MODELING DEPTH-AVERAGED VELOCITY IN SINUOUS MEANDERING CHANNEL USING GEP

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ABSTRACT*: Analysis of flow in meandering channel is highly influenced by the geometry of the channel and other flow parameters such as velocity ,pressure distribution and flow profiles on different sectional parameters like width ratio , aspect ratio and relative depth. The geometry selected for this study is that of a smooth sine generated trapezoidal main channel flanked on both sides by wide flood plains. The parameters which are changed in this research work include the overbank flow depth, main channel flow depth ,incoming discharge of the main channel and flood plains. This report presents a practical method to get the discharge value at different section in trapezoidal meandering channels. Flow structure in meandering channels is more complex than straight channels due to 3-Dimensional nature of flow. Continuous variation of channel geometry along the flow path associated with secondary currents makes the velocity computation difficult. Design methods based on straight-wide channels incorporate large errors while estimating discharge in meandering channel. A commercial code, in Gene Expression programming is used to simulate a 90 degree meander channel with sinuosity 2.04 and to obtain the optimum depth-averaged velocity values and to compare with experimental results*

Keywords: *Aspect Ratio; Compound Channel; Discharge; Flow depth; Meandering channels; Secondary currents.*

INTRODUCTION

Modelling of flow using analytical method is very intricate .The advancement in software algorithms made it possible for the engineers and scientists to cope up with the worst situation with an optimum accuracy. In relevance to empirical studies, numerical research on open channels are restricted because it is tough to model flow in open channels than in closed conduits. This is because flow conditions in open channels are clumsy by the fact that the position of the free surface is spatial and time variant. In recent years, the gene expression programming is used to solve a number of critical phenomenon which can't be solved easily by analytical methods. A number of general purpose can now be solved by optimization techniques which are available commercially and academically and could be used in river engineering. They all provide a numerical solution of the continuity and the flow calculations are performed by solving the mathematical equations. The velocity distribution along the channel cross section is an essential investigation . The model equations are solved numerical analysis with a general purpose software set. The depth-averaged velocity distribution were visualised for a 90° bend compound meandering channel. The experimental results of a simple trapezoidal channel were also compared with the numerical analysis results obtained in meandering channel which approximately yielded a better set of results of velocity distribution than those obtained using basic fundamental equation. The work of previous researchers regarding the advancements in numerical modeling of open channel flow has been listed. Macleod (1997) and Lju and James (2000) used neural networks for flow discharge prediction in meandering channel. Lambert and Myers (1998) observed that VDCM with a horizontal division over-estimates the main channel mean velocity while VDCM with horizontal division under -estimates the main channel velocity, and vice versa for the floodplain velocity. Coleman(1981) developed velocity equation for sediment-laden flow in open channel. Sharma (1983) observed velocity distribution for a limited aspect ratio. Maynord, Ruff and Abt (1989) got an idea about the similarities of the local depth-averaged velocity as characteristic velocity. Julien (1995) studied the wide channels and proposed logarithmic form of velocity profile equation which is mostly used for evaluating depth-averaged velocity. Wilkerson G.V (2005) developed two equation in which one equation use velocity data for calibrating coefficient, whereas the second equation uses the evaluated coefficients. This was only restricted to straight trapezoidal channels only. Knight (2007) uses Shiono and Knight Method (SKM), which is a new approach for calculating lateral distribution of depth-averaged velocity for straight prismatic channel taking secondary flow into consideration. Haris et al.(2003) based on genetic programming solved the depth averaged velocity distribution in vegetated flood plains. Sharifi (2009) applied gene algorithm for conveyance estimation in compound channels.

In this paper a new and more accurate method based on the evolutionary Gene Expression Programming has been used to solve the main problem of the study of the velocity distribution across the cross section and to determine the depth-averaged velocity. The channel is meandering and having trapezoidal cross-section. The variables were chosen as per the requirements to develop the modelled equation.

