Assessing the Performance of Grass Cover on Flood Embankments

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ABSTRACT: Grass cover on flood embankments and embankment dams helps to provide protection against erosion that might occur during overtopping or overflow conditions. This protection can prevent or at least delay the onset of breach during flood events. The performance of grass cover may be taken into account when undertaking a flood risk assessment, and with increasingly extreme load conditions arising from climate change impacts, the need to consider acceptable overflow conditions as part of the performance design of a flood embankment means that a reliable method for the assessment of the performance of grass cover becomes increasingly important. A range of publications and guidance exists regarding the maintenance of grass cover, but only a limited number of guides provide specific guidance on the performance of grass under overflow or overtopping conditions. Many of these publications appear to be based upon limited and similar data sets collated many decades ago. The applicability of concepts developed for different grass species and climates to embankments in Europe is also unclear.

As part of the EU FloodProBE project a review of grass performance research under overflow and overtopping has been undertaken. The purpose of this review was to establish what guidance existed and what data this was based upon in order to identify whether or not existing guidance could be improved upon through further analysis of available data or whether additional research was required to improve the reliability of performance prediction. Data and research performed at the USDA research centre in Stillwater, Oklahoma, USA, has also been reviewed, since this appears to under-pin much of the existing guidance. This paper provides an overview of the review findings along with recommendations as to how we might improve the reliability of predicting grass performance under varying load conditions.

1 BACKGROUND

FloodProBE is a European research project that has an overall objective of providing cost-effective solutions for flood risk reduction in urban areas. To achieve this, it aims to develop technologies, methods and tools for flood risk assessment and for the practical adaptation of new and existing buildings, infrastructure and flood defences leading to a better understanding of vulnerability, flood resilience and defence performance. It also supports implementation of the Floods Directive through the development of more effective flood risk management strategies. The work is being undertaken in close partnership with industry, and is utilising pilot sites across Europe, to help provide practical industry guidance and cost effective construction solutions.

The FloodProBE activities have been structured according to the following work packages (WPs):

- WP2 addresses issues related to the vulnerability understanding and assessment of the vulnerability of urban areas or systems.
- WP3 deals with failure modes and the assessment and identification of weak spots in urban flood defences.
- WP4 investigates cost-effective construction technologies and concepts for improving the performance of existing and new flood defences and for increasing the flood resilience of urban systems and assets.
- WP5 supports integration of the research and newly developed knowledge into existing decision support models or systems, the production of industry guidance and the interaction and integration of pilot site studies across Europe.
- The dissemination and stakeholder-involvement activities are addressed under WP6 whilst WP1 comprises all activities related to the management of the consortium.

The work described in this paper forms part of the WP3 research programme. The two key goals of this WP are:
1. To improve fundamental understanding of erosion failure processes that have proven to be critical in recent major flood events in urban areas.
2. To increase the effectiveness and efficiency of risk based asset management by applying and refining innovative and cost-effective measurement and monitoring technologies in combination with other information sources for the identification of high risk areas (weak spots).

To achieve the first objective, the following topics related to the flood defences performance have been investigated:
1. Internal erosion.
2. Structure transitions.

This paper focuses on the performance of vegetation during flooding, i.e. it attempts to address the questions of how well grass can protect the underlying soil when subjected to flow and what are the limiting loadings that will remove (or partly remove) the grass cover and hence remove the protection this provides against soil erosion. In this context, vegetation is taken to mean grass cover on earthen flood embankments; this research does not address the performance of woody vegetation or trees on flood embankments.

2 INTRODUCTION
2.1 Why grass cover is important

The grass surface cover on a flood embankment protects against soil erosion and can either prevent breach or delay the onset of breach. Assessing the performance of grass in this context is therefore an important aspect of the overall performance assessment (and hence flood risk assessment) for flood embankments.

