56 and 1.12 cfs. From Figure 1 it can be seen that the American Excelsior's excelsior (AE EW) wattle does not satisfy the *y/E* ≥ 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.

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.

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.

5 REFERENCES

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