EXPERIMENTAL SETUP AND PROCDURE

Apparatus and Procedure

The experiments were performed using the channel facilities available in the Hydraulics Laboratory of civil engineering department at N.I.T, Rourkela. The fabrication of the channel was made with the Perspex sheet of 6mm thick in dimension inside a tilting flume. The dimensions of the flume were 15m in length with a rectangular cross-section of 4m wide .The bed slope was adjusted by hydraulic jack arrangement. The channel in which the experiment was carried out was having trapezoidal cross-section. The observations were recorded at bend-apex. The figures of the experimental channel are listed below

Channel Photographs

Fig.1 (a) View of Experimental Channel

Fig.1 (b) Rectangular Notch arrangement

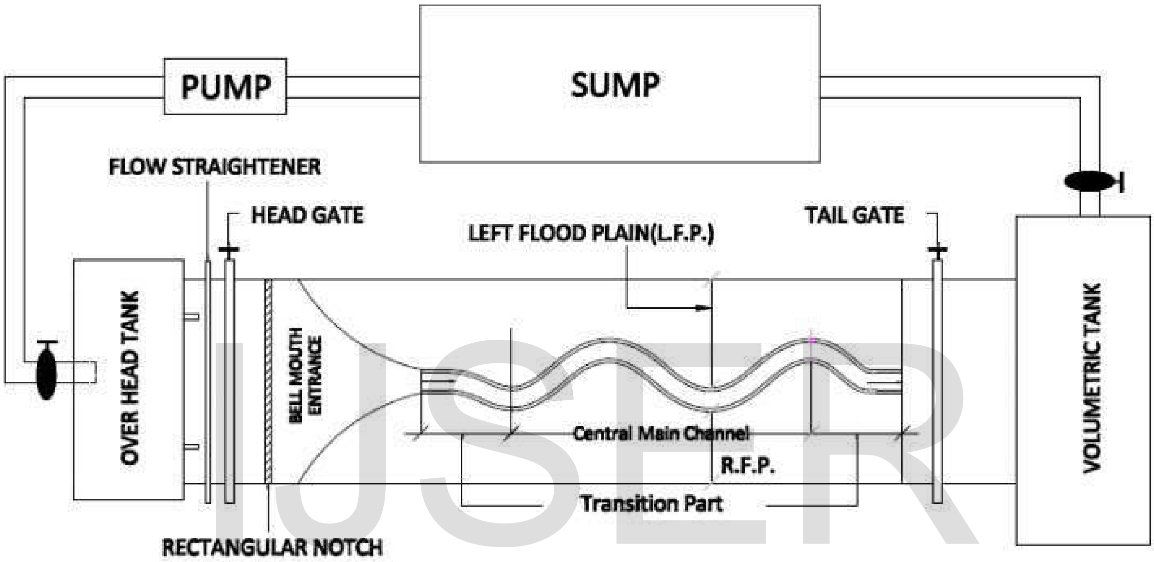
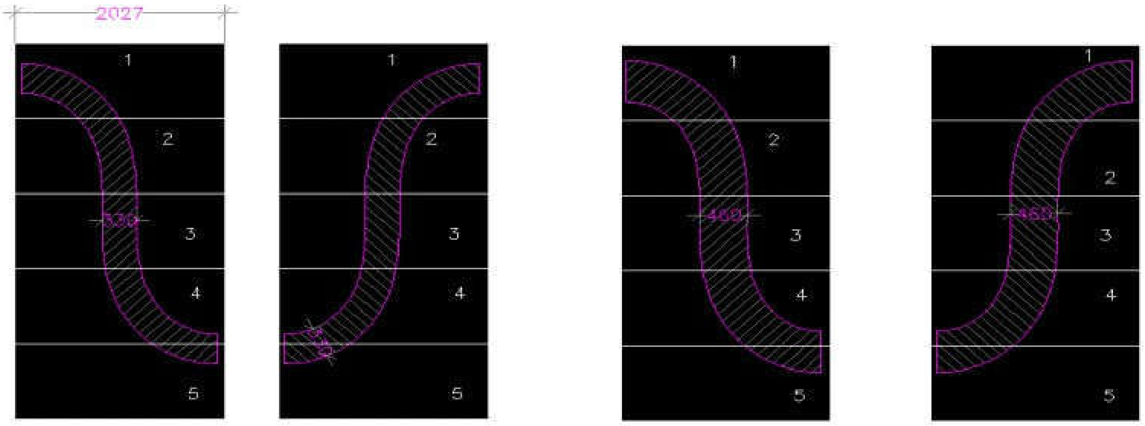