The significance of grass cover performance is increased if “acceptable overtopping / overflow” is permitted as part of flood risk management practice. Under such conditions, the estimated performance of the flood embankment will include and depend upon the performance of the grass cover. The impacts of climate change appear to be leading towards more extreme conditions for both hydraulic loading (magnitude of flood event) and climatic conditions (prolonged wet and dry periods). These changes pose an increasing pressure upon the performance of grass on flood embankments. Not only do the hydraulic load conditions increase, but the environment pressures affecting the quality and stability of the grass cover are also changing.

2.2 Scope of work

The aim of this research is the development of extended or revised guidance based upon a review of European and International research results and existing grass performance data from the last 25 years. Specific research actions on grass performance comprises:
- A review of project initiatives related to the performance of grass.
- Confirmation of existing European and US guidance on grass performance, followed by identification of either (i) Updates to guidance using existing international research findings or (ii) clarification of longer term R&D needs to improve knowledge and performance of embankment grass cover layers.

3 LITERATURE REVIEW

The performance of grass during flooding has been studied by a number of organisations in Europe and worldwide. In order to build upon the knowledge gained from these studies, a literature review was undertaken. The main objectives of this review were to:
- Identify major work that was or is being undertaken to assess vegetation performance during flooding.
- Undertake critical analysis of the work identified above.
- Gain greater understanding of the performance of grass during flooding.
- Recognise gaps in knowledge.
- Propose a way forward (to improve performance guidance for use in flood risk management).

The literature review was structured according to the following two main categories:

1. Literature related to grass performance under (steady) overflow conditions
2. Literature related to grass performance under (wave) overtopping conditions

3.1 Overflow Literature

There have been a number of initiatives to assess the performance of grass under overflow conditions. The Soil Conservation Service (SCS) of the US Department of Agriculture (USDA) developed a method for the design of grass-lined channels based on a permissible velocity approach in 1954. The method adopted the Manning equation as the resistance equation and established a dependency of the Manning roughness coefficient, n, on the product VR (V being the mean flow velocity and R the hydraulic ra-
This method established five different retardance classes corresponding to different levels of resistance to the flow offered by various American grasses. A curve n-VR was allocated to each class as shown in Figure 1.

\[ \tau_e = \gamma y S (1 - C_F) \left( \frac{n_s}{n} \right)^2 \]  

where:
\( \gamma \) = the unit weight of water;  
\( y \) = the flow depth;  
\( C_F \) = the vegetal cover factor (values between 0.5 and 0.9 are suggested, depending on the type of vegetation);  
\( n_s \) = the Manning’s coefficient associated with the soil only; and  
\( n \) is the Manning’s coefficient for the whole channel.

According to this method, the effective tractive force is then compared with the allowable tractive force for the channel (variable according to the type of soil) to check whether the design is valid or not. This condition was enhanced by further testing by the USDA Agriculture Research Services (ARS) to take into account the duration of flow (or overflow) by integration of the erosionally effective stress over time and thus determine the point of effective failure of the grass cover. The value of the integral corresponding to cover failure is shown in Equation 2 (NRCS, 1997):

\[ \int_0^{t_f} \tau_e \, dt = 0.2 I_w + 1 \]  

where:
\( t_f \) = the time corresponding to failure with time expressed in hours;  
\( \tau_e \) = the erosionally effective stress expressed in lb/ft²; and  
\( I_w \) = the plasticity index of the soil material being eroded.

In Europe, the Construction Industry Research and Information Association (CIRIA) in the UK in 1976 published a technical note (Whitehead, 1976) to provide guidance on the use of grass to stabilise surfaces subject to erosion by the intermittent flow of water. The note (TN71) included recommendations on grass mixtures, establishment and management procedures. The protection against erosion was expressed in terms of a velocity-duration envelope (i.e. the length of time for which a grass surface can safely withstand a given flow without dangerous erosion). Figure 2 shows a velocity - duration diagram which is based on information from various laboratory investigations.

\[ \int_{t=0}^{t_f} \tau_e \, dt = 0.2 I_w + 1 \]  

where:
\( I_w \) = the plasticity index of the soil material being eroded.

