Validation of Geotechnical Computer Program "2d-DMM (Version 2.0)"

GEO Report No. 332

R.P.H. Law & F.W.Y. Ko

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
Special Administrative Region

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Preface

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet.

W.K. Pun
Head, Geotechnical Engineering Office
February 2018

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Foreword

This Technical Note presents the details of the validation exercise of the geotechnical computer program, 2d-DMM (Version 2.0).

The validation exercise was carried out by Dr R.P.H. Law, under the supervision of Ms F.W.Y. Ko and myself. The Drafting Unit of the Standards and Testing Division assisted in formatting this report. All contributions are gratefully acknowledged.

Y.K. Shiu
Chief Geotechnical Engineer/Standards and Testing

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Abstract

Geotechnical computer program, 2d-DMM (Version 1.2), is currently used to simulate and analyse debris mobility. The computer program was developed on Microsoft Excel with Visual Basic Applications. It contains a number of limitations in both pre- and post-processing of data pertaining to its development platform. In order to overcome the limitations, 2d-DMM (Version 1.2) was revamped using the computer language C#, which is an improved version of C++, to 2d-DMM (Version 2.0).

The validation exercise of 2d-DMM (Version 2.0) includes a comparison of results of back-analyses of some historical and hypothetical landslides with those obtained from the existing pre-accepted programs, 2d-DMM (Version 1.2) and DAN-W (Release 10). It is demonstrated that 2d-DMM (Version 2.0) produces results consistent with both the pre-accepted programs.

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1 Introduction

Geotechnical computer program, 2d-DMM (Version 1.2) (GEO, 2012), is currently used to simulate and analyse debris mobility. It was developed based on the dynamic analysis proposed by Hungr (1995) and the improvements proposed by Kwan & Sun (2006) for simulation of the dynamics of landslide debris.

2d-DMM (Version 1.2) was developed on Microsoft Excel with Visual Basic Applications (VBA). It contains a number of limitations in both pre- and post-processing of data pertaining to its development platform. In order to overcome the limitations, 2d-DMM (Version 1.2) was revamped in 2014 using the computer language C#, which is an improved version of C++, to 2d-DMM (Version 2.0).

This Technical Note presents the details of the validation exercise of 2d-DMM (Version 2.0).

2 Key Improvements

The following are the key improvements made in 2d-DMM (Version 2.0):

(a) an interactive user interface is developed to facilitate input of parameters, visualisation of debris mobility and review and report of results,

(b) the user can specify the number of boundary blocks that represent the landslide debris. In 2d-DMM (Version 1.2), the number of boundary blocks is fixed at 11. An increase in the number of boundary blocks would increase the accuracy of the computed solution,

(c) the user can specify the channel geometry, including the topography, width and side angles, using coordinates instead of six-order polynomials as in 2d-DMM (Version 1.2), and

(d) the user can visualise the calculation results, e.g. debris velocity and thickness, in each time step easily on screen or on print-outs using the newly developed plot and export functions.

3 Methodology

Table 3.1 shows seven historical and three hypothetical landslides that were used in the validation exercise of 2d-DMM (Version 2.0). Cases 1 to 9 are the landslides that were previously compared in the validation exercise of 2d-DMM (Version 1.2). Case 10 is a case borrowed from the validation exercise of 2d-DMM (Version 1.1) (GEO, 2010). It is included to evaluate flow behaviour along rectangular and trapezoidal sections using friction model. Among the historical landslides, six are Hong Kong cases and one is from overseas.

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Table 3.1 Summary of Cases in the Validation Exercise

Summary Table

Case No.	Case	Source volume (m^3)	Entrainment Volume (m^3)	Density (kg/m^3)	Trapezoidal Cross Section	Friction angle (°)	Turbulent Coefficient (m/s^2)	Comparison with 2d-DMM (Version 1.2)	Comparison with DAN-W (Release 10)	Remarks
1	Liu Pok Landslide	305	0	2,000	-	11.32	500	✓		-
2	Cloudy Hill Landslide	90	0	1,800	-	8	500	✓		Number of boundary blocks: 11 and 50
3		90	0	1,800	✓	8	500	✓		
4	Lei Pui Street Landslide	250	470	1,800	-	11	500	✓	✓	-
5	Tip No.7 Flow Slide of 1966 at Aberfan, South Wales	35000	0	1,730	-	9.08	0*	✓	✓	-
6	ENTLI Case No. 03SEA2011E	200	0	1,800	-	29	500	✓	-	Initial velocity and chainage of the landslide debris in Case 7 are 4.8 m/s^2 and 36.8 m respectively.
7		200	0	1,800	-	29	500	✓	-	
8	Hypothetical Slope Profile A	400	0	1,800	-	25	0*	✓	-	Initial velocity and chainage of the landslide debris in Case 9 are 10.7 m/s^2 and 82.7 m respectively.
9		400	0	1,800	-	25	0*	✓	-	
10	Hypothetical Slope Profile B	150	0	150	✓	17.5	0*	✓	-	Both 45° and 90° side angles are adopted.

Legend:

* The friction model is adopted in the simulation

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The number of boundary blocks was set at 50 in the validation exercise. The computed runout distance, debris velocity profile and debris thickness profile, as well as the debris velocity and thickness hydrographs at the selected observation point along the flow path of each case, were compared with the results obtained from 2d-DMM (Version 1.2). The observation point was located at two-third of the flow path, just before reaching the horizontal ground, as illustrated in Appendix A.

Key information for each case in the validation exercise is highlighted below.

(a) For the Cloudy Hill Landslide, a rectangular channel was adopted in Case 2 while a trapezoidal channel was adopted in Case 3,

(b) For Cases 4 and 5, additional comparisons were made with the results obtained from the existing pre-accepted program, DAN-W (Release 10),

(c) For the ENTLI Case No. 03SEA2011E, the initial debris was located at the crest without an initial velocity in Case 6 while in Case 7, an initial velocity of 4.8 m/s was set for the landslide debris at its initial location at chainage = 36.8 m,

(d) The slope profiles for both Cases 8 and 9 are hypothetical. In Case 8, the initial debris was located at the crest without an initial velocity. In Case 9, an initial velocity of 10.7 m/s was set for the landslide debris at its initial location at chainage = 82.7 m,

(e) For Case 10, flow behaviour along both rectangular and trapezoidal cross sections was examined.

4 Key Findings

A summary of the results in terms of runout distance, maximum debris velocity and maximum debris thickness is given in Table 4.1. Details of the comparisons are presented in Appendix A.

The key findings are outlined below.

(a) For runout distance, the results between 2d-DMM (Version 2.0) and 2d-DMM (Version 1.2) are in general consistent, with a percentage difference less than ±5%. Case 5 is the only exception with a percentage difference of -12.7%. It is noted that the most frontal block of the landslide debris simulated by 2d-DMM (Version 1.2) moves exceptionally far from its succeeding blocks. The same is not observed in the simulations by 2d-DMM (Version 2.0) and DAN-W (Release

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10), which give consistent results. The difference may be due to the different number of blocks adopted in simulating the landslide debris and the different assumptions made in distributing the landslide volume among the blocks. This difference manifests especially when the debris volume is very large. The landslide volume of Case 5 is 35,000 m^3. 2d-DMM (Version 1.2) distributes about 1% of the landslide volume to the most frontal block while 2d-DMM (Version 2.0) distributes the landslide volume equally to all the blocks. In the former, the most frontal block carries a lot less amount of mass and momentum than its succeeding blocks and therefore, its motion is very sensitive to the motion of its succeeding blocks. In the latter, the same is not observed as each block carries equal amount of mass and momentum.

(b) For maximum debris velocity, the results between 2d-DMM (Version 2.0) and 2d-DMM (Version 1.2) are in general consistent, with a percentage difference less than ±5%. Cases 4 and 5 are the exceptions, with a percentage difference of -6.1% and -20.7% respectively. The same is not observed in 2d-DMM (Version 2.0) and DAN-W (Release 10) simulations, which give consistent results. The same reason given in (a) above applies.

(c) For maximum debris thickness, the results between 2d-DMM (Version 2.0) and 2d-DMM (Version 1.2) are comparatively less consistent. Cases 2, 3, 5 and 6 have a percentage difference greater than ±10%. It is noted that the maximum debris thickness of the landslide debris simulated by 2d-DMM (Version 1.2) is, in most of the time, recorded at the time when the landslide debris has nearly deposited. In contrast, the maximum debris thickness of the landslide debris simulated by 2d-DMM (Version 2.0) occurs at the time when the landslide debris is still moving downstream. This is also true even when the number of boundary blocks is reduced from 50 to 11 in the simulation. No comparison can be made with the results obtained from the DAN-W (Release 10), which does not provide information on maximum debris thickness. It is probable that the calculation of debris thickness is highly sensitive to the numerical techniques applied and sufficient robustness should be put in place when applying the computed debris thickness in design.

(d) For both rectangular and trapezoidal cross sections in Case 10, the results between 2d-DMM (Version 2.0) and 2d-DMM (Version 1.2) are consistent.

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Table 4.1 Summary of Results from 2d-DMM (Versions 1.2 and 2.0) and DAN-W

Case No.	Case	Runout Distance (m)					Maximum Debris Velocity (m/s)					Maximum Debris Thickness (m)		
		V 2.0	V 1.2	Percentage Difference	DAN-W	Percentage Difference	V 2.0	V 1.2	Percentage Difference	DAN-W	Percentage Difference	V 2.0	V 1.2	Percentage Difference
1	Liu Pok Landslide	199	201	-1.2%	-	-	12.36	12.38	-0.2%	-	-	1.60	1.49	+7.4%-
2	Cloudy Hill Landslide	127	128	-0.7%	-	-	6.05	5.86	3.2%	-	-	0.65	0.75	-13.3%
3	Cloudy Hill Landslide	131	131	-0.1%	-	-	6.12 (6.05)*	6.08	0.7% (-0.4%)*	-	-	0.67 (0.69)*	0.82	-18.3% (-15.9%)
4	Lei Pui Street Landslide	334	336	-0.8%	339	-1.5%	11.33	12.06	-6.1%	11.02	2.8%	1.32	1.22	8.2%
5	Tip no.7 Flow Slide of 1966 at Aberfan, South Wales	1138	1303	-12.7%	1109	2.6%	33.30	42.00	-20.7%	31.87	4.5%	4.70	5.98	-21.4%
6	ENTLI Case No. 03SEA2011E	141	142	-0.3%	-	-	11.25	11.22	0.3%	-	-	1.06	0.96	10.4%
7	ENTLI Case No. 03SEA2011E	141	140	0.8%	-	-	5.08	4.99	1.8%	-	-	1.01	0.98	3.1%
8	Hypothetical Slope Profile A	198	200	-0.8%	-	-	13.76	13.59	1.3%	-	-	0.80	0.85	-5.9%
9	Hypothetical Slope Profile A	200	199	0.1%	-	-	10.70	10.68	0.2%	-	-	0.81	0.88	-8.0%
10	Hypothetical Slope Profile B	72	73	-2.1%	-	-	-	-	-	-	-	-	-	-
10	Hypothetical Slope Profile B	75	73	2.8%	-	-	-	-	-	-	-	-	-	-

Legend:

* 11 numbers of boundary block

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5 Discussion

Both 2d-DMM (Version 1.2) and 2d-DMM (Version 2.0) adopt the Saint-Venant equation to simplify the calculation of motion of landslide debris. The assumptions of shallow flow and smooth flow path, relative to the flow thickness, are implicit in modelling debris mobility using 2d-DMM. Therefore, neither 2d-DMM (Version 1.2) nor 2d-DMM (Version 2.0) can be used to carry out simulation which involves rapid rate of change of momentum of landslide debris due to abrupt slope changes. In particular, the analysis of impedance of baffle arrays and short rigid barriers on landslide debris cannot be performed using either 2d-DMM (Version 1.2) or 2d-DMM (Version 2.0) explicitly.

Entrainment rate in both versions of 2d-DMM is specified using a negative rate of change in debris volume in the unit of m^3/s. The debris volume would start to increase with time once the most frontal block of the debris reaches a designated entrainment zone, through adding volume to the blocks of the debris within the entrainment zone. The volume of a block would not increase further when the thickness of the block reaches a user-specified threshold value. Due to these formulation requirements, it is a trial and error process in both versions of 2d-DMM to obtain a design entrainment volume. Furthermore, in 2d-DMM (Version 1.2), deposition of debris is allowed by specifying a negative entrainment rate (i.e. a positive rate of change in debris volume). This is merely a mathematical formulation and there is no physical meaning for this negative entrainment rate. Therefore, the use of a prescribed deposition rate in 2d-DMM (Version 1.2) to decelerate debris mobility has, all along, not been recommended. Instead, deceleration and deposition of debris should follow the progressive deceleration of the blocks that is worked out by the numerical solutions of the governing equations in 2d-DMM (Version 1.2). In this regard, the input of a deposition rate is scrapped from the graphical user interface of 2d-DMM (Version 2.0).

Unlike 2d-DMM (Version 1.2), channel topography in 2d-DMM (Version 2.0) is specified using coordinates of a flow path. The recommendation regarding specification of flow path using points given in Hungr (2010) is relevant:

> "*The input profile should be made reasonably smooth to avoid instability. Do not use too many points and avoid details such as minor steps in the profile. Round out abrupt slope changes. The user should test the influence of such simplification (usually it has relatively small effect on the results, but excessive roughness could unrealistically reduce the runout). Ideally, a slope profile should have about 15-25 input points.*"

Besides, smooth profiles of channel width and side angles are also recommended. The complex interactions between abrupt change of channel width and side angles are usually not modelled in two-dimensional numerical formulations such as 2d-DMM (Version 2.0). Advanced three-dimensional codes using, such as, discrete element modelling are necessary for taking these complex interactions into account.

2d-DMM (Version 2.0) was released to the staff of the Landslip Preventive Measures Division 2 and the Geotechnical Projects Division for trial use in November and December 2014, subsequent to a briefing session introducing the key components and functions of the computer program. Comments received over the trial period have been addressed and

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incorporated in 2d-DMM (Version 2.0). There is certainly still room for improvement, in terms of enhancing user experience and model accuracy. The advancement of 2d-DMM will be kept in view and more up-to-date versions may be released on a need basis.

6 Conclusions

The validation exercise demonstrates that 2d-DMM (Version 2.0) produces results consistent with the existing pre-accepted programs, 2d-DMM (Version 1.2) and DAN-W (Release 10). It is recommended for prior acceptance for use in simulating and assessing debris mobility.

