# THE ROLE OF UNDERCUTTING OF BANKS IN THE COLLAPSE AND EVOLUTION OF SMALL CHANNELS.

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**ABSTRACT**

*The influence of undercutting in rill banks on the development and collapse of rill banks and on the subsequent evolution of the rill channels were investigated in a laboratory flume. Undercutting of rill banks were observed to develop in rill channels by 'reverse roller' effect of plunging water jet into scour holes, cutting the underside of the head cut wall. The extent of undercutting and the rate of drawdown of water into the rill influenced the collapse of the rill wall. Slumping was the predominant mode of failure of rill banks from this study, although other types of failures were observed. The type and mode of failure determined the amount of soil that collapsed into the rill. This in turn greatly influenced the evolution of the rill channel. Rill bank collapse was observed to contribute as much as* 53% *of the total sediments from the rill. It is therefore emphasized that its effect be included in present-day process- based rill erosion models.*

***KEYWORDS:*** *Rill bank collapse; Undercut; Headcut; Slope; Stability; Evolution*

## 1.0. INTRODUCTION

Rill wall, gully and river bank collapses have been observed in many studies [1,2,3,4,5]. In a related study [6], it was shown that headcutting in rills contribute about 40% of the total sediment yield in a rill. Rill wall collapse can also be a major erosion component especially in rills formed on freshly tilled soils with low cohesion and high capillary pressures. No detailed investigations have been carried out to elucidate this important phenomenon in rills, though it is widely believed that rill wall collapse contributes a good percentage of sediments removed from rills [1] . The predominant failure mechanisms of rill banks have also not been established. Furthermore, the influence of undercuts on the evolution of rills has not received much attention. There is need for studies that focus on the effects of undercuts on rill erosion, especially those conducted under isolated and controlled conditions, if the rill erosion processes are to be completely understood and if better rill erosion prediction models are to be developed.

Most of the existing rill erosion models assume that all soil erosion is due to hydraulic erosion alone. It is hypothesised that better predictions will be achieved if other rill processes are included in the model. This will improve our processed-based modelling of rill erosion, and will provide information to stake holders so that control efforts will be channelled towards combating the most important contributing factors to rill and soil erosion problems. This study was therefore carried out to characterise the dominant factors of sediment production in rills. The specific objective of the study is to determine the influence of undercuts on rill wall stability and the percentage contribution by rill wall collapse to the total sediment produced from a rill channel in an erosion event. Implications from this study can be extended to the role undercutting of rills can play towards the contribution of rills to the development of drainage basin network.

## 2.0. MATERIALS AND METHODS.

This study was carried out in a laboratory flume (3.4m x 1.0m x 0.4m) tilted to a constant slope of 2°. A single rill (at a time) was performed at the centre of a sandy loam soil packed in the flume. The density of the soil after packing at 18% moisture content was between 1.4 and 1.7 *g/cc.* Table 1 shows the physical and textural properties of the sandy loam soil used.

Three different rill sizes (denoted R1, R2 and R3) were used. R1, the smallest rill, had bottom width, w = 4.2cm and depth, d = 2.5cm, while R3, the largest rill had bottom width, w = 7.0cm and depth, d = 4.4cm. The bottom width and depth of the intermediate rill, R2, were 5.0cm and 4.9cm respectively. The rills were trapezoidal in shape, with bank slope angle of 65°. The initial length of the rills was 210cm. Different rill sizes were chosen to investigate how the initial size of the rill affects amount of sediment lost. The sizes used in this experiment were chosen to conform with the rill sizes observed in the same flume in an earlier study [7], and for ease of creating the initial undercuts in the rill banks. Figure 1 shows the sketch of a sloping rill bank with initial undercut made in it.

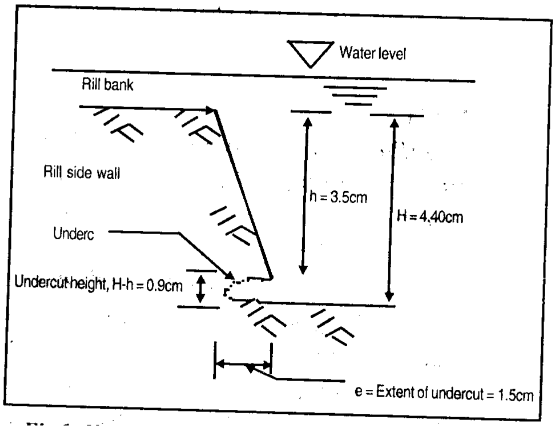


***Fig 1:** Sketch of a half section of a ponded rill bank with undercut*

Three different lengths of undercuts of el = lcm, e1.5 = 1.5cm and e2 = 2cm were used. The undercuts were made into the banks of the pre-formed rill at four locations: two at the upper section (from the inlet up to 65cm length of rill) and two at the lower section (from 130 of the inlet to 190cm) of the rill, but on opposite sides of the channel, offset from each other at 15cm. The longitudinal length of each undercut along the rill varied between 20 and 30cm. Figure 2 is a sketch of the undercutting positions in the rill.