TN71 was also updated by CIRIA in 1987 (Hewlett et al, 1987) to set out the procedure and principles for the planning and design of plain and reinforced grass waterways. The CIRIA report (Report 116) recommends the use of limiting velocity vs overflow duration curves for the design of plain and reinforced grass types. Figure 3 shows the curves provided in this report.

Other work that followed the CIRIA publication, such as the ‘Use of vegetation in civil engineering’ report (Coppin & Richards, 1990) and the ‘Waterway bank protection: a guide to erosion assessment and management’ report (Environment Agency, 1999) focused on the performance of grass along channels rather than grass on embankments.

A number of other initiatives also existed in Europe such as The Urban River Basin Enhancement Methods (URBEM) project (2002-2005) which was funded by the EC under the 5th Framework to provide new tools, techniques and procedures to enhance watercourses located in urban areas across
Europe. The project gave specifications for new materials and techniques that use bioengineering to improve stream performance including performance during flooding. Those techniques also incorporate an aesthetic aspect to improve the visual view of the river defences in urban areas. The resistance limits of these soil bioengineering methods were given in the project report and were either based upon investigations or from experiences (Faber, 2004). They were based upon limiting shear stress or velocity.

Based upon this review, three methods were identified to assess grass performance under overflow conditions. These were:


Following identification of these methods, the next step was to evaluate their capability in assessing grass performance. Two test cases were selected for this purpose; Section 4 contains a description of the test cases, modelling undertaken and analysis of the modelling.

3.2 Overtopping

The Dutch research programme SBW (Strength and Loads on Water Defences) includes the latest research into the performance of grass cover under wave overtopping; the project started in 2007 and will proceed until 2017. The programme aims to update the statutory safety assessment tools for primary water defences in The Netherlands.

The research has led to a technical report on the safety assessment of grass covered dikes, yet to be published (2012 -in Dutch). However, the following papers on the SBW wave overtopping tests are in English and give a good summary of the developments: Van der Meer et al. 2010; Steendam et al. 2010, Van Hoven et al. 2010.

Wave overtopping is different from overflow (Section 3.1). By definition, in the case of wave overtopping the still water level is below the defence crest level and only waves overtop the crest. In the case of overflow, the still water level exceeds the crest level. The subsequent hydraulic load on the grass is also different. For overtopping, the load is highly variable, pulsating as waves of different height and period result in different overtopping volumes, water depth and flow velocity. In between overtopping events the slope can become dry for some time. Overflow is a constant discharge, flow velocity and water depth.

Water defences along the sea, estuaries and lakes are generally designed to have extra crest height to prevent or limit wave overtopping. These defences are typically challenged by high water levels in combination with severe storm conditions and waves; however, river defences can also experience a combination of high water level with wind and waves.

The current Dutch statutory assessment tool for erosion of grass covers in the case of wave overtop-
ping is based on the limiting velocity graph in Figure 3, however, somewhat adjusted (Figure 4).

\[
\begin{align*}
&v_r = 700 \frac{H}{T_p} \left( 0.085 - \frac{H}{L_{op}} \right) \left( 1 - \frac{z}{z_q} \right)^{0.5} \tan \alpha \\
&\text{(3)}
\end{align*}
\]

Where the sea state is characterized by \( H_c \) (m), the significant wave height, \( T_p \) (s), the wave peak period and \( L_{op} \) (m), the deep water wave length. The dike geometry is described by the (averaged) slope angle \( \alpha_c \) (deg.), \( z \) (m) the crest level relative to a reference level and \( z_q \) (m) the crest level relative to the same reference level, at which the average overtopping discharge is 0.1 l/s per m. Note that \( z_q \) will be an imaginary level if the dike is lower than this level. Equation 3 limits the overtopping load \( v_r \) to zero if the average overtopping discharge is lower than 0.1 l/s per m. Parameter \( z_q \) can be calculated using the EurOtop manual (www.overtopping-manual.com).