7 References

GEO (2010). *Computer Program Assessment Report for 2d-DMM (Spreadsheet Version) Version 1.1.* Geotechnical Engineering Office, Hong Kong, 91 p.

GEO (2012). *Computer Program Assessment Report for 2d-DMM (Version 1.2).* Geotechnical Engineering Office, Hong Kong, 68 p.

Hungr, O. (1995). A model for the runout analysis of rapid flow slides, debris flows and avalanches. *Canadian Geotechnical Journal*, vol. 32, pp 610-623.

Hungr, O. (2010). *User's Manual of DAN-W.* O. Hungr Geotechnical Research Inc., Canada, 61 p.

Kwan, J.S.H. & Sun, H.W. (2006). An improved landslide mobility model. *Canadian Geotechnical Journal*, vol. 43, pp 531-539.

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Appendix A

Detailed Input and Output of the Validation Exercise

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A.1 Validation Case No. 1

Liu Pok Landslide

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Case 1 : Liu Pok Landslide					
Debris Properties		Section 1			
Density (kg/m^3)	2,000	Friction angle (^{o})	35	Entrainment start location (m)	0
Volume (m^3)	305	Turbulent coefficient (m/s^2)	500	Entrainment end location (m)	0
Initial horizontal length of flow mass (m)	25	Pore pressure for friction	0.7141	Entrainment rate (m^3/s)	0
K_a	0.8	Section 2			
K_0	1	Start location of section 2 (m)	200	Entrainment start location (m)	0
K_p	2.5	Friction angle (^{o})	35	Entrainment end location (m)	0
Pore pressure ratio, R_u	0.7141	Turbulent coefficient (m/s^2)	500	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	0	Pore pressure for friction	0.7141		
Initial velocity (m/s)	0			Threshold entrainment depth (m)	0

Please refer to Appendix B for the input data points of the channel geometry for all verification cases.

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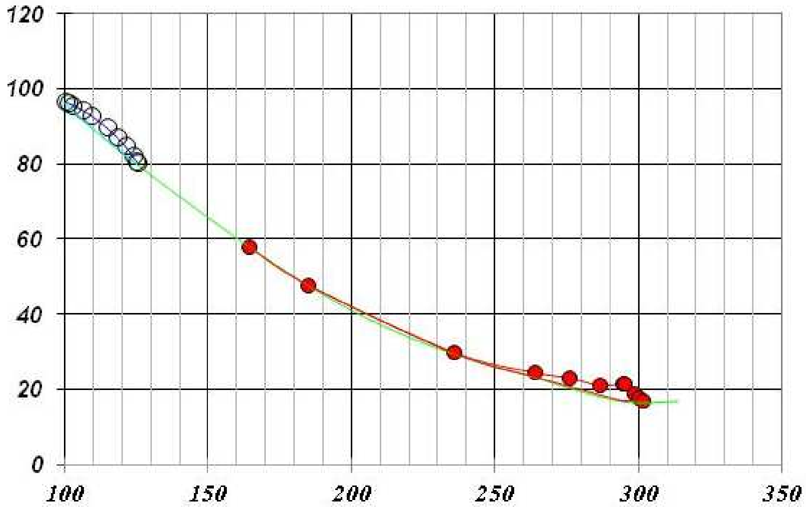
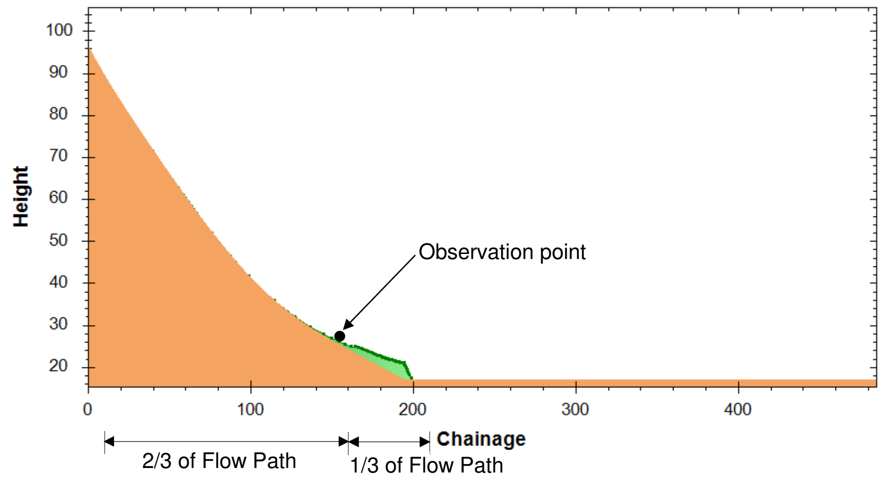
Summary - Case 1			
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference
Runout distance (m)	201.19	198.85	-1.17%
Max. debris velocity (m/s)*	12.38	12.36	-0.16%
Max. debris thickness (m)*	1.49	1.60	+7.38%

Legend:

* Excluding the frontal blocks due to numerical instability.

2d-DMM (Version 1.2)	2d-DMM (Version 2.0)
	
Final Result	

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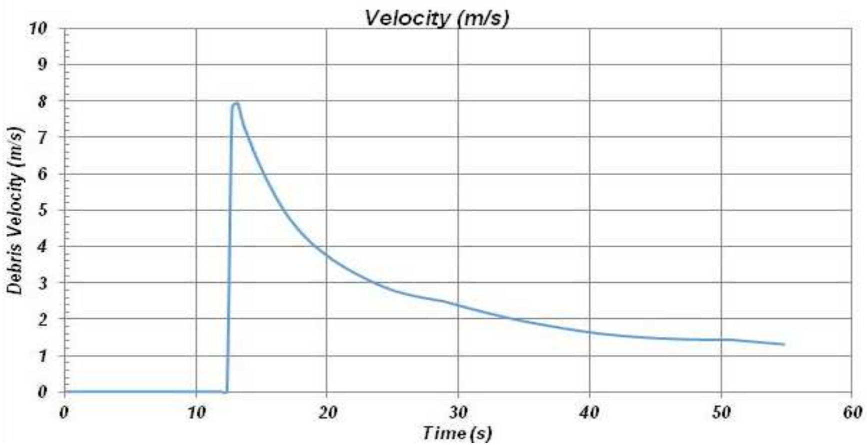

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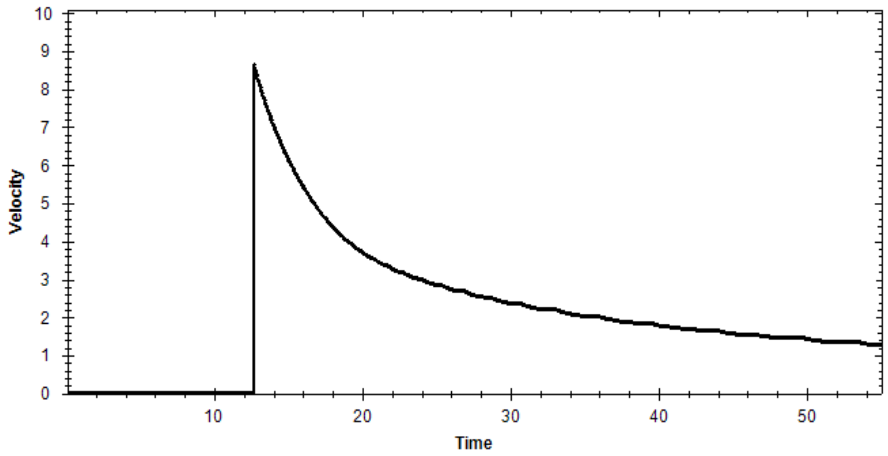
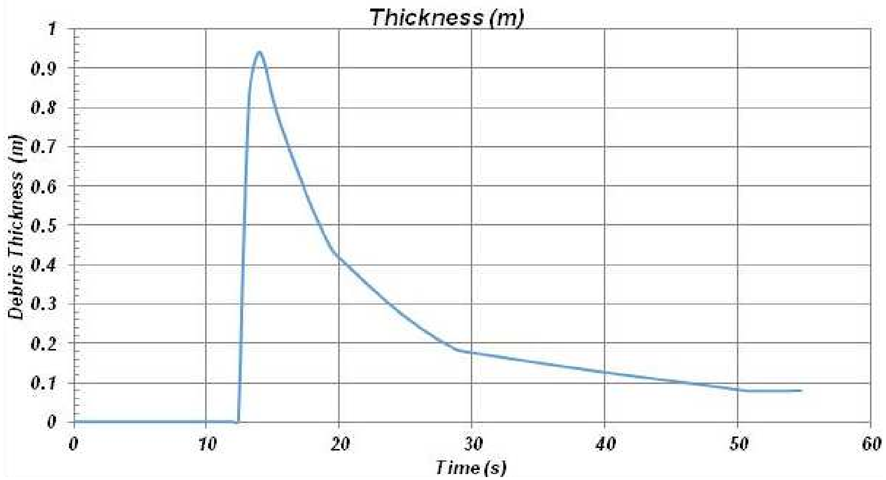


(At x = 130)

Velocity Hydrograph



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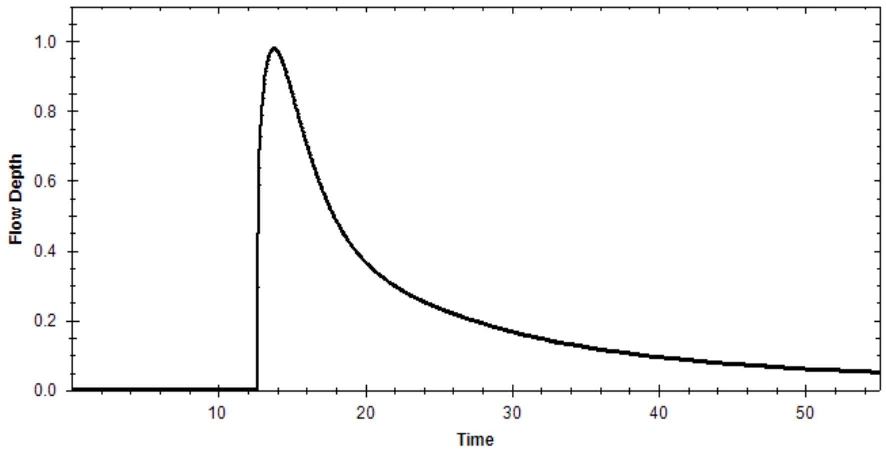
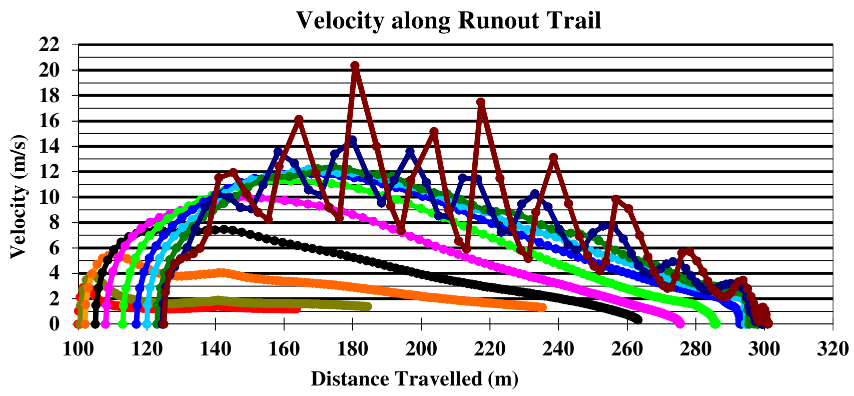
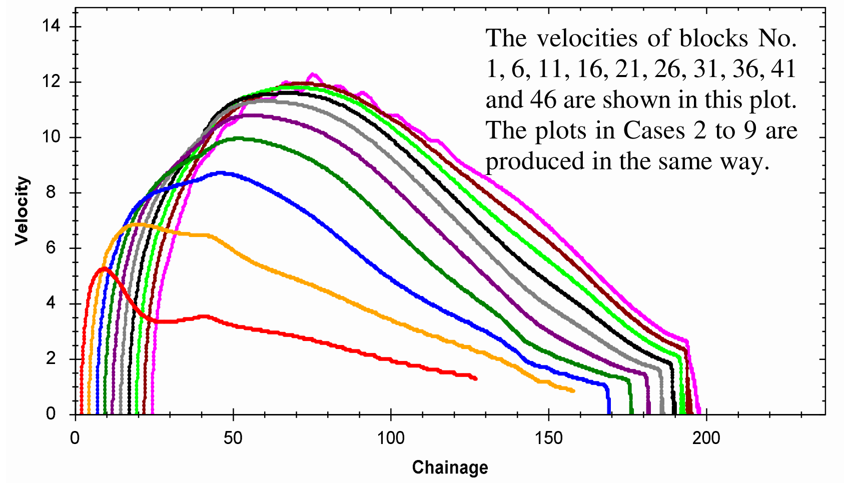


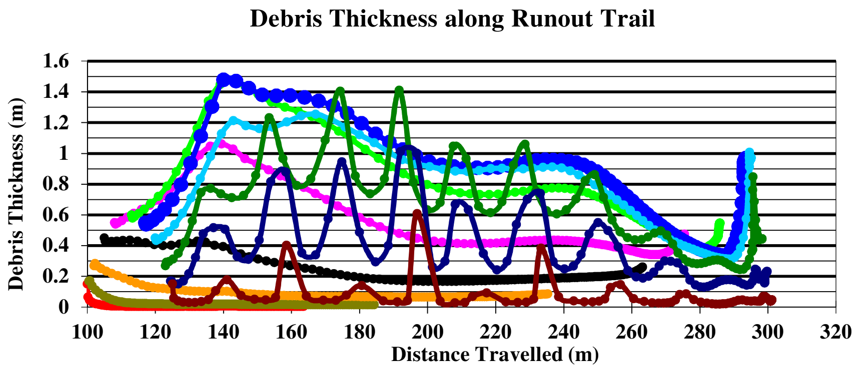
(At x = 130)