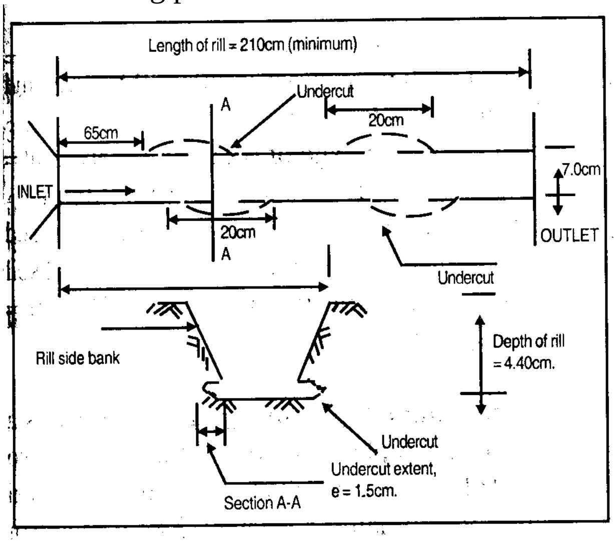


***Fig. 2:** Sketch of the rill indicating undercutting positions.*

**Table 1: Some physical and textural properties of the sandy loam soil used for the experiment**

| Soil | Textural classification, % | | | Particle Diameter> x % passing | | |
|---|---|---|---|---|---|---|
| | Clay | Silt | Sand | $D_{10}$ (urn ) | Dso(μm) | $D_{90}$(μm) |
| Sand | - | 4 | 96 | 212 | 30 | 520 |
| Sandy loam | 13 | 18 | 69 | 65 | 280 | 1800 |

Dry density = 1.6g/cc; Average m.c. = 18.5%; m.c. of soil during runs ranged between 25 and 37% (GMC); Cohesion = 1.98kPa (Shear box test); ϕ = 10°; Void ratio = 0.85. Erodibility = 0.28 (Using erodibility nomograph of Wischmeier et al, 1971). Porosity = 0.46; Density of solids = *2.45g/cc;* Total Water Stable Aggregates =17.24% (>2mm=2.25%, 1-2mm =5.76%, 0.5- 1mm =9.23%). Organic matter content =5.33%

A water flow rate Q = *36ml/s* was applied to the rills. This flow rate was chosen as it was considered large enough to produce adequate erosion effects in the rill. Two replicates were made. The rill channel was first ponded for 10 minutes to ensure complete saturation before release of the flow. Depth of ponding above rill bank in each run varied from 2 to 3cm. This induced drawdown into the rill after the flow was released. The effects of the drawdown and the effect of the extent of undercutting on the rate of collapse, the amount of collapse, and the type of failure of the rill wall were investigated,

Sediment concentration in the flow was measured at the outlet every 1 minute during the first 15 minutes and thereafter at 5 minute intervals. Bulk density, dry density, shear strength, moisture content, percent organic matter content, the soil erodibility, and the total water stable aggregates of the soil were determined before and after the runs. The bulk density and dry densities were determined from undisturbed core soil samples, following the procedure in [8]. The shear strength characteristics (cohesion, C, and angle of shearing resistance $\phi$) were determined using the shear box test method also described in [8]. The moisture content was determined by the gravimetric method, while the organic matter content was determined using the Walkey-Black method described in [9]. The soil erodibility was determined using the erodibility nomograph of Wischmeier etal. [10], while the soil water stable aggregate was determined by the aggregate stability method as described in [11].

Collapse and changes in rill size and profile were measured after each experiment. The number of soil collapse incidents, type of failure of bank at undercuts and other points, and the amount of collapsed soil at these same points were also determined.