The grass quality is determined by assessing parameters such as maintenance strategy, grass and herb species inventory, grass coverage percentage and root density. These parameters determine whether the grass quality is good, average or poor. Use of the graph is limited to a sand content in the sod, by mass, of 70% for a good grass quality and to 50% for an average or poor grass quality.

The loading time \( t_{sr} \) (hour) is reduced, accounting for the duration the slope is not attacked by a wave induced current i.e., the time between wave overtopping events. The correction on the storm duration \( t_s \) is given by:

\[
\begin{align*}
&t_{sr} = \left( 1 - \frac{z}{z_q} \right) t_s \\
&\text{(4)}
\end{align*}
\]

The actual assessment consists in comparing the reduced loading time \( t_{sr} \) (hours) with the lines in Figure 4. If \( t_{sr} \) stays within the lines, the assessment result is “good”. If \( t_{sr} \) stays within the highlighted band, the assessment result is “sufficient”, else the grass fails the assessment and needs to be improved.

The effect of the pulsating hydraulic load caused by wave overtopping is not incorporated in the failure prediction model, although it was thought to have considerable influence. This observation led to the initiation of the research on grass erosion in the SBW programme, using the wave overtopping simulator on actual dikes in The Netherlands (Van der Meer et al. 2006).

More than twenty sections of grass have been tested so far. Each section is four metres wide and covers primary dikes at different locations throughout The Netherlands and Belgium.. The test loads reached a maximum average discharge of 75 l/s per m given a wave height \( H_c = 2 \) m. The maximum overtopping volume produced by the simulator was 5500 l/m (22000 l over the 4 m wide test strip). Tests were carried out in the winter season when the grass was weakest and the chance of storms is the largest. The substrate quality varied from plastic clay to sand. The grass quality was mostly “good” according to the current assessment tool, however, the quality “poor” was also tested.

Overall, the test results indicate that a closed grass sod can withstand much more than the current Dutch design guidelines of 0.1 or 1 l/s per ‘m. Compared to the current safety assessment tool described above, the differences are not that pronounced.

Observations and analyses during the testing period from 2007 up until 2012 has lead to a proposal of an improved failure model for erosion of grass due to wave overtopping (Van der Meer et al. 2010).

\[
\sum_{i=1}^{n} (u_i^c - U_i^c) = 1000 \\
\text{(5)}
\]

Where \( u_i \) (m/s) is the maximum depth averaged flow velocity during the \( i \)-th overtopping wave in a storm situation where \( n \)-(-) waves produce an overtopping event, \( U_c \) (m/s) is the critical velocity depending on the grass quality and the value of 1000 \((\text{m}^2/\text{s}^2)\) represents a damage type, in this case multiple sod damages but not yet failure of the grass cover. At a value of 500 \(\text{m}^2/\text{s}^2\) incidental damage of the sod occurs, at 3500 \(\text{m}^2/\text{s}^2\) failure of the grass cover can occur.

Using the formulations on wave height distribution within a standard, common, wave field in the EurOtop manual the model leads to the following graph for practical use. The graph predicts the overload \((\text{m}^2/\text{s}^2)\) for a one hour sea state and dike geometry described by \( H_c \) and \( q \). The value of \( U_c \) in this case is set at 4 m/s which was found to be a lower boundary for a closed sod and hence a dense root system. Note that the value of \( U_c \) is dependent on the root density within the substrate and could possibly vary with different types of vegetation e.g. grass.
The test data upon which the graph is based were from The Netherlands and Belgium.

![Image](image_url)

Figure 5. Overload (m²/s²) for a one hour storm event described by \( q \) (l/s per m) and \( H_s \) (m).

The storm duration (hour) should be multiplied by the result of the graph to acquire the overload for the full storm duration.