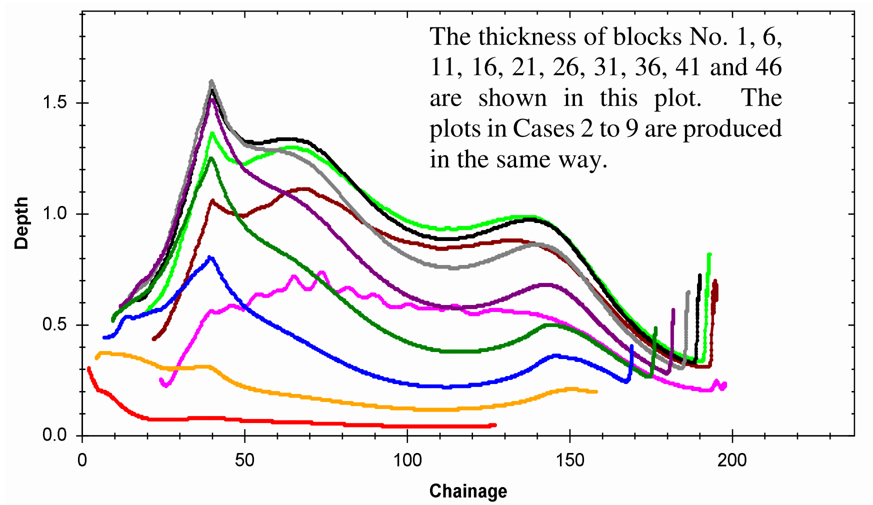
Thickness Hydrograph





Velocity profile





Thickness profile

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A.2 Validation Case No. 2

Cloudy Hill Landslide

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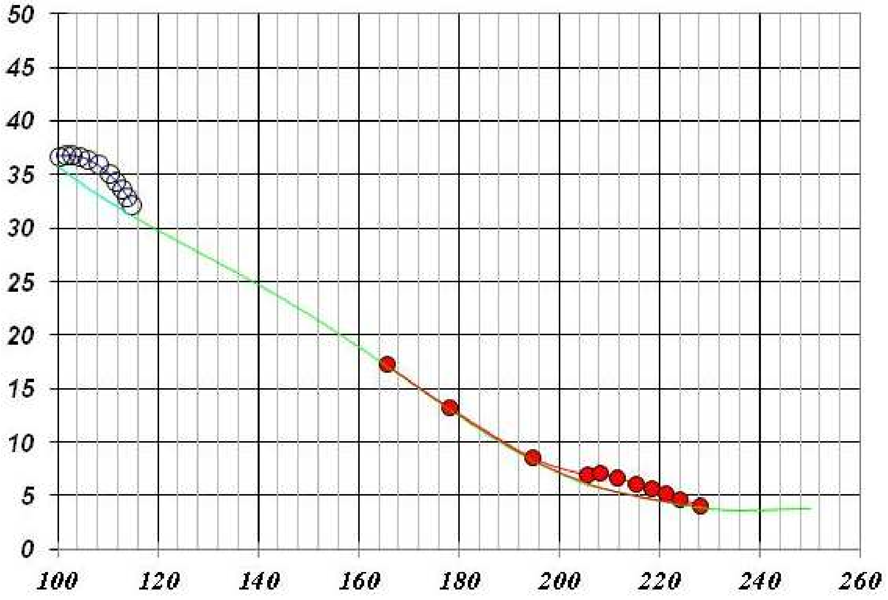
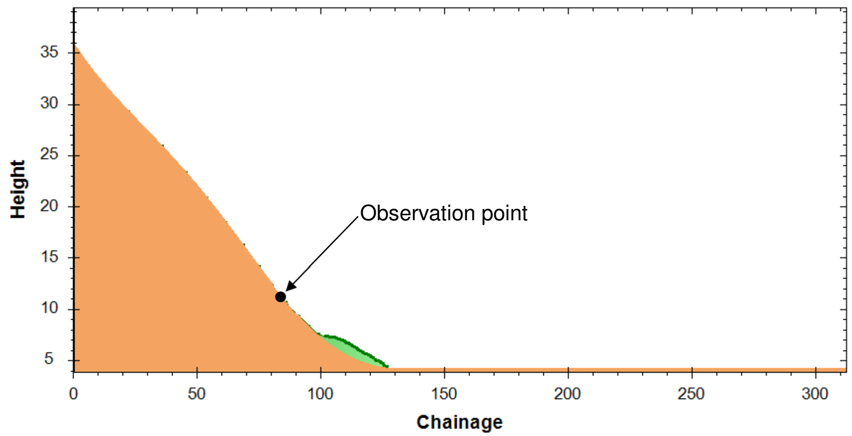
Case 2 : Cloudy Hill Landslide					
Debris Properties		Section 1			
Density (kg/m^3)	1,800	Friction angle (^{o})	35	Entrainment start location (m)	0
Volume (m^3)	90	Turbulent coefficient (m/s^2)	500	Entrainment end location (m)	0
Initial horizontal length of flow mass (m)	14.5	Pore pressure for friction	0.7993	Entrainment rate (m^3/s)	0
K_a	0.8	Section 2			
K_0	1	Start location of section 2 (m)	160	Entrainment start location (m)	0
K_p	2.5	Friction angle (^{o})	35	Entrainment end location (m)	0
Pore pressure ratio, R_u	0.7993	Turbulent coefficient (m/s^2)	500	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	0	Pore pressure for friction	0.7993		
Initial velocity (m/s)	0			Threshold entrainment depth (m)	0

Summary - Case 2			
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference
Runout distance (m)	127.86	126.94	-0.72%
Max. debris velocity (m/s)	5.86	6.05	3.24%
Max. debris thickness (m)	0.75	0.65	-13.33%

2d-DMM (Version 1.2)	2d-DMM (Version 2.0)
	
Final Result	

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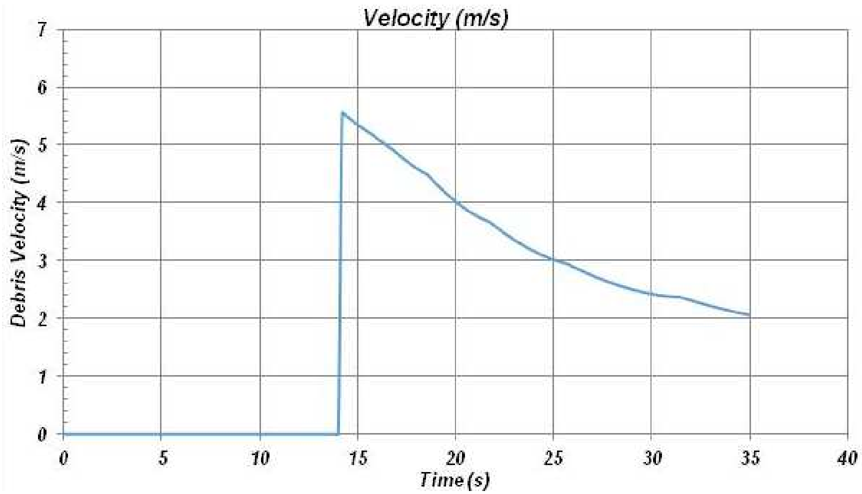
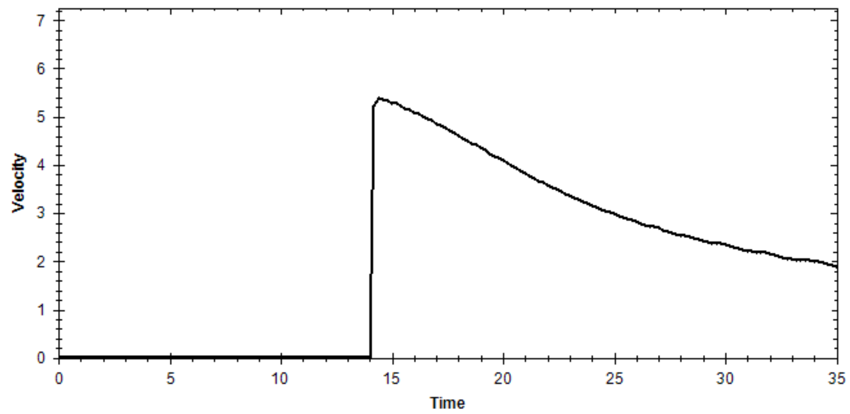
 (At x = 187) (Version 1.2) (Chainage offset +100m)	 (At x = 87)
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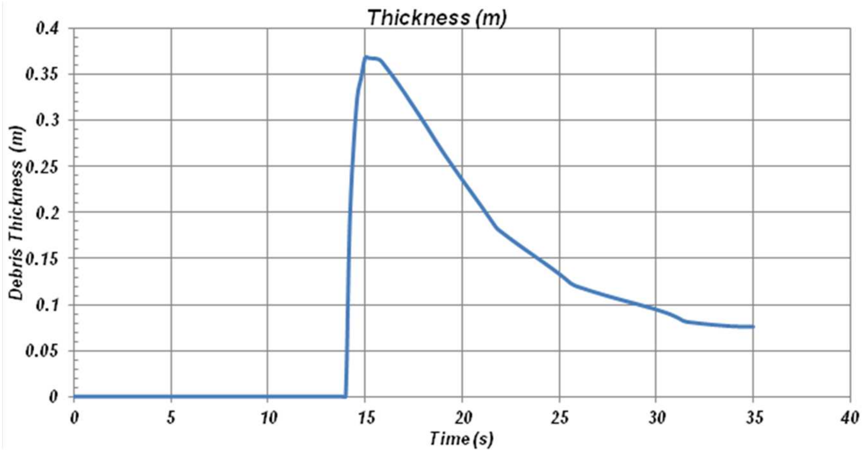
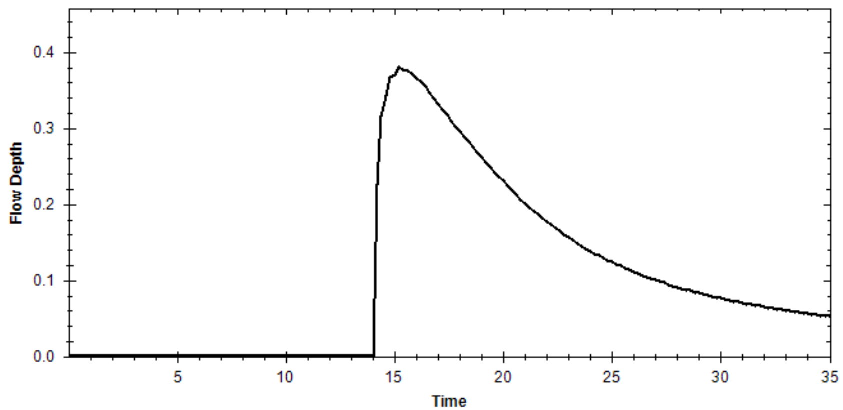
 (At x = 187) (Version 1.2) (Chainage offset +100m)	 (At x = 87)
Thickness Hydrograph	

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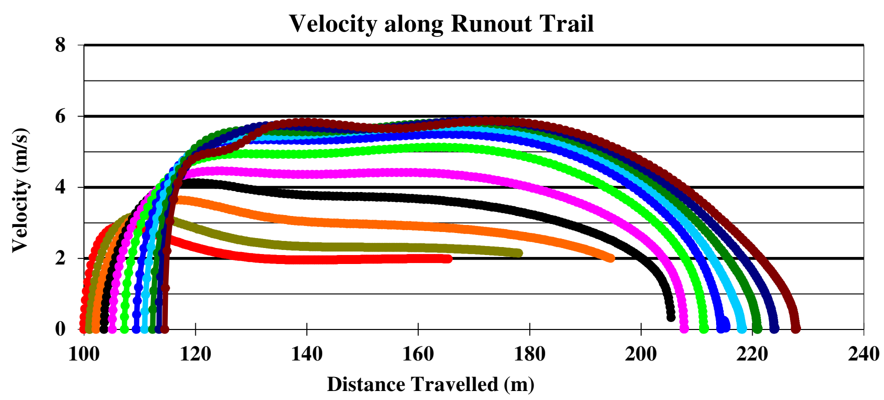
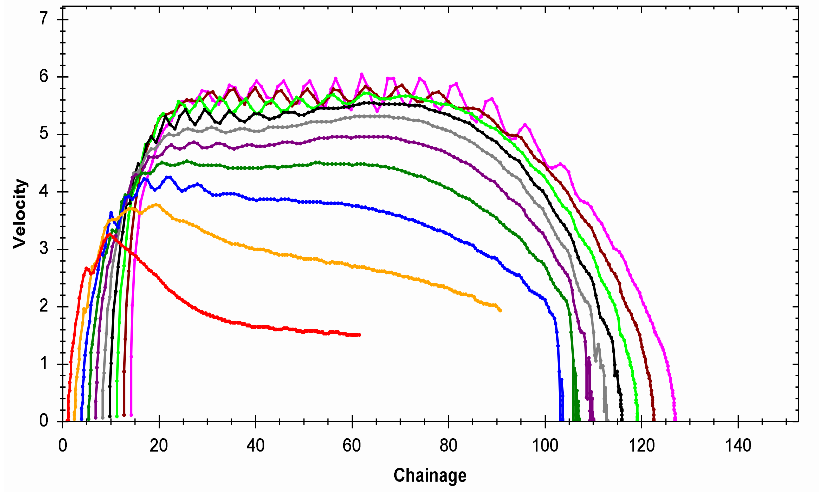
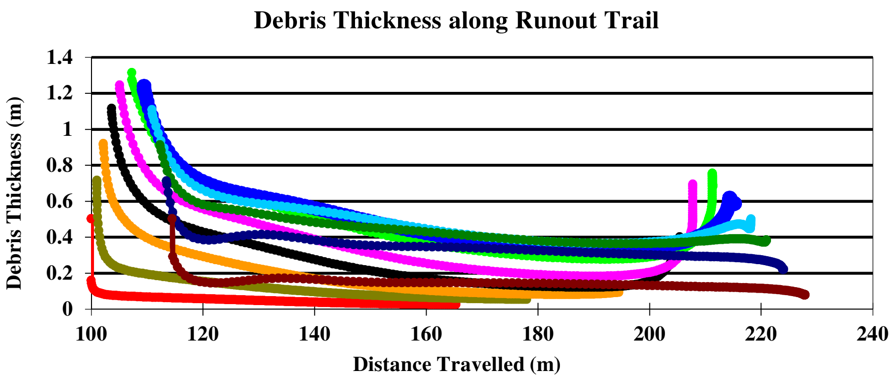
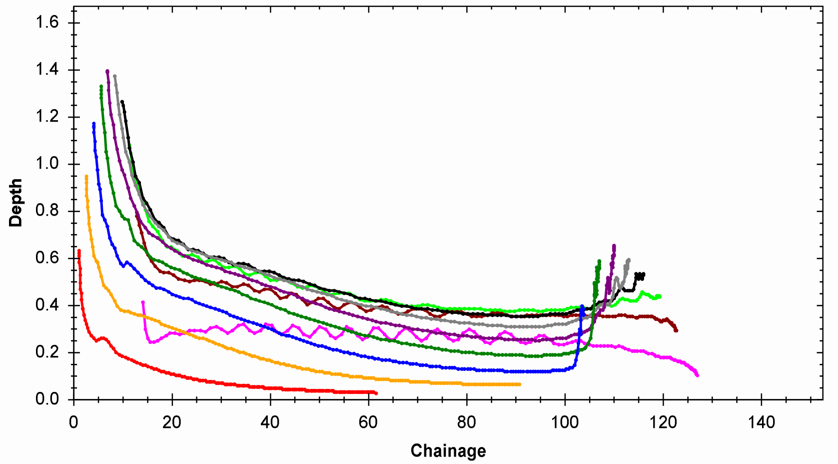