## 3.0 RESULTS

### i) Sediment concentration with time

Figure 3a shows the fluctuation of sediment concentration with time, while figure 3b shows a typical total detachment trend with time, In figure 3a, the sediment concentration increased from zero to very high values *(17.4Sg/l)* in about 30 seconds at the initial stages of the run as soon as ponding was released, but then gradually declined with time. The number of rising and falling limbs for the sediment concentration coincided with significant erosion, rill bank collapse, deposition and other events in the rill. More bank collapse occurred in the initial stages of the run. The erosion, the number of collapses and the amount of bank collapse of the rill at the undercuts followed the same declining trend with time.

Different trends were observed at the upper and the lower parts of the rill. The data show that higher values of sediment concentration were obtained at the upper sections than at the lower section (See point No.2 below) In the mid- section to lower section (about 80cm to I80cm from the inlet) of the rill channel, there was more deposition of sediments, silting-up the rill.

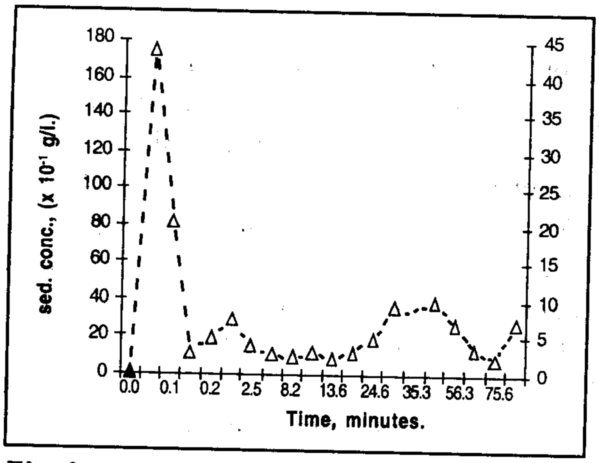


*Fig. 3a: Sediment concentration with time.*

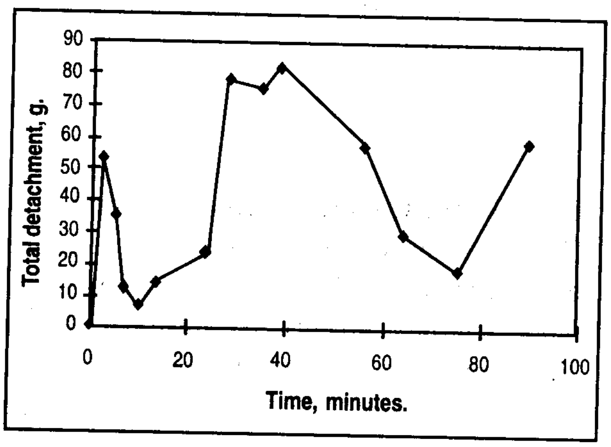


*Fig. 3b: Total detachment trend with time.*

**ii) Amount of soil collapsed at the undercuts.**

A typical example from the data collected is presented here to relate the amount of soil collapse from an undercut to the total discharge of soil from the rill.
Preformed rill side slope = 65°;
Bed floor slope = 2°.
A trapezoidal rill channel was made.
Area of a trapezium = $ZH^2 + bH$, where z = *1*/tanβ, β = bank slope (= 65°), b = bottom width, and H = channel depth
Bottom width, b = 7cm before experiment Average bottom width after experiment = 9cm. Depth, H, of rill = 4.4cm before experiment; Average depth after experiment = 5.52cm.
Length of rill = 210cm. Extent of undercut = 1.5cm.
Area of rill before experiment = 39.83cm$^2$, and after the run = 63.89 cm$^2$
Total volume change of rill after experiment = (63.89 x 210) - (39.83 x 210) = 5052.6cm$^3$.The measured specific weight of the collapse soil is *1.6g/cc.* Therefore, estimated weight of soil eroded after experiment = 1.6 x 5052.6 = 8084.9g = 8.10kg.

**At the Upper LHS undercut** - There was a partial / incomplete collapse of the bank soil, so height of wall, h, that pulled off into the rill channel was = 3cm initially, and later = 3.8cm, length of undercut = 20cm, radius of influence = 5cm. Partial collapse is by tension pull. Volume of collapsed soil = 3.8 x 20 x 5 = 380cm$^3$(assuming a rectangular soil mass)

**At the Upper RHS** - Complete collapse or slump failure occurred when ponding was released.
Length = 30cm, height = 5.5cm, radius of influence = 5cm.
Volume of collapsed soil = 5.5 x 5 x 30 = 825cm$^3$.

**At the Lower RHS**- Partial collapse, (that is, upper part of 3cm still hanging). This implies tensile failure.
L = 14cm, height, h = 2.5cm, radius of influence, r =5cm.
Volume of collapsed soil = 14 x 2.5 x 5 = 175cm$^3$.