The load is described by the average overtopping discharge \( q \), the significant wave height \( H_s \) and the load duration. The combination of \( q \) and \( H_s \) generate a distribution of over topping volumes. Each over topping volume results in a characteristic maximum depth average flow velocity along the crest and landward slope. With steep slopes (steeper than 1V:2.5H) the flow velocity tends to increase significantly and with a mild slope (more gentle than 1V:4H) the velocity tends to decrease, however, this effect has not yet been incorporated in the model.

The strength of the grass cover was observed to be mainly dependent on the dense root system of the grass, and not much on the substrate plasticity or sand content. The sand in the tested sand dike seemed cemented, or bonded, which is probably for a large part subsequent to the grass sod root system. Even damaged spots and subsequent gully erosion did not lead to a quick failure of the grass cover for the sand dike. The roots still present and cemented sand underneath the grass sod were still erosion resistant against overtopping. Any limitations regarding a maximum sand content in the substrate have been left out in the proposed failure model.

4 TEST CASES, MODELING AND PERFORMANCE EVALUATION

In this section, details of the modelling work that has been undertaken to evaluate the capability of the different (overflow performance) methods identified during the review detailed above are presented together with the test case data that was used.

4.1 Evaluation methodology

The main objective of the evaluation was to investigate how the performance of the different methods compared over a range of conditions. This allows the understanding of how the underlying assumptions of each method (e.g. considering or not considering soil type, effect of grass type and quality, etc.) could affect the results. This, in turn, helps to conclude which method(s) should be used or updated for future use.

A number of parameters were chosen for the evaluation. These parameters were selected on the basis that they could significantly impact the grass performance during an overflow event. A list of the selected parameters with a brief definition of each is given below:

1. Maximum overflow head\(^1\) which is the maximum depth of water applied on the grass during an overflow event.
2. Downstream (dry) slope which is the vertical to horizontal distance ratio.
3. Critical shear stress which is defined as the threshold stress below which no soil erosion occurs.
4. Soil erodibility which represents the erosion rate of the soil.
5. Soil plasticity index which is defined as the difference in moisture content between the soil liquid limit and the soil plastic limit.
6. Vegetation type which is linked to the friction of different vegetation types
7. Vegetation quality which describes the uniformity, density and length of the grass.

Since grass performance Methods 1 and 2 are velocity based whereas the Method 3 is shear stress based (which means they use different criteria to predict the grass cover failure), it was necessary to find an approach that allows the performance comparison to be undertaken objectively. A solution was to use two breach models, within which the grass performance methods were already coded, to simulate the various test conditions. The HR BREACH model (Mohamed (2002), and Morris (in prep.) and the WINDAM B model (Visser et al, 2010) were therefore used to simulate the failure of the grass cover using the three different methods. Taking this approach avoids calculating intermediate values whilst helping to ensuring that identical test case conditions were used for the comparisons.

4.2 Test Cases

Identification of suitable test case data to evaluate grass performance was not an easy task. Data show-

\(^1\) Changing the overtopping head was achieved by lowering and raising the breach initial invert level.
ing grass failure due to flooding is rare and often incomplete. However, USDA data (Hanson et al., 2005) was a good source for such information and provided data on two embankment cases for testing. The two test cases were test embankments that were 2.23 m high and 7.32 m long with other geometric details as shown in Figure 6. The embankments were constructed from silty sand (Test case 1) and clay-loam (Test case 2) soils both with an average to poor quality of grass cover. Table 1 shows the soil properties of each case.