Velocity profile





Thickness profile

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A.3 Validation Case No. 3

Cloudy Hill Landslide

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Case 3 : Cloudy Hill Landslide					
Debris Properties		Section 1			
Density (kg/m^3)	1,800	Friction angle (^{o})	35	Entrainment start location (m)	0
Volume (m^3)	90	Turbulent coefficient (m/s^2)	500	Entrainment end location (m)	0
Initial horizontal length of flow mass (m)	14.5	Pore pressure for friction	0.7993	Entrainment rate (m^3/s)	0
K_a	0.8	Section 2			
K_0	1	Start location of section 2 (m)	200	Entrainment start location (m)	0
K_p	2.5	Friction angle (^{o})	35	Entrainment end location (m)	0
Pore pressure ratio, R_u	0.7993	Turbulent coefficient (m/s^2)	500	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	0	Pore pressure for friction	0.7993		
Initial velocity (m/s)	0			Threshold entrainment depth (m)	0

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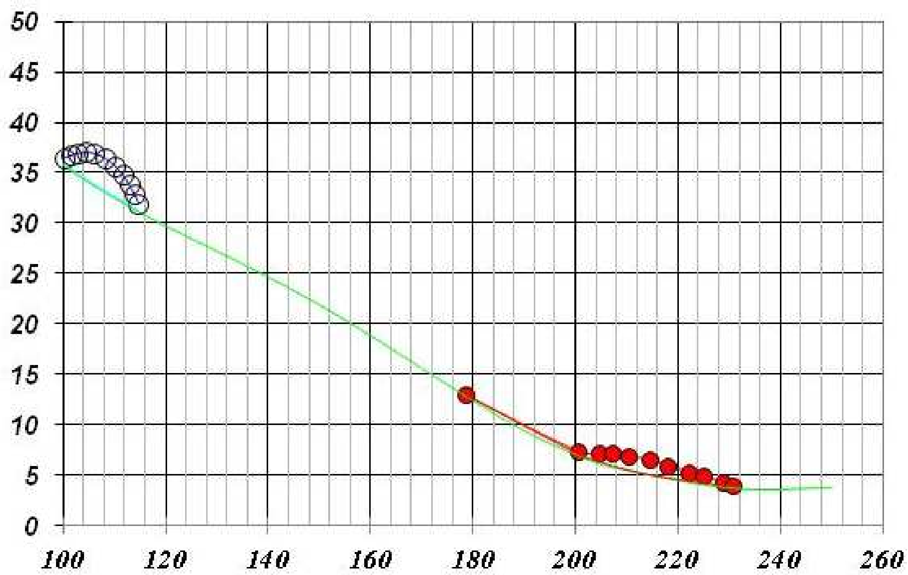
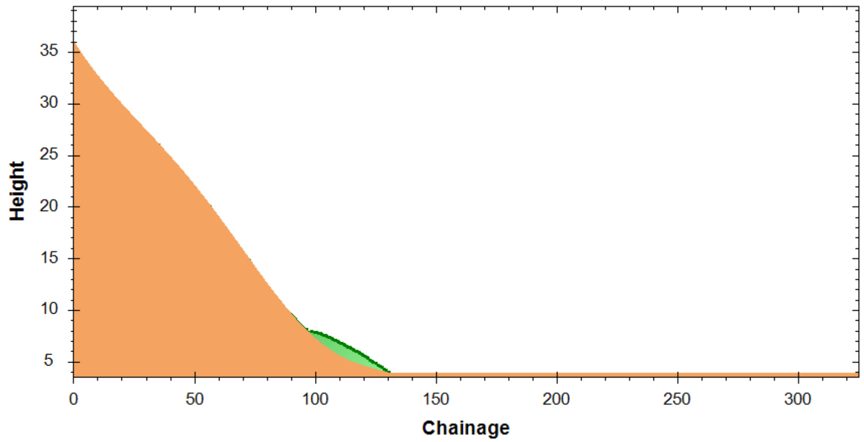
Summary - Case 3			
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference
Runout distance (m)	130.74	130.59	-0.11%
Max. debris velocity (m/s)	6.08	6.12	0.66%
Max. debris thickness (m)	0.82	0.67	-18.29%

2d-DMM (Version 1.2)	2d-DMM (Version 2.0)
	
Final Result	

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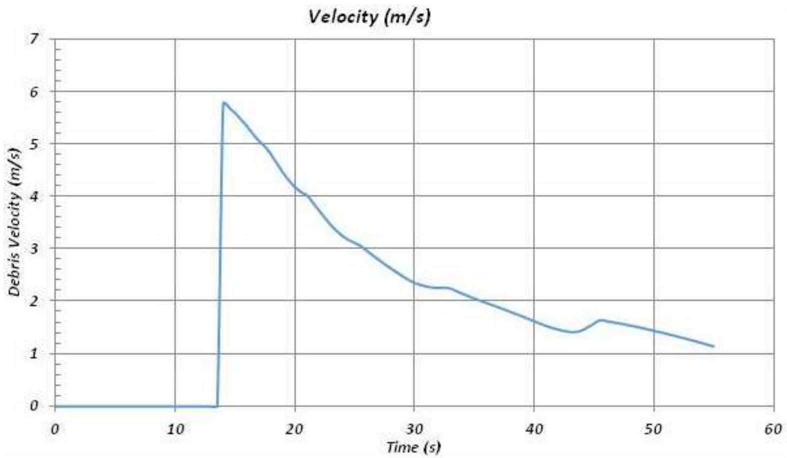

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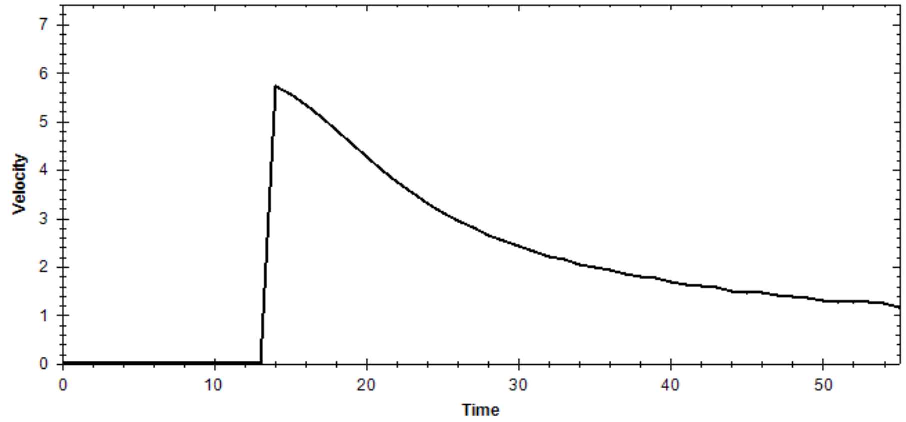
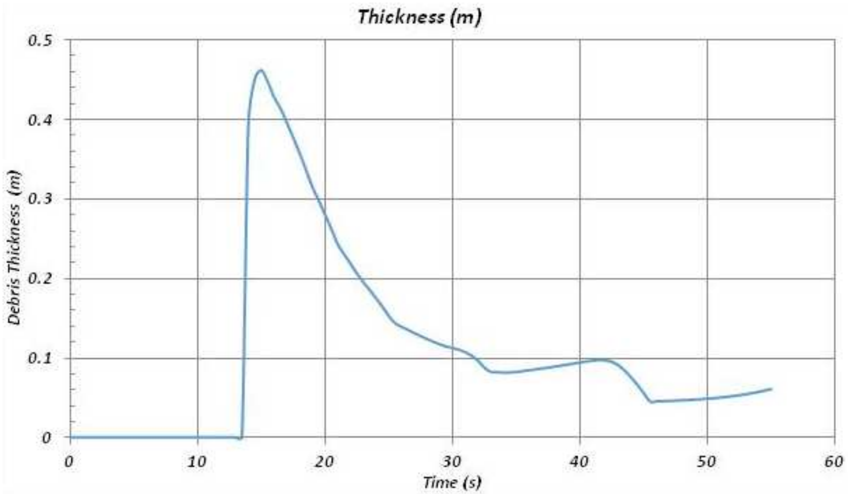
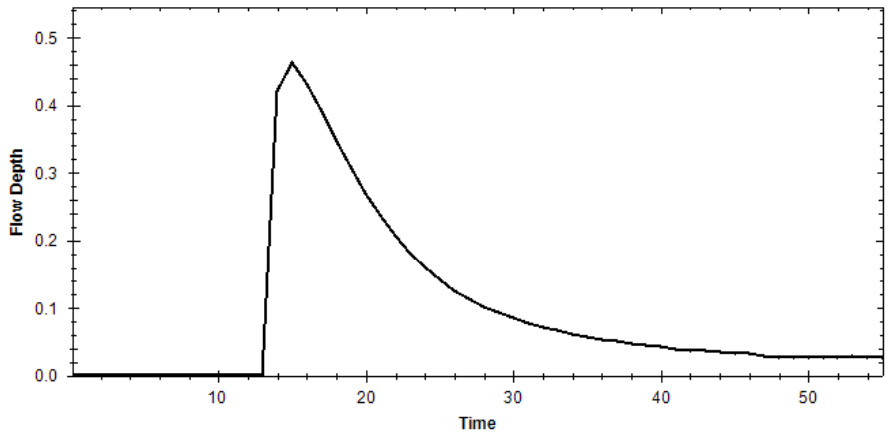


(At x = 87)

Velocity Hydrograph



(At x = 187) (Version 1.2) (Chainage offset +100m)



(At x = 87)

Thickness Hydrograph

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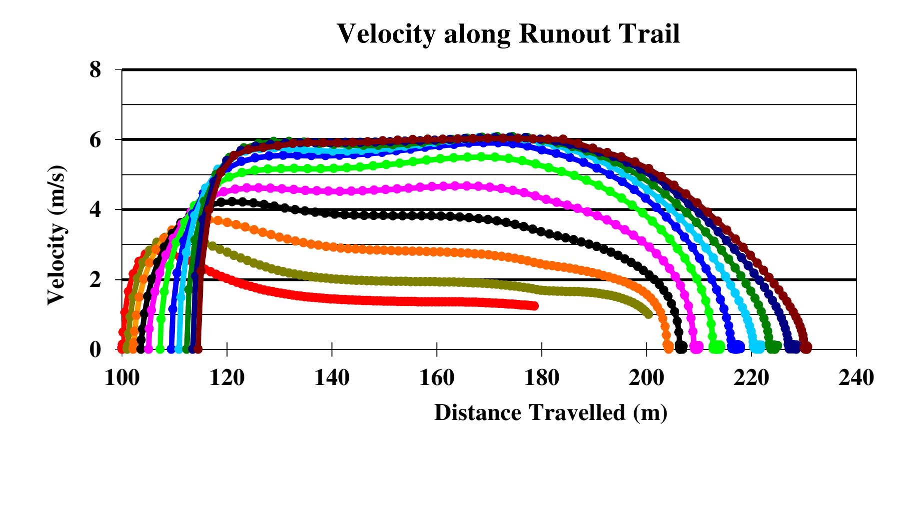
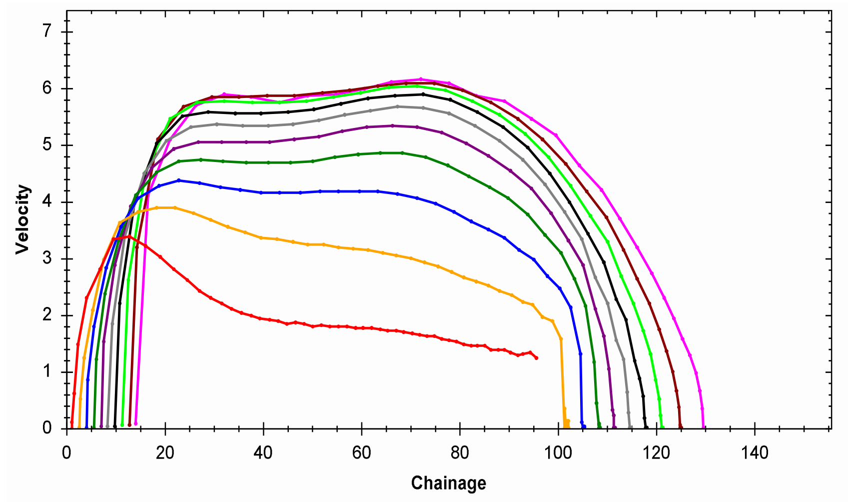
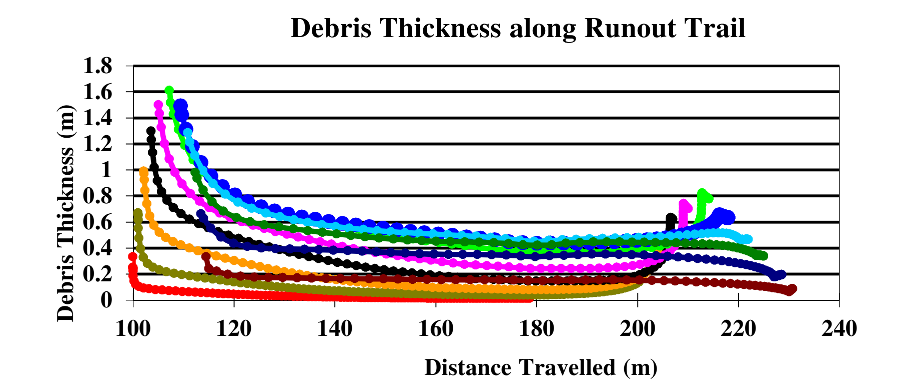
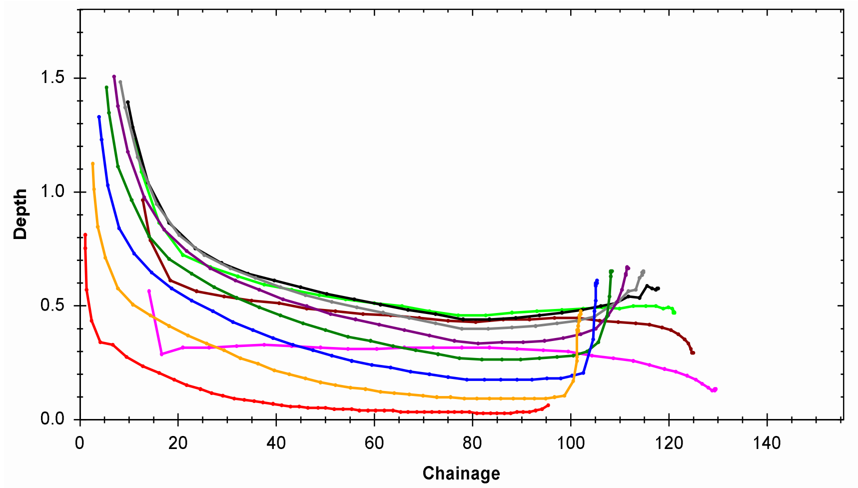