**At the Lower LHS** - Complete collapse or slumping failure.
L = 24cm, height, h = 4.5cm, radius of influence, r = 5cm.
Volume of collapsed soil = 24 x 4.5 x 5 = 540cm$^3$. Total volume of soil due to collapse at undercuts = 1920cm$^3$•
Weight of soil collapsed = 1920 x 1.6 = 3072 = 3.1kg.
Total soil lost from rill considering volume change = 8. 1kg;
Percent lost by collapse = (3.1 x *100)/*8.1 = 39%.

Similar calculations with other data obtained from the experiment showed collapse contributing more than 53% of total soil loss from the rill.

iiii) **Predominant mode of rill bank failure due to the undercuts.**

Three main modes of failure for cantilever overhangs have been identified - shear (slumping), beam and tension failures [4, 5]. Table 2 shows the effect of rill size and undercut extent on the mean amount of soil collapse at the pre-formed undercuts and the mode of failure of the bank. Most failures during the experiment were more tensile pull-offs (45 during ponding and 55 during the run), followed by shear or slumping failures (17 during ponding and 53 during the run). Toppling or beam failure occured least (2 during ponding and 3 during the run). This may be due to the fact that the soil was of homogeneous material, with little or no tension cracks developed in the experiments.

**Table 2: Effect of undercut extent and size of rill on the amount of collapse and mode of rill wall failure.**

| Rill size (cm) | Undercut extent (cm) | Type and no. of collapses during ponding | | | Type and no. of collapses during flow | | | No. of collapses during ponding | No. of collapses during flow | Predominant mode | Amount of collapses (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | T | B | S | T | B | | | | |
| Rl | 1.0 | 0 | 6 | 0 | 1 | 8 | 0 | 6 | 9 | T | 1601 |
| | 1.5 | 3 | 2 | 0 | 6 | 6 | 1 | 5 | 13 | S/T | 1454 |
| | 2.0 | 2 | 3 | 0 | 9 | 5 | 1 | 5 | 15 | S | 2461 |
| R2 | 1.0 | 2 | 7 | 0 | 6 | 0 | 0 | 9 | 12 | S/T | 1807 |
| | 1.5 | 3 | 7 | 2 | 7 | 7 | 0 | 12 | 14 | S | 1879 |
| | 2.0 | 2 | 7 | 0 | 4 | 6 | 0 | 9 | 10 | S | 1998 |
| R3 | 1.0 | 1 | 4 | 0 | 2 | 8 | 0 | 5 | 10 | T | 3757 |
| | 1.5 | 3 | 3 | 0 | 7 | 5 | 0 | 6 | 12 | S | 5118 |
| | 2.0 | 1 | 6 | 0 | 11 | 4 | 1 | 7 | 16 | S | 5678 |
| | Total = | **17** | **45** | 2 | **53** | **55** | 3 | | | | |

Rl = rill size with width = 4.2cm and depth = 2.5cm; R2 = rill size with width = 5.0cm and depth = 4.9cm; R3 = rill size with width = 7.0cm and depth = 4.4cm. S = slumping failure, T = tensile failure, B = beam failure; S/T = equal nos. of slumping or tensile failures.

**iv). Effect of interaction of undercut extent and rill size on amount of soil collapse**

When the effects of the interaction of undercut extent and rill sizes on amount of soil collapse were compared, there was no significant difference in the amount of soil collapse for the 1.0 and 1.5cm undercuts for rill size R1, but there was difference between the 2.0cm and the 1.0cm or the 1.5cm undercut for this rill size. There were difference between them and the 2.0cm undercut for rill size R2.

## 4.0. DISCUSSIONS

The stability of the rill banks studied was influenced by the process of undercutting. Since undercutting is a necessary pre-cursor to rill bank collapse, a criterion for rill wall stability must be based on sediment entrainment and transport within the rill channel. The discharge and bank material determine the extent of undercutting that occurs and this in turn influence the rate and frequency of bank collapse.

Tensile failure of the bank at the

undercuts was more predominant for all the extents of undercutting during ponding. But during the experimental run, shear failure (slumping) was the predominant mode of failure for undercut extents of 1.5cm and2cm (15 for slumping, 10 for tensile failure, and a for beam failure). For all the undercuts, the numbers of slumping failures and tensile failures were close (S = 17, T = 20 and B = 0). However, tensile failure contributed the greatest amount of soil collapse at the undercuts (6.6kg total for slumping and 4.2kg total for tension, and only 0kg for beam failure, Table 3). Thus, slumping failure was the predominant mode controlling failure at undercuts. It also affected the changes in the size of the rill more than the other modes of failure, even though tensile failures occurred more frequently. Table 3 shows the effect of different rill sizes to the number of collapses and this in turn influence the rate and frequency of bank collapse.