Fig.2 Detailed Plan View of Meandering Channel

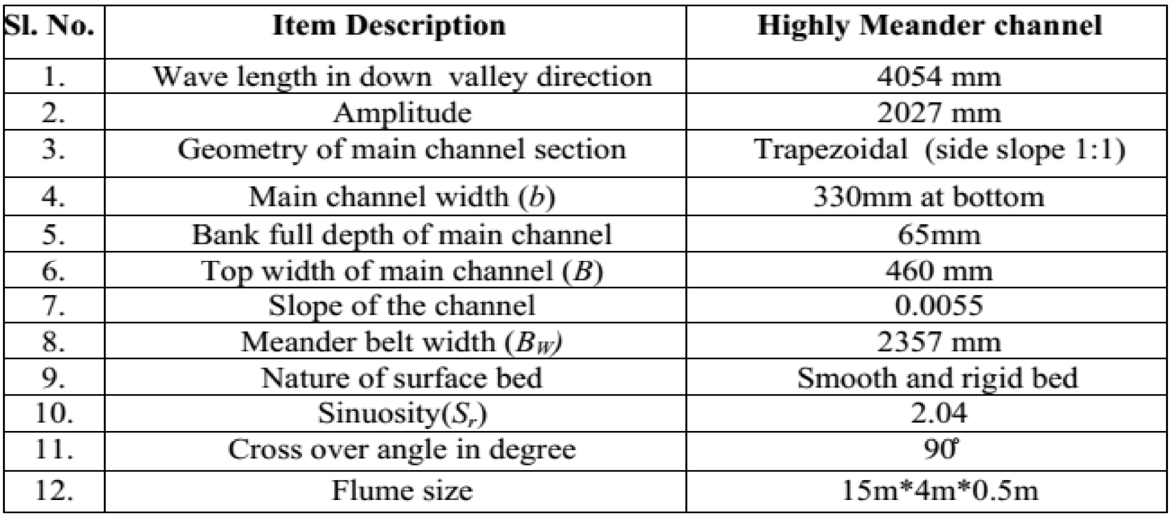


(a) At Bed Level

(b) At 6.5cm above Bed

Fig.(3) Sectional Plan View

Table 1. Geometry Parameters of the Experimental Meandering Channel



Sl. No.	Item Description	Highly Meander channel
1.	Wave length in down valley direction	4054 mm
2.	Amplitude	2027 mm
3.	Geometry of main channel section	Trapezoidal (side slope 1:1)
4.	Main channel width (*b*)	330mm at bottom
5.	Bank full depth of main channel	65mm
6.	Top width of main channel (*B*)	460 mm
7.	Slope of the channel	0.0055
8.	Meander belt width (B_W)	2357 mm
9.	Nature of surface bed	Smooth and rigid bed
10.	Sinuosity(S_r)	2.04
11.	Cross over angle in degree	90°
12.	Flume size	15m*4m*0.5m

The recirculation system of water supply is established with pumping of water from an underground sump to an overhead tank from where water could flow under gravty to a stilling tank. From the stilling tank water is led to the experimental channel through a baffle wall ,and a transition zone helped to reduce error due to turbulence. Tail gate was used to achieve the uniform flow over the test reach in the channel for the given discharge . Water from the channel was collected in volumetric tank for measuring flow discharge ,from where the water runs back to underground sump, thus establishing a closed circuit flow. Rectangular notch arrangement was provided at the upstream to get reduced level of water for stage-discharge relationships. The height of water of water flowing above the rectangular notch was measured by point gauge attached to the notch. Discharge 'Q_a' for each run was calculated from notch equation as:-

$$Q_a = C_d \frac{2}{3} L \sqrt{2g} H_n^{2/3}$$

where Q_a =actual discharge , C_d = coefficient of discharge calculated from notch calibration =0.74 , L= Length of notch , H_n =height of water above notch, g = acceleration of gravity.

For each experimental run , the water slope was tried to be maintained parallel to the bed slope for achieving steady and uniform flow conditions. The measuring devices consisted of point gauge mounted on a traversing mechanism to measure depths having a least count of 0.1mm. The flow depths varying from 1.7cm to 5 cm were measured using the point gauge. Five parallel connected micro- Pitot tubes (4.6mm external diameter) in different locations of the top experimental channel. The whole system of Pitot-tube and point gauge is mounted on the top of experimental flume can be moved both in longitudinal as well as transverse direction of experimental channel by suitable guide rail arrangements. All the measurements are taken at the bend apex of the third wave reach of experimental channel from the upstream end.