Velocity profile





Thickness profile

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A.4 Validation Case No. 4

Lei Pui Street Landslide

Case 4 : Lei Pui Street Landslide					
Debris Properties		Section 1			
Density (kg/m^3)	1,800	Friction angle (^{o})	35	Entrainment start location (m)	40
Volume (m^3)	250	Turbulent coefficient (m/s^2)	500	Entrainment end location (m)	128
Initial horizontal length of flow mass (m)	25	Pore pressure for friction	0.7224	Entrainment rate (m^3/s)	0.265
K_a	0.8	Section 2			
K_0	1	Start location of section 2 (m)	370	Entrainment start location (m)	0
K_p	2.5	Friction angle (^{o})	35	Entrainment end location (m)	0
Pore pressure ratio, R_u	0.7224	Turbulent coefficient (m/s^2)	500	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	0	Pore pressure for friction	0.7224		
Initial velocity (m/s)	0			Threshold entrainment depth (m)	100

Remarks: Final slide volume is 720 m^3. For DAN-W analysis, erosion depth is set to 0.275 m, the friction angle is set to 35° and the pore pressure for friction is 0.7224.

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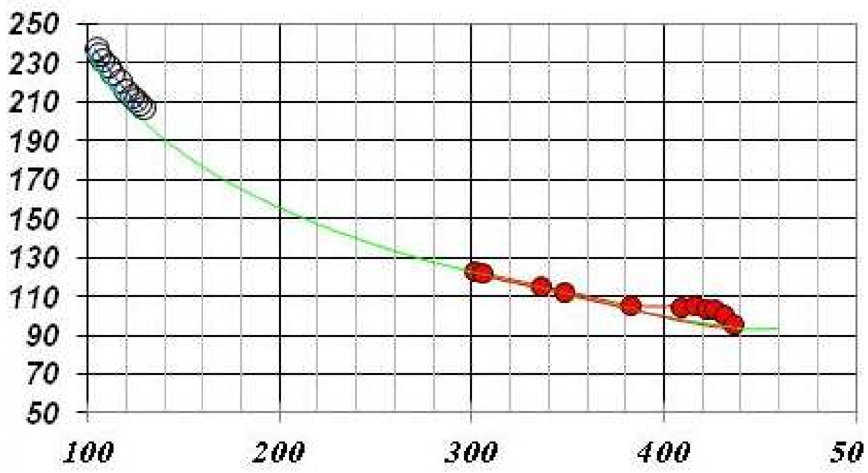
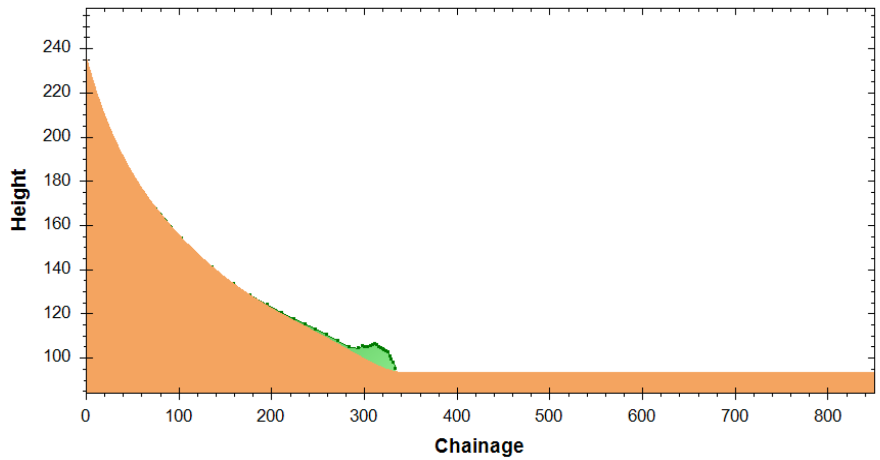
Summary - Case 4					
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference (Versions 1.2 & 2.0)	DAN-W (Release 10)	Percentage Difference (Version 2.0 & DAN-W)
Runout distance (m)	336.31	333.80	-0.75%	338.93	-1.51%
Max. debris velocity (m/s)	12.06	11.33	-6.05%	11.02	2.81%
Max. debris thickness (m)	1.22	1.32	8.20%	-	-

2d-DMM (Version 1.2)



* Rectangular block

2d-DMM (Version 2.0)



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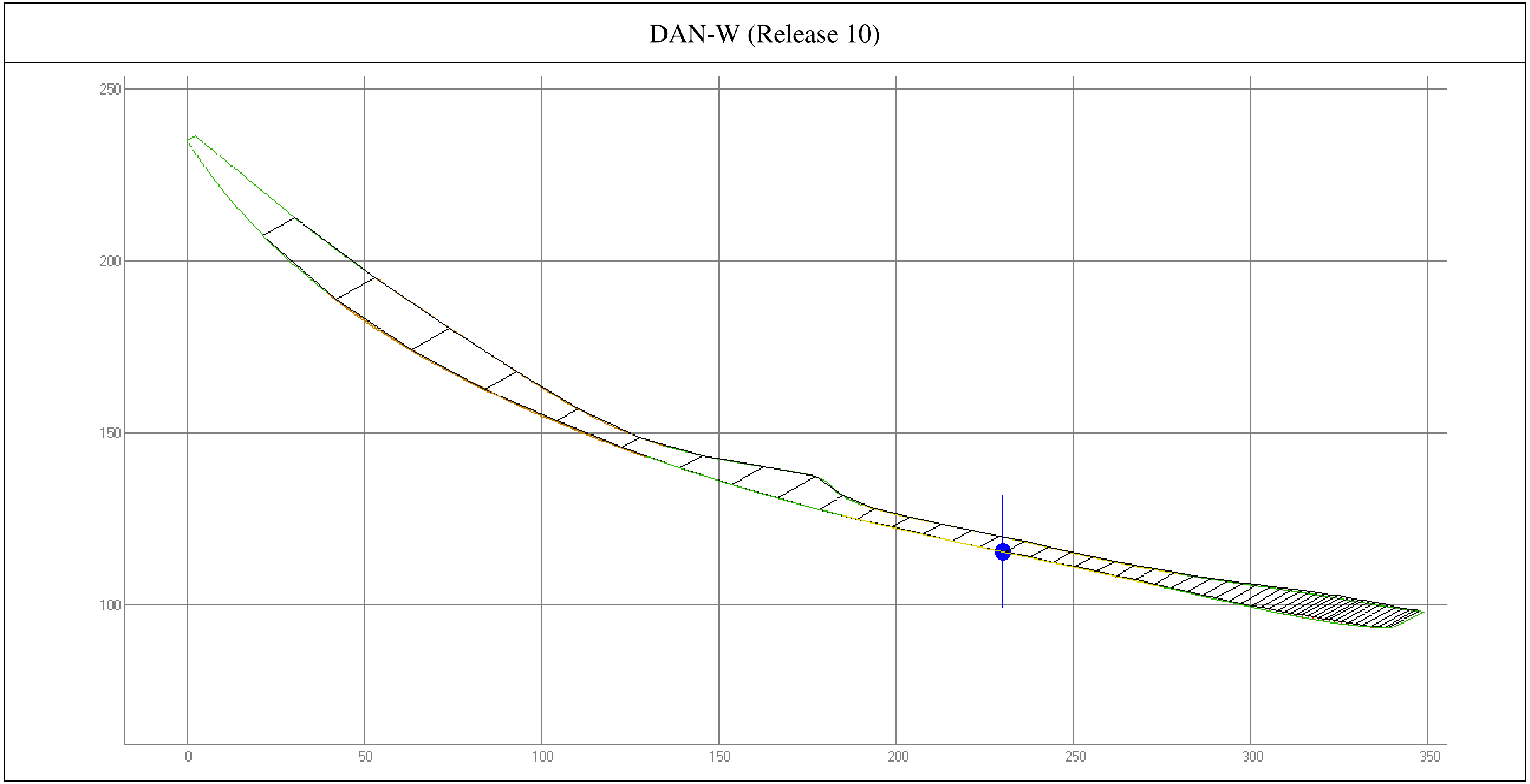

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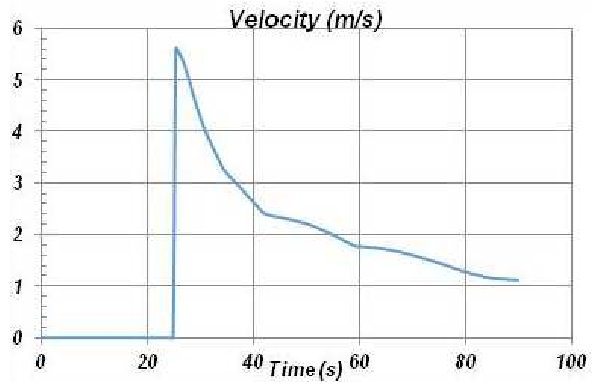
<td>

(At x = 330)
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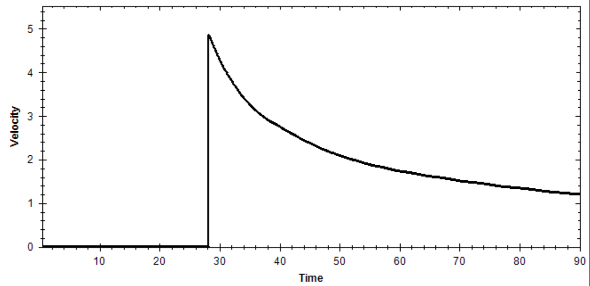
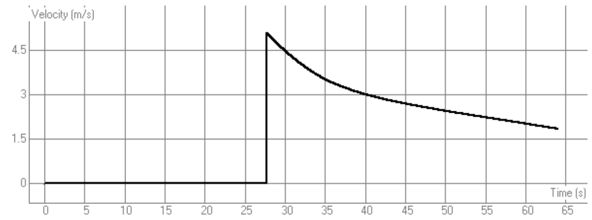
<td>

(At x = 230)</td>
<td>

(At x = 230)</td>
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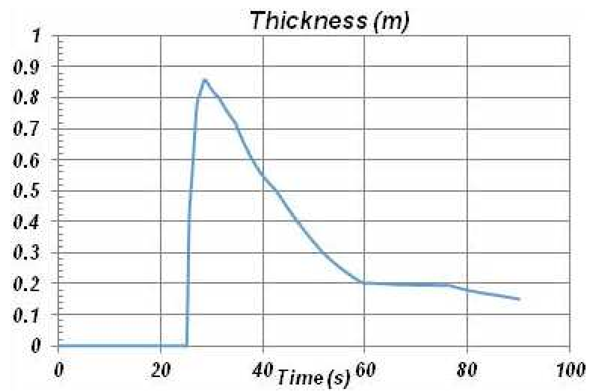
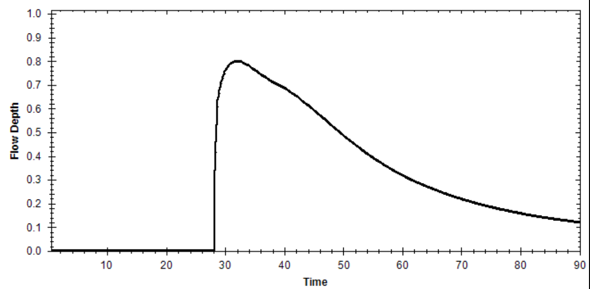
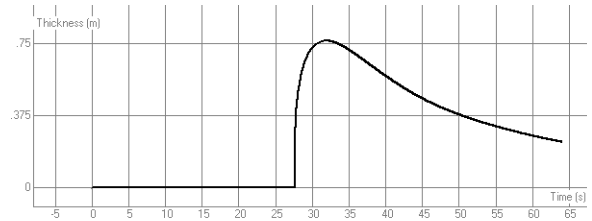
<td>