***Table 3: Effect of size of rill on the number and amount of rill banks collapse***

| Rill size (cm, cm) | Undercut extent, e (cm) | Number of collapsing incident | | | | | | | | Total No. | Grand Total | Amount of Colapse by each type f failure | | | Total amount of collapse | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | During Pnding | | | | During Run | | | | | | | | | | |
| R1 | 1.0 | **S** | **T** | **B** | **T** | **S** | **T** | **B** | **$T_E$** | | | S | T | B | (g) | |
| | 1.5 | 0 | 2 | 0 | 2 | 0 | 4 | 0 | 4 | 6 | | 375 | 0 | 0 | 375 | |
| | 2.0 | 1 | 1 | 0 | 2 | 2 | 2 | 0 | 4 | 6 | 19 | 96 | 214 | 0 | 310 | 23.36 |
| | | 3 | 2 | 0 | 2 | 2 | 3 | 0 | 5 | 7 | | 287 | 573 | 0 | 860 | |
| R2 | 1.0 | 1 | 2 | 0 | 3 | 1 | 2 | 0 | 4 | 7 | | 231 | 195 | 0 | 426 | |
| | 1.5 | 1 | 3 | 1 | 5 | 3 | 3 | 0 | 5 | 10 | 23 | 208 | 313 | 0 | 521 | 23.27 |
| | 2.0 | 1 | 2 | 0 | 3 | 1 | 2 | 0 | 3 | 6 | | 190 | 402 | 0 | 592 | |
| R3 | 1.0 | 1 | 2 | 0 | 3 | 1 | 3 | 0 | 4 | 7 | | 515 | 520 | 0 | 1035 | |
| | 1.5 | 1 | 1 | 0 | 2 | 3 | 1 | 0 | 4 | 6 | 18 | 507 | 709 | 0 | 1216 | 53.36 |
| | 2.0 | 0 | 1 | 0 | 1 | 4 | 0 | 0 | 4 | 5 | | 0 | 1278 | 0 | 1278 | |
| Total | 13 | 6 | 16 | 0 | 23 | 17 | 20 | 0 | 37 | 54 | 60 | 6613 | 4204 | 0 | 6613 | |

Rl = rill size wih width = 4.2cm and depth = 2.5cm; R2 = rill size with width = 5.0cm and depth = 4.9cm; R3 = rill size with width = 7.0cm and depth = 4.4cm. T p = Total number of failures during ponding; T E = total number of failures during run. S = slumping, T = tensile, B = beam falures.

When there is no undercut, the rill bank may remain stable until erosive forces of flow create undercuts to undermine the banks and set in disequilibrium in the bank.

When the rill channels become deeper, shear failure such as rotational slumping become more frequent and takes over the criteria for rill wall collapse. Slumping is controlled by the height, slope and shear strength of the bank material (cohesion of the soil at saturation). Downcutting of rill channel floor is also important for slumping to occur. If high banks due to downcutting are formed and they cannot be supported by the strength of the bank material, shear failure occurs, which widens the rill channel and somehow regulates or controls the extent or degree to which oversteepening of rill channels can occur.

This trend observed in rills can be

likened to the situation in gullies and river channels where oversteepening of channel rarely occurs, because slumping of over-steepened banks aids the widening of the channel. This is the case for homogeneous soil materials. Where the soil is layered, the channel shape is affected by the differential resistance of the layers.

**CONCLUSIONS.**

This study investigated the influence of the extent of undercutting of rills and the size of rills on the stability and evolution of rill walls. The predominant mode of rill bank failure due to the undercuts was also investigated

From the study, the following conclusions can be made:

1. The predominant mode of failure of rill banks is by slumping/shear failure. Tension pull-off of bank soil aids the occurrence of slumping.
2. Presence of undercuts, their extent and the height of rill walls affect the stability of rills.

3. Where and when rill wall collapse occur in rills, they contribute about half the total sediment discharged from a rill.

Based on these, rill wall collapse is an important rill erosion sub-process and should be adequately incorporated in rill erosion models. Such incorporation may improve the prediction of sediment yield from rills. Results from this type of study can also be extended to monitor collapses in gullies and rivers.

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