### Table 1. Test case soil properties

<table>
<thead>
<tr>
<th>Gradation</th>
<th>Test case 1</th>
<th>Test case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Clay &lt; 0.002 mm</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td>% Silt &gt; 0.002 mm</td>
<td>25</td>
<td>49</td>
</tr>
<tr>
<td>% Sand &gt; 0.105 mm</td>
<td>70</td>
<td>25</td>
</tr>
<tr>
<td>Plasticity Index</td>
<td>Non-plastic</td>
<td>17</td>
</tr>
<tr>
<td>Unconfined Compressive Strength (kN/m²)</td>
<td>20.30</td>
<td>67.92</td>
</tr>
<tr>
<td>Average Dry Density (g/cm³)</td>
<td>1.71</td>
<td>1.65</td>
</tr>
<tr>
<td>Average Water Content @ construction (%)</td>
<td>8.9</td>
<td>16.4</td>
</tr>
<tr>
<td>Average Total Density (g/cm³)</td>
<td>1.87</td>
<td>1.92</td>
</tr>
<tr>
<td>Erodibility Coefficient kd (cm³/N.s)</td>
<td>10.2</td>
<td>0.04</td>
</tr>
<tr>
<td>Critical stress tc (kN/m²)</td>
<td>0.00</td>
<td>0.01</td>
</tr>
</tbody>
</table>

#### 4.3 Modelling results and analysis

The evaluation results for the two test cases are presented in the following sections:

##### 4.3.1 Test Case 1

Table 2 shows the parameter variations that were used for Test case 1 whilst Figure 7 shows the results for each parameter.

The results show that for this test case some parameters do not have any impact on the grass performance in all methods. These parameters are the soil erodibility and critical shear stress. This was because those parameters are not included in the grass performance assessment formulation in all of the methods. The plasticity index variations showed a significant impact for Method 3 but not for Methods 1 and 2. This can also be explained as the plasticity index is only included in formulation of Method 3. Other parameters such as the overtopping head, the downstream slope and the vegetation quality show various degrees of impact with the vegetation quality showing the highest impact. Vegetation type was not varied for Methods 1 and 2 as they do not inherently have this in their formulation. But, this was varied for Method 3 and surprisingly did not have any effect on the failure time of the grass. This was investigated and found that it could be because the grass cover had a maintenance code of 3 (i.e. poor) with short length and low density. Therefore, vegetation type features did not have a significant impact on the results.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base case</th>
<th>Var. 1</th>
<th>Var. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breach initial invert level (m)</td>
<td>32.25</td>
<td>31.95</td>
<td>32.55</td>
</tr>
<tr>
<td>Downstream (dry) slope</td>
<td>1:3</td>
<td>1:2</td>
<td>1:4</td>
</tr>
<tr>
<td>Critical shear stress (kN/m²)</td>
<td>0.00</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Soil erodibility (cm³/N.s)</td>
<td>10.2</td>
<td>5.1</td>
<td>20.4</td>
</tr>
<tr>
<td>Soil plasticity index</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Vegetation type</td>
<td>Bermuda</td>
<td>Buffalo</td>
<td>Mixture / alfalfa</td>
</tr>
<tr>
<td>Vegetation quality</td>
<td>Poor / 3</td>
<td>Medium /2</td>
<td>Good /1</td>
</tr>
</tbody>
</table>

Generally, the three methods followed one trend for all variations in the selected parameters which is that:

1. Method 2 (CIRIA 116 curves) suggested the most rapid failure times
2. Method 3 (USDA equations) suggested the slowest failure times
3. Method 1 (TN71 curves) typically falls between the Method 2 and 3 predictions.

It should be also noted that in comparison to observed test data, all the methods predicted a slower failure than the actual failure time.

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2 Applicable for Method 3 only.
3 Vegetation quality is expressed as poor, medium and good in Methods 1 and 2. This is equivalent to maintenance code 3, 2 and 1, respectively, in Method 3.
The failure time results. Variation in the plasticity index also showed a significant impact for Method 3 but not for Methods 1 and 2 and the overtopping head, the downstream slope and the vegetation quality showed various degrees of impact with the vegetation quality showing the highest impact. The influence of vegetation type was also identical to Test Case 1, also because of the low quality of the grass cover.

For this second test case, the relative performance of the 3 methods followed the same trends as for Test Case 1, namely:

1. Method 2 (CIRIA 116 curves) suggested the most rapid failure times
2. Method 3 (USDA equations) suggested the slowest failure times
3. Method 1 (TN71 curves) typically falls between the Method 2 and 3 predictions.