(At x = 330)
(Version 1.2) (Chainage offset +100m)</td>
<td>

(At x = 230)</td>
<td>

(At x = 230)</td>
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<tr><td colspan="3">Thickness Hydrograph</td></tr>
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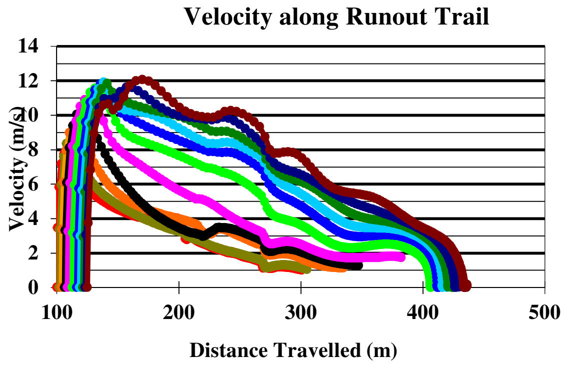
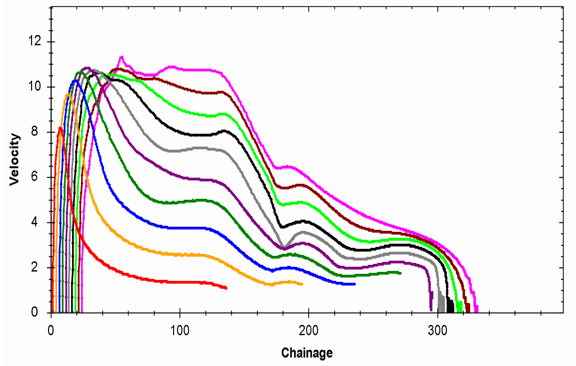
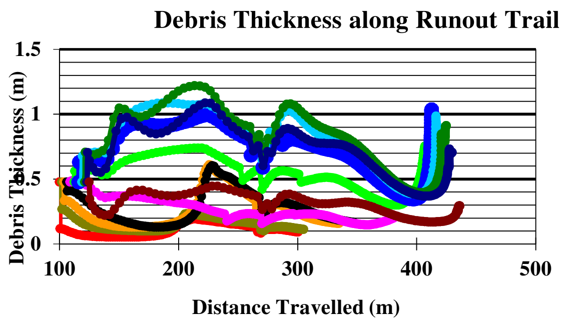
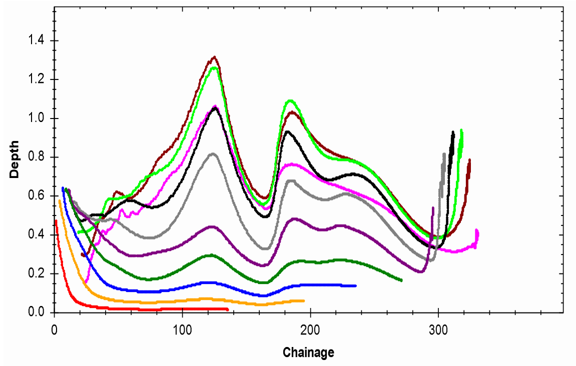
2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	DAN-W (Release 10)
		No of Blocks = 50 Time step = 0.001 seconds End at time = 90.12 seconds Configuration = 3-dimensional Boundary Block Geometry = Normal Shape factor = 1.00 Maximum velocity = 11.02 at X = 33.54 Maximum front velocity = 10.70 at X =115.96 FRONT DISPLACEMENT: X = 338.928 Z = 93.282 Curvilinear Displ.= 337.379 Horiz. Displ. = 313.93 REAR DISPLACEMENT: X = 21.50 Z = 207.47 Curvilinear Displ.= 34.85 Horiz. Displ. = 21.50 CENTRE OF GRAVITY: X-Source = 13.67 Z-Source = 217.05 X-Depos. = 289.26 Z-Depos. = 102.66 CG Ratio = 0.42 Travel angle = 22.54 FAHRBOSCHUNG = 22.67 SLIDE VOLUME: Initial = 250.46 Final = 716.86 AREA IN PLAN: Initial = 334.31 Final = 4776.92 Runout not completed, V-MAX = 1.17
		

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A.5 Validation Case No. 5

Tip No.7 Flow Slide of 1966 at Aberfan, South Wales

Case 5 : Tip No.7 Flow Slide of 1966 at Aberfan, South Wales					
Debris Properties		Section 1			
Density (kg/m^3)	1,730	Friction angle (^{o})	36	Entrainment start location (m)	0
Volume (m^3)	35,000	Turbulent coefficient (m/s^2)	0	Entrainment end location (m)	0
Initial horizontal length of flow mass (m)	160	Pore pressure for friction	0.78	Entrainment rate (m^3/s)	0
K_a	0.8	Section 2			
K_0	1	Start location of section 2 (m)	2100	Entrainment start location (m)	0
K_p	2.5	Friction angle (^{o})	35	Entrainment end location (m)	0
Pore pressure ratio, R_u	0.78	Turbulent coefficient (m/s^2)	0	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	0	Pore pressure for friction	0.78		
Initial velocity (m/s)	0			Threshold entrainment depth (m)	0
Remarks: For DAN-W analysis, the friction angle is set to 36° and the pore pressure for friction is 0.78.					

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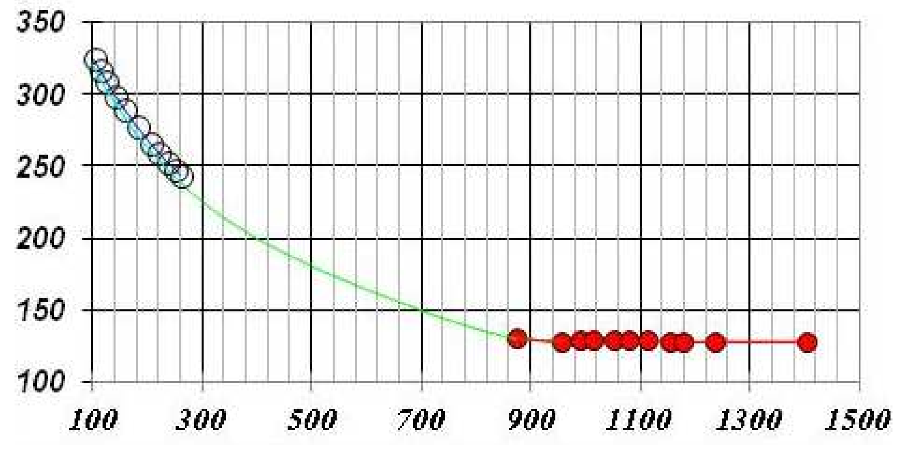
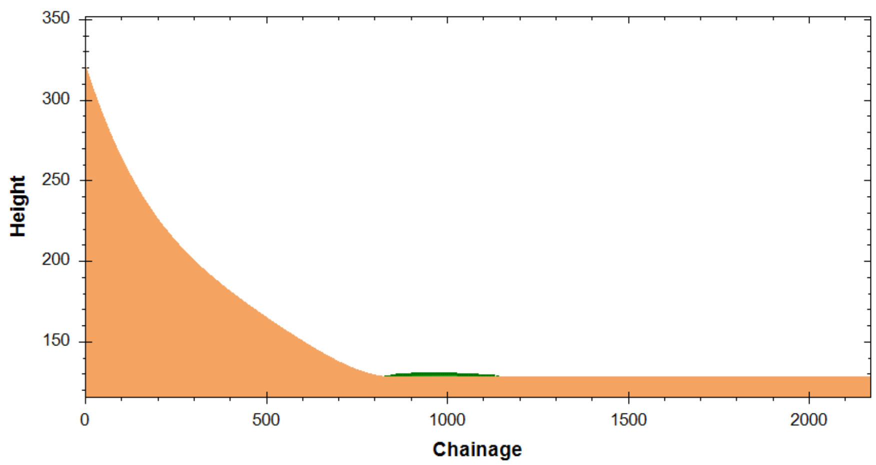
Summary - Case 5					
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference (Versions 1.2 & 2.0)	DAN-W (Release 10)	Percentage Difference (Version 2.0 & DAN-W)
Runout distance (m)	1,303.44	1,138.20	-12.68%	1,109.07	2.63%
Max. debris velocity (m/s)	42.00	33.30	-20.71%	31.87	4.49%
Max. debris thickness (m)	5.98	4.70	-21.40%	-	-

2d-DMM (Version 1.2)	2d-DMM (Version 2.0)
 * Rectangular block	

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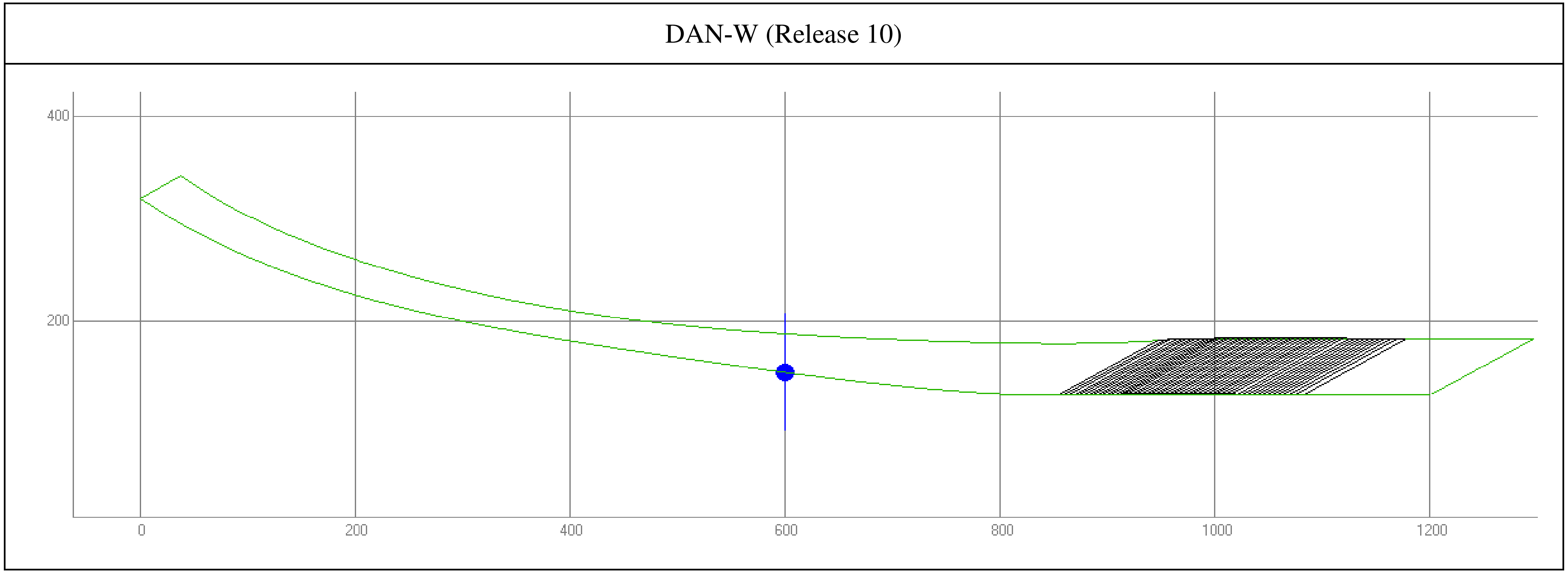

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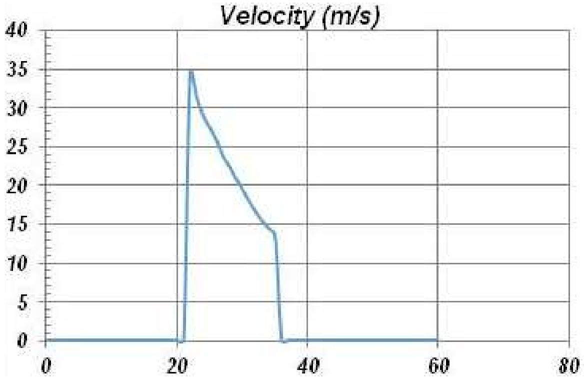
<td>

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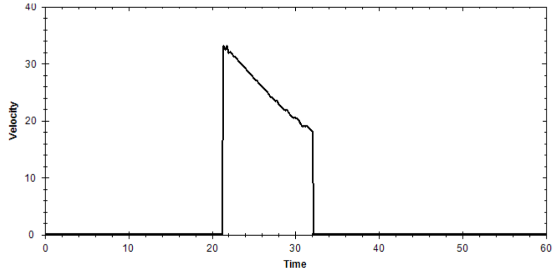
<td>

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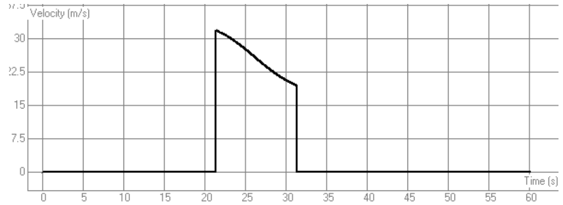
<td>

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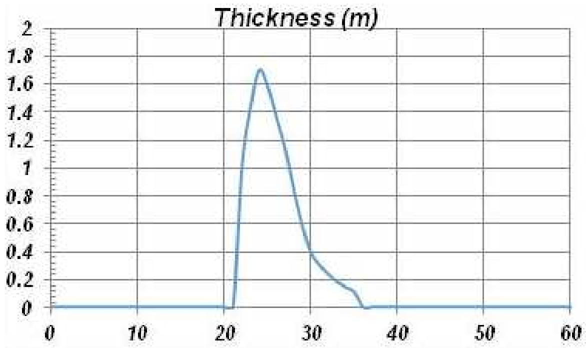
<td>

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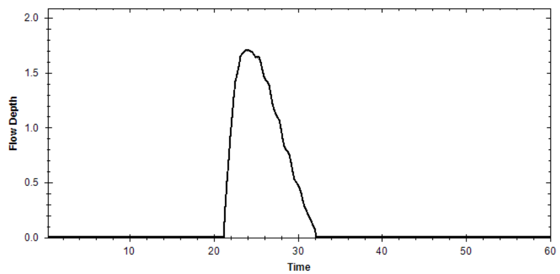
<td>

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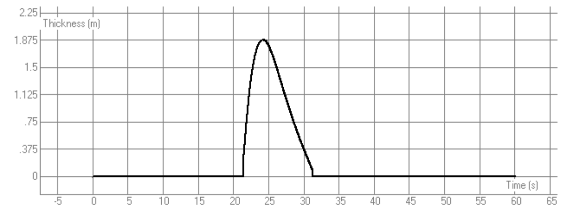
<td>

(At x = 600)</td>
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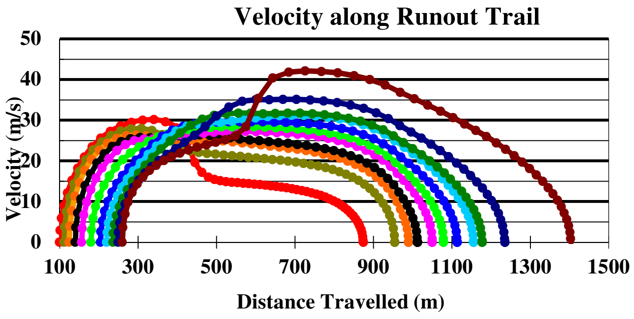
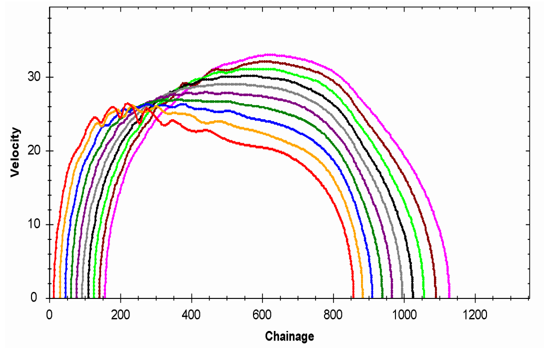
<td></td>
<td></td>
<td>No of Blocks = 50
Time step = 0.01 seconds
End at time = 60.10 seconds
Configuration = 3-dimensional
Boundary Block Geometry = Normal
Shape factor = 1.00
Maximum velocity = 31.87 at X = 635.95
Maximum front velocity = 31.87 at X =635.95