EXPERIMENTAL RESULTS

Distribution of tangential (longitudinal) velocity

Total head *h* reading by the Pitot-tube at the predefined points of flow-grid in the channel was used to measure the magnitude of longitudinal point velocity vector as $U=\sqrt{2gh}$ .Observations were recorded at the bend apex with the direction normal to flow path. The radial distribution of tangential velocity for four flow depths are shown in Figs.4 (a ,b ,c and d).

Lateral distribution of Depth averaged velocity

The lateral variation of depth averaged velocity along the channel bed and wall, observed at0.4 times the depth of flow is shown in Figs.5(a , b). Series I depicts the observed values of lateral distribution of depth-averaged velocity for experimental meandering channels while Series 2 shows the cross-section of trapezoidal meandering channel at the bend apex.

ANALYSIS AND DISCUSSIONS

Wilkerson et al.,(2005) proposed two models to fit data from three independent studies for straight trapezoidal channels. The second model which uses prescribed coefficients is given as,

$$\frac{U(d)}{U(*)}=(1+0.104Z)-(0.125Z)\exp\left(2.24Z^{0.582}\left(\pm\frac{z-z_{toe}}{YZ}\right)\right) \quad (2)$$

where$^{\pm}$ z-z_{toe} = lateral distance from the toe of the slope to the point of interest (positive going towards edge of water and negative over the channel bed), Y= depth of flow over channel bed , Z= cotangent of bank slope, U(d) = depth -averaged velocity and U(*) = cross-sectional averaged velocity. Equation (2) was improved and modified to model the depth-averaged longitudinal velocity along the channel cross-section for the present channel and departure of the observed depth-averaged velocity points in reference to Wilkerson's model points were shown in Figs.6(a, b). The point velocity measurements were taken along vertical axes and are used to compute depth-averaged velocity at the axis location in one-half trapezoidal channels.

As shown in Figs.(6), the lateral distribution U(z) predicted by(2) does not agree with the observed data for this wide channel. The deviation ascertains that Wilkerson formula of U(z) for straight trapezoidal channel needs to be modified for present channel to involve meandering effect.

For analysis in meandering channels, the cross-section of the channel is divided along its centreline axis to separate inner and outer regions at the bend apex. Percentage error is calculated for (2) and observed values. Best fit equations based on regression analysis are were used to fit the curve. A linear fit was found for both inner and outer region.

Equation(2) was improved to hold curvature effect in trapezoidal channel for inner and outer regions respectively to take the form,

$$\frac{U(d)}{U(*)_{inner}} = -0.02902 + (0.9416*Sr) + \left(\frac{0.0193885*z - z_{toe}}{YZ}\right) - (0.7100352*Z) \qquad (3)$$

$$\frac{U(d)}{U(*)_{outer}} = 3.82821 - (1.7026*Sr) - \left(\frac{0.038459*z - z_{toe}}{YZ}\right) + (0.562524*Z) \qquad (4)$$

Variation of error in evaluation of the U(d)/U(m) using the modelled equations (3, 4) against the observed data for inner and outer regions presented in Figs.7(a, b).