The most notable difference between the results of Test Case 2 and Test Case 1 is in the comparison of the model predictions with the actual failure time. In Test Case 2, Methods 1 and 2 predicted faster failure than observed, while Method 3 predicted slower.

5 CONCLUSIONS

The review of current guidance, and the data upon which this guidance is based, highlighted some noteworthy issues:

1. Practical and detailed quantitative guidance on performance of grass is quite hard to find. There appear to be many research initiatives, but little generic guidance with actual methods provided for the design or performance analysis of grass cover. To the contrary there seems to be plenty of general guidance on the maintenance and use of vegetation.

2. A lot of research initiatives seem to focus on the hydraulic resistance of grass / vegetation to flow, rather than performance of the grass in protecting soil from erosion.

3. Research relating to grass performance under wave overtopping – rather than overflow – is currently being investigated through the Dutch SBW programme (2007 – 2017). Initial results start to provide revised guidance for grass performance under wave overtopping conditions.

4. Based upon the literature review undertaken, the main sources of guidance on erosion pro-

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**Table 3. Parameters variation for Test Case 2**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base case</th>
<th>Var. 1</th>
<th>Var. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breach initial invert level (m)</td>
<td>32.25</td>
<td>31.95</td>
<td>32.55</td>
</tr>
<tr>
<td>Downstream (dry) slope</td>
<td>1.3</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Critical shear stress (kN/m²)</td>
<td>0.01</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Soil erodibility (cm³/N.s)</td>
<td>0.04</td>
<td>0.02</td>
<td>0.08</td>
</tr>
<tr>
<td>Soil plasticity index</td>
<td>17</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Vegetation type</td>
<td>Bermuda</td>
<td>Buffalo</td>
<td>Mixture / alfalfa</td>
</tr>
<tr>
<td>Vegetation quality</td>
<td>Poor / 3</td>
<td>Medium /2</td>
<td>Good /1</td>
</tr>
</tbody>
</table>

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4 Applicable for Method 3 only.
5 Vegetation quality is expressed as poor, medium and good in methods 1 and 2. This is equivalent to maintenance code 3,2 and 1, respectively, in method 3.
tection from grass cover (overflow) seem to be limited to:


It should be noted that the CIRIA 116 method builds from the CIRIA Technical Note 71 data. It also incorporates USDA data, hence all three methods are related to some degree.

5. The extent to which US grass performance data is valid in Europe remains unclear. Where grass performance is related to root density, soil strength etc. it would seem ‘transferable’, but research looking at this issue does not appear to have been undertaken. The CIRIA 116 design guidance does incorporate US data within the analysis.

The method comparison highlighted some interesting issues:

1. The CIRIA 116 design curves consistently predicted quicker grass failure times than the CIRIA Technical Note 71 data. This is consistent with the inclusion of a factor of safety into the CIRIA 116 performance curves (Morris et al., 2010). Users of the CIRIA 116 curves should note that a factor of safety has been included since the relevance of this differs if the curves are used for design or performance / reliability assessment (with design leading to a safer design, whilst with performance assessment, leading to a pessimistic assessment of behaviour).

2. The USDA approach incorporates the plasticity index, which reflects to a degree, the soil erodibility (Morris, in prep). This shows a significant variation in performance, as soil erodibility reduces, whereas the CIRIA methods show no variation, because soil parameters are not considered.

It would seem logical that the physical process of grass erosion, with the removal of roots from the soil, would also relate to the resistance of the underlying soil to erosion. The trend in breach analysis is towards the use of soil erodibility in order to improve representation of the embankment performance. Similarly, with the likely trend being towards design or planning for acceptable over flow during increasingly extreme flood events, adoption of a method that includes representation of soil erodibility would seem sensible.

At the time of writing further test data was being sought through which to widen the range of method comparison before drawing final conclusions for future development of grass performance guidance.

REFERENCES

The International Levee Handbook project. See www.leveehandbook.net


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