FRONT DISPLACEMENT: X = 1109.069 Z = 128.067
Curvilinear Displ.= 959.833
Horiz. Displ. = 949.07

REAR DISPLACEMENT: X = 840.13 Z = 127.86
Curvilinear Displ.= 870.79
Horiz. Displ. = 840.13

CENTRE OF GRAVITY: X-Source = 81.65
Z-Source = 275.00
X-Depos. = 973.54
Z-Depos. = 128.42

CG Ratio = 0.16
Travel angle = 9.33
FAHRBOSCHUNG = 9.81

SLIDE VOLUME: Initial = 34935.17
Final = 34935.17

AREA IN PLAN: Initial = 12053.89
Final = 56837.63

Runout time = 50.00</td>
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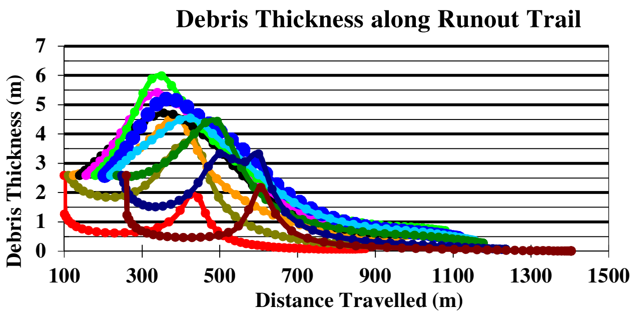
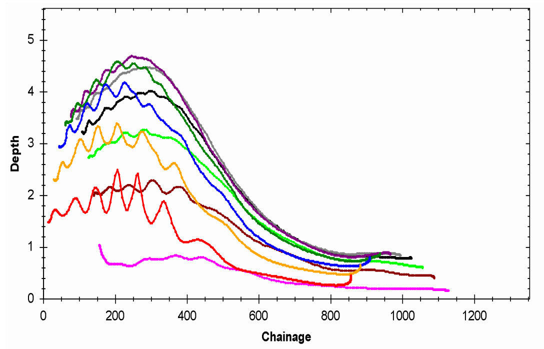
<td></td>
<td></td>
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A.6 Validation Case No. 6

ENTLI Case No. 03SEA2011E

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Case 6 : ENTLI Case No. 03SEA2011E					
Debris Properties		Section 1			
Density (kg/m^3)	1,800	Friction angle (^{o})	29	Entrainment start location (m)	0
Volume (m^3)	200	Turbulent coefficient (m/s^2)	500	Entrainment end location (m)	0
Initial horizontal length of flow mass (m)	7.1	Pore pressure for friction	0	Entrainment rate (m^3/s)	0
K_a	0.8	Section 2			
K_0	1	Start location of section 2 (m)	1,000	Entrainment start location (m)	0
K_p	2.5	Friction angle (^{o})	0	Entrainment end location (m)	0
Pore pressure ratio, R_u	0.21	Turbulent coefficient (m/s^2)	0	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	0	Pore pressure for friction	0		
Initial velocity (m/s)	0			Threshold entrainment depth (m)	0

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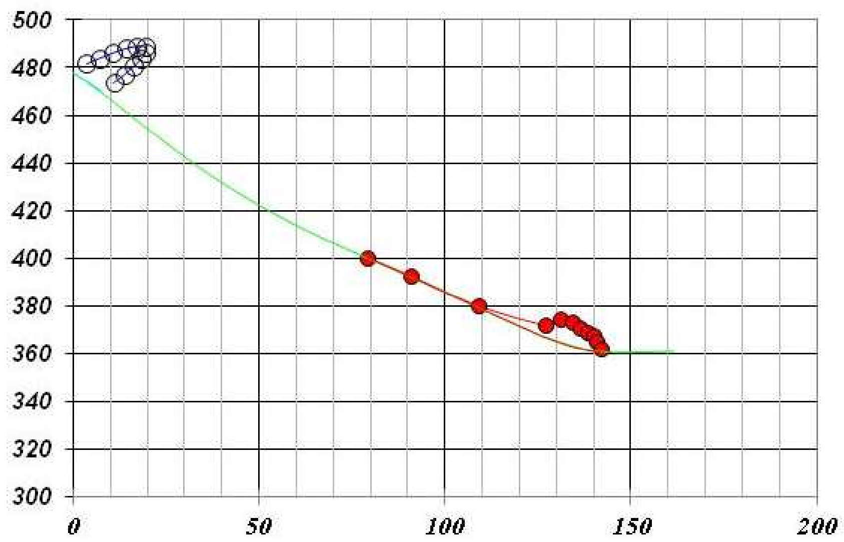
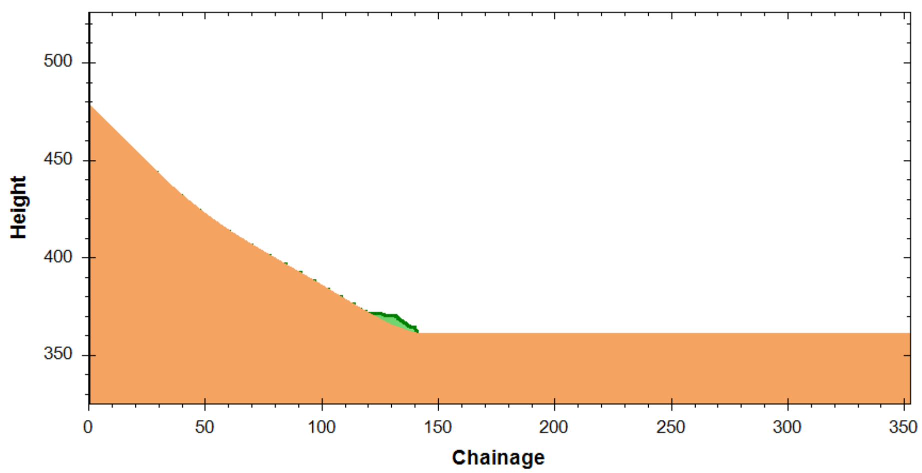
Summary - Case 6 ENTLI Case No. 03SEA2011E			
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference
Runout distance (m)	141.63	141.28	-0.25%
Max. debris velocity (m/s)	11.22	11.25	0.27%
Max. debris thickness (m)	0.96	1.06	10.42%

2d-DMM (Version 1.2)	2d-DMM (Version 2.0)
	
Final Result	

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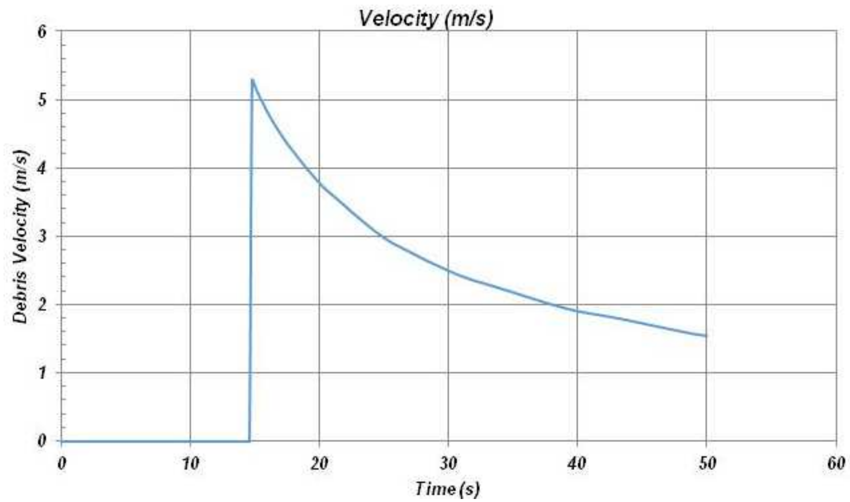
<td>

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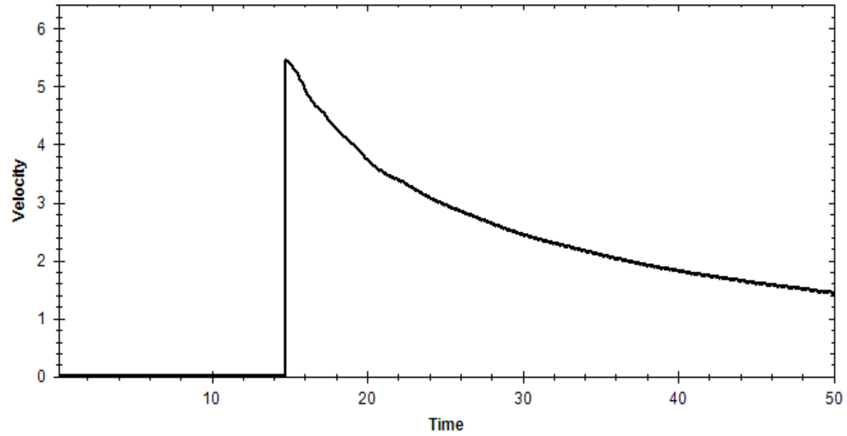
<td>

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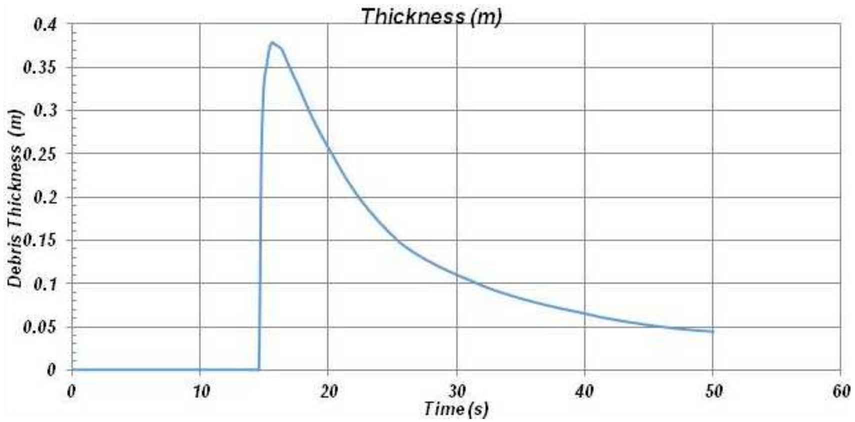
<td>

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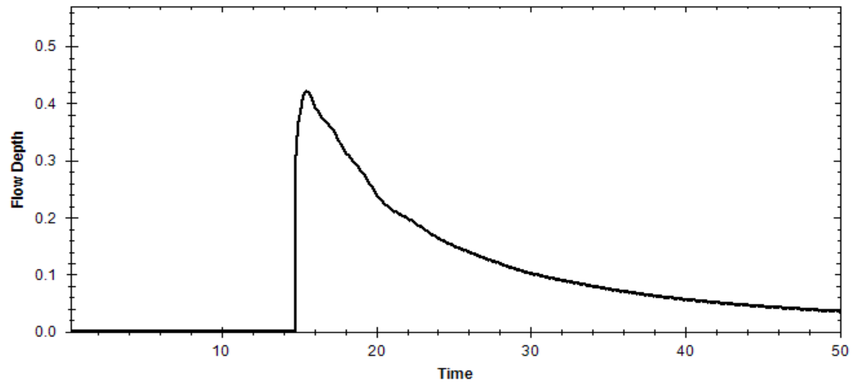
<td>