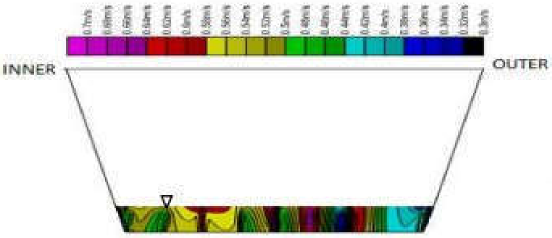


Fig.4(a) Flow depth (h) =1.7cm

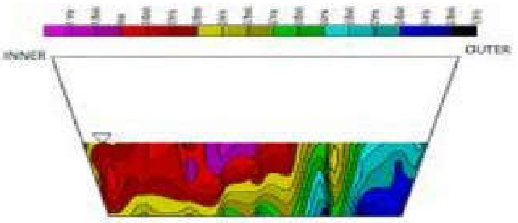


Fig.4(b) Flow depth (h) =3.8cm

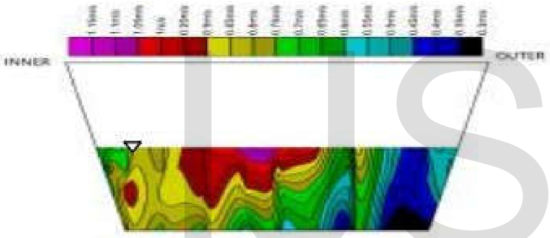


Fig.4(c) Flow depth (h) =4cm

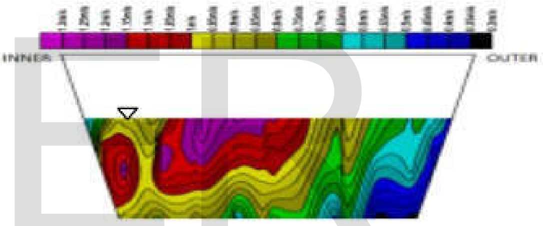
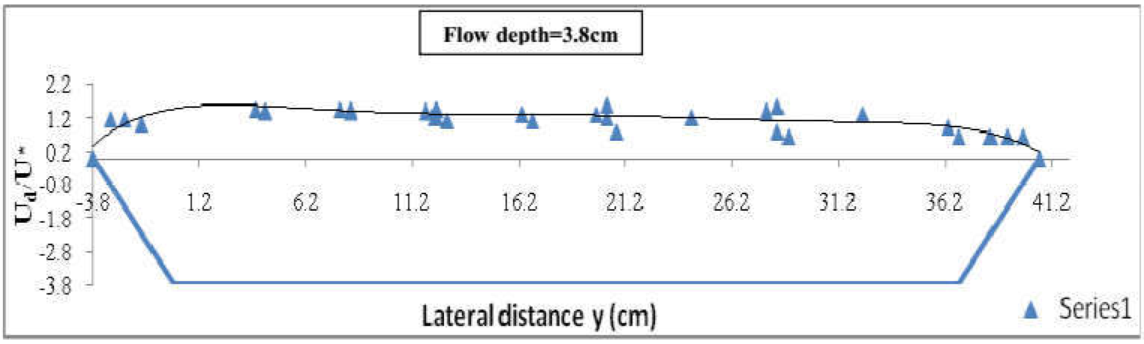


Fig.4(d) Flow depth (h) =5cm



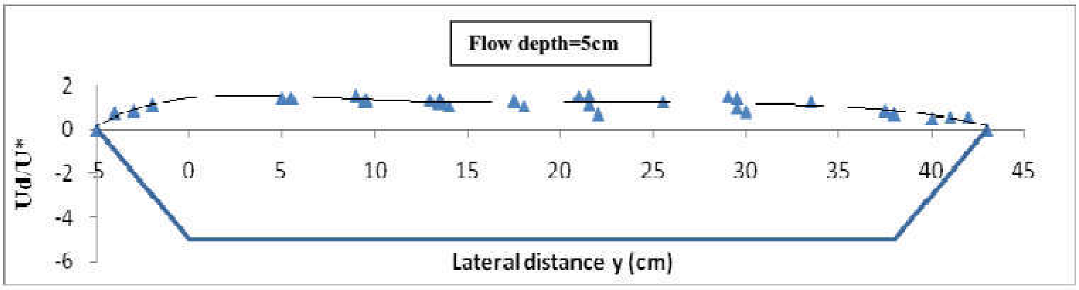


Fig.5 Lateral Distribution of Depth -Averaged Velocity along the cross-section of Experimental Chanel at Bend Apex