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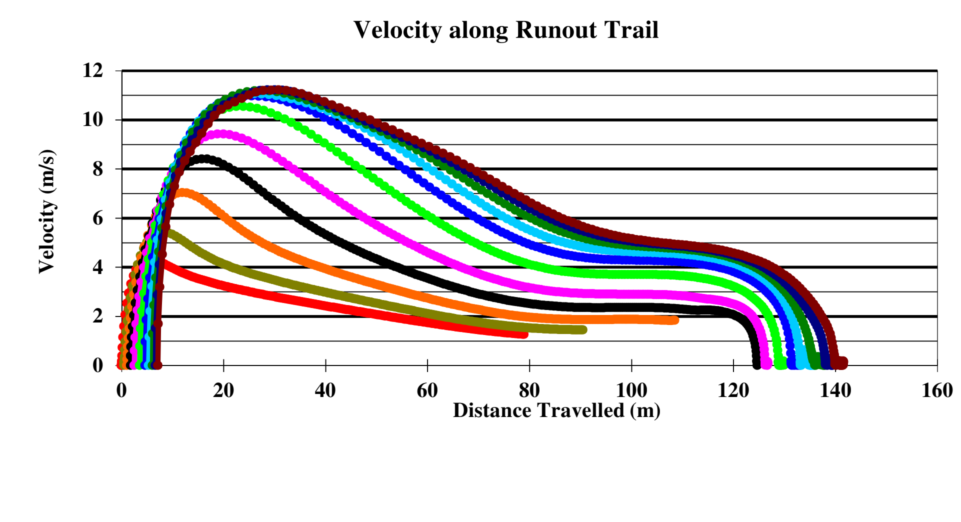
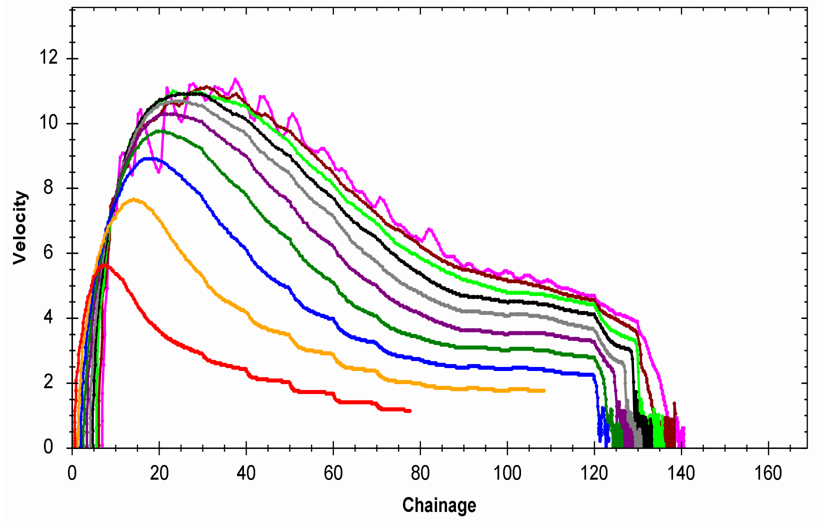
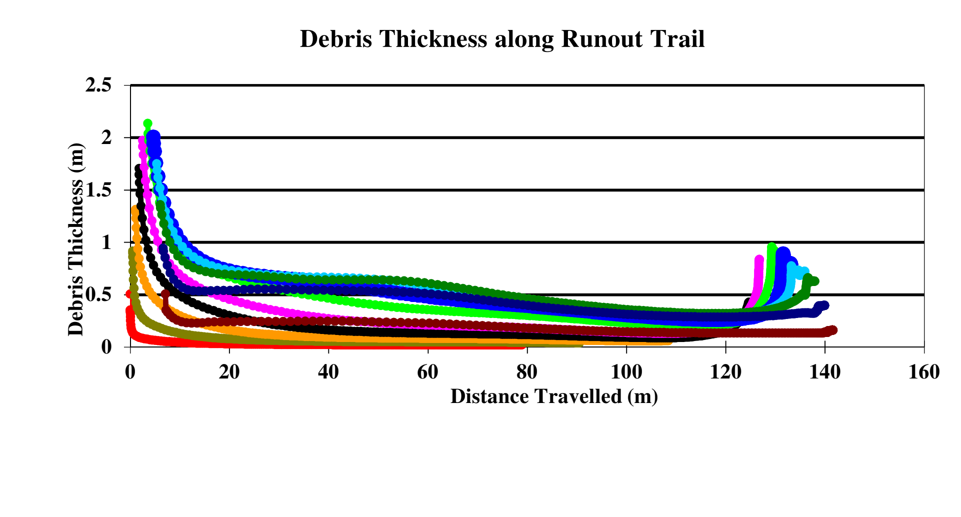
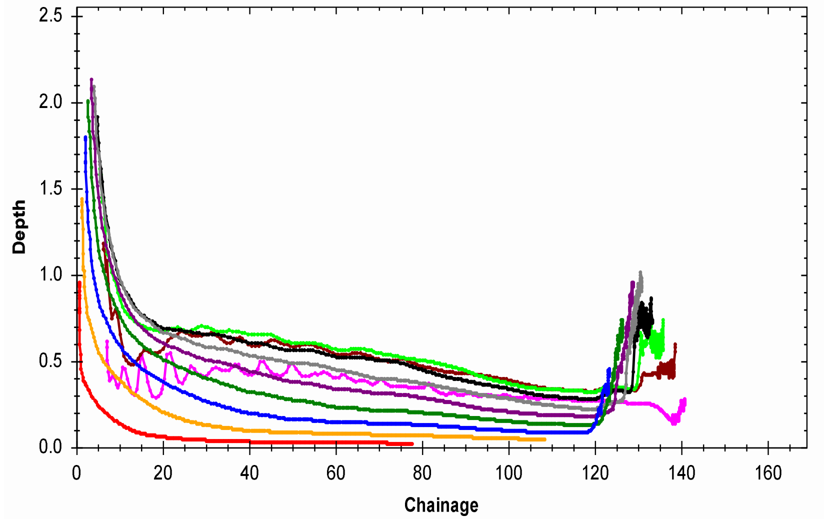




Velocity profile





Thickness profile

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A.7 Validation Case No. 7

ENTLI Case No. 03SEA2011E(2)

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Case 7 : ENTLI Case No. 03SEA2011E(2)					
Debris Properties		Section 1			
Density (kg/m^3)	1,800	Friction angle (^{o})	29	Entrainment start location (m)	0
Volume (m^3) :	200	Turbulent coefficient (m/s^2)	500	Entrainment end location (m)	0
Initial horizontal length of flow mass (m)	54.8	Pore pressure for friction	0	Entrainment rate (m^3/s)	0
K_a	0.8	Section 2			
K_0	1	Start location of section 2 (m)	1000	Entrainment start location (m)	0
K_p	2.5	Friction angle (^{o})	0	Entrainment end location (m)	0
Pore pressure ratio, R_u	0.21	Turbulent coefficient (m/s^2)	0	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	36.80	Pore pressure for friction	0		
Initial Velocity (m/s)	4.79			Threshold entrainment depth (m)	0
Remarks: Initial velocity is set to 4.8 m/s.					

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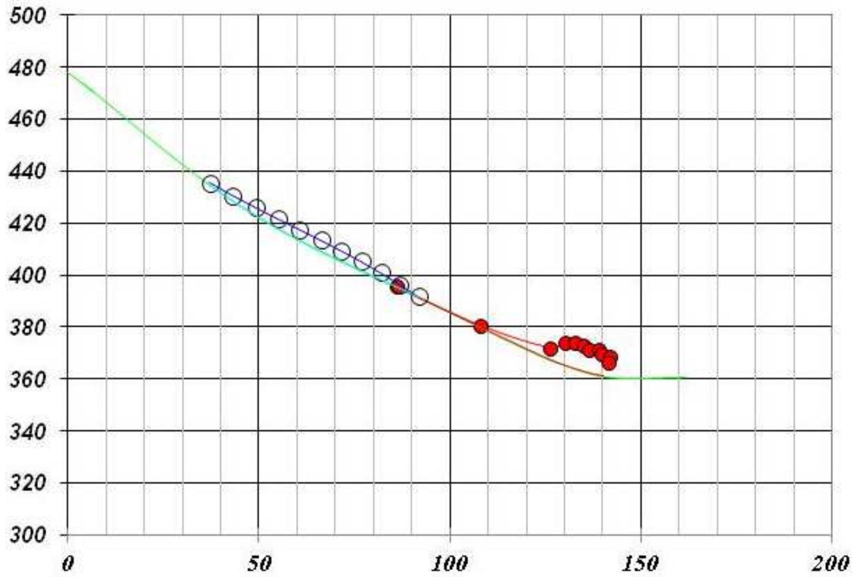
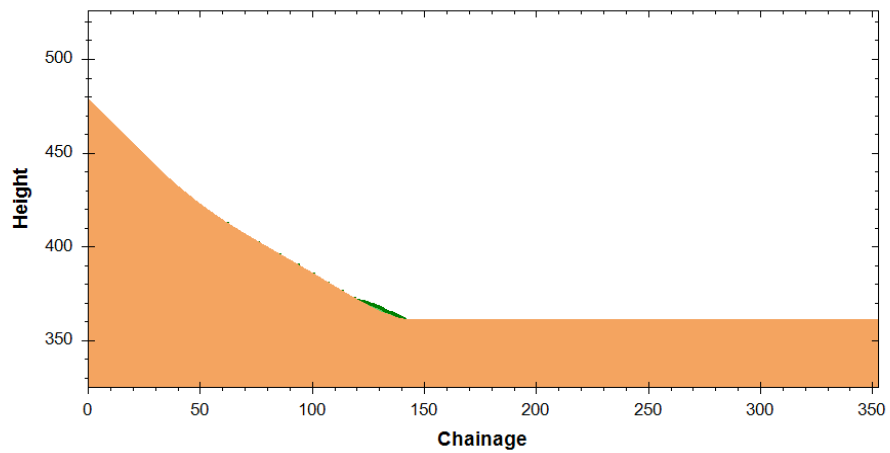
Summary - Case 7 ENTLI Case No. 03SEA2011E(2)			
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference
Runout distance (m)	140.36	141.42	0.76%
Max. debris velocity (m/s)	4.99	5.08	1.80%
Max. debris thickness (m)	0.98	1.01	3.06%

2d-DMM (Version 1.2)	2d-DMM (Version 2.0)
	
Final Result	

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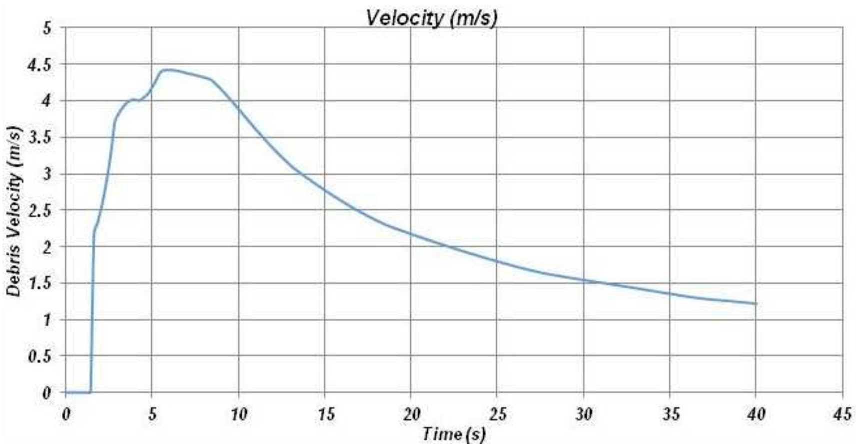

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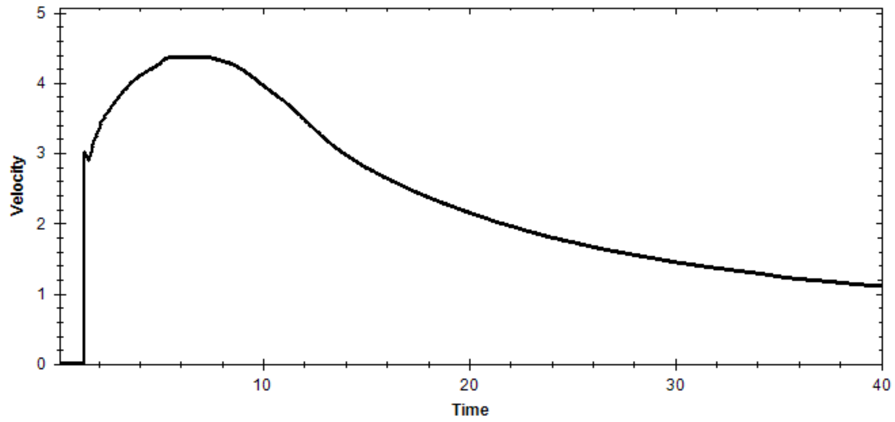
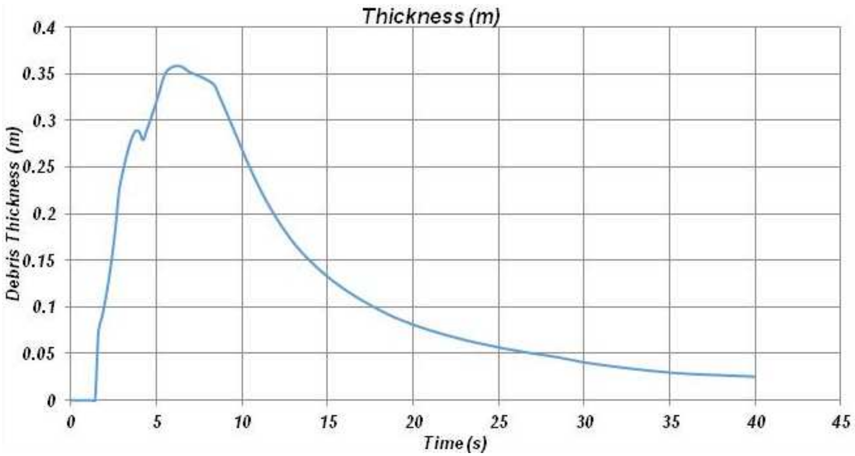
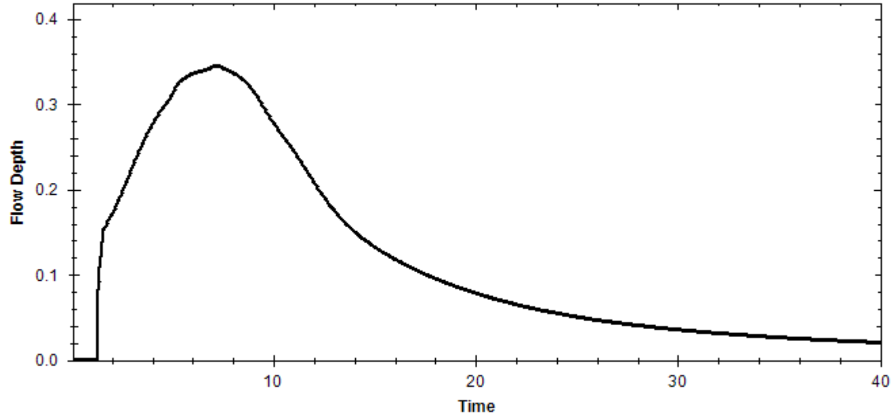


(At x = 95)

Velocity Hydrograph



(At x = 95)



(At x = 95)

Thickness Hydrograph

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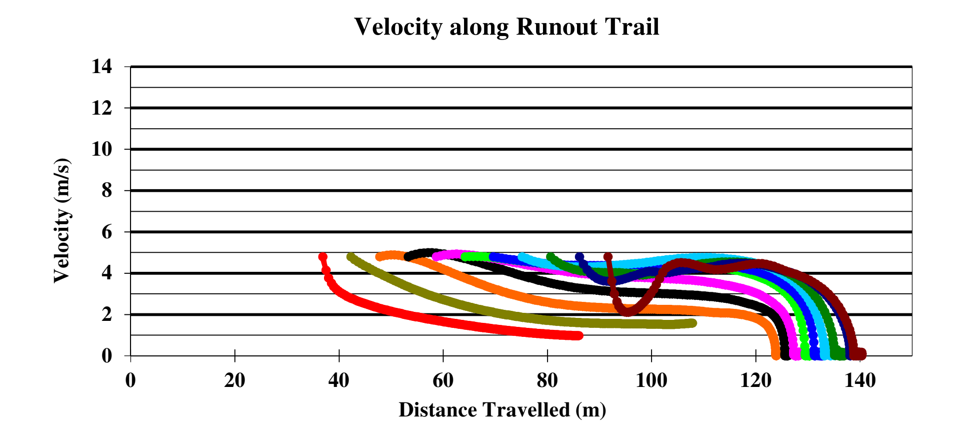