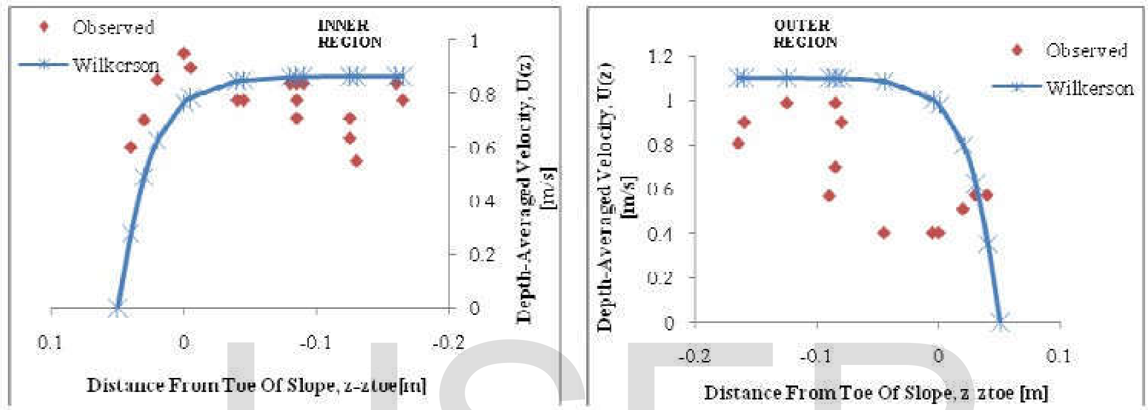


Fig.6 Depth-Averaged Velocity Profile (Q =14.87l/sec, Y=5cm ,Z=1.0 , S_o=0.0055

(a) (b)

Fig.7 Variation of observed and modelled Values of (Ud/Um) and its comparison with Wilkerson's Mode

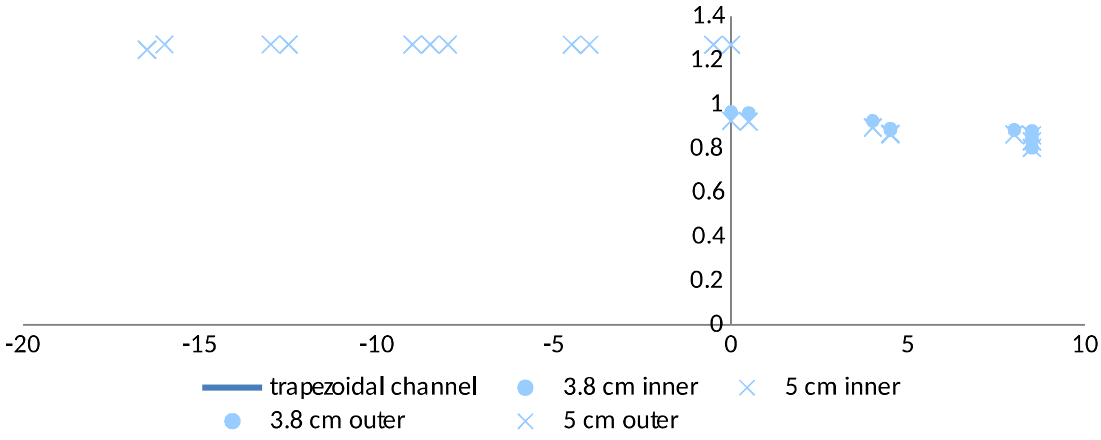


Fig.8 Lateral Depth-averaged Velocity Distribution along Channel Section at Bend Apex

CONCLUSIONS

1. The proposed equations (3, 4) for computing depth-averaged velocity distribution in the channel cross sections takes the help of influencing dimensionless channel parameters and are found to be sufficient for the present set of channel data. These equations are significantly improved when compared to equations proposed by Wilkerson (2005)

2. The trend line fitted to normalised depth-averaged velocities (Ud/Um) at inner wall were found higher than the outer wall in the present wide meandering channel (Fig.5). But the distributions of the local depth average velocity (Fig.8) are higher around the centre line zone of meander channel. This was in line with the velocity observations for wide natural channels. Moving from the channel centre towards the channel corner , decrease in depth velocity can be observed. The rate of decrease is faster for lower depths as compared to higher flow depths.

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NOTATIONS:-

Symbols used are given below:

b = Channel base width

C_d = coefficient of discharge calculated from notch calibration =0.71

g = acceleration due to gravity

H_n = height of water above the notch

L = Length of the notch

Q_a = Actual discharge

S_r = Sinuosity

U = Longitudinal point velocity

U(z) , U_d = Depth-averaged velocity

U_d / U^* = Normalized Depth-averaged velocity

x = ($\pm|z - z_{toe}|/YZ$)

Z = Cotangent of the slope

y = Lateral distance

Y , h = depth of flow over channel bed

$\pm|z - z_{toe}|$ = Lateral distance from toe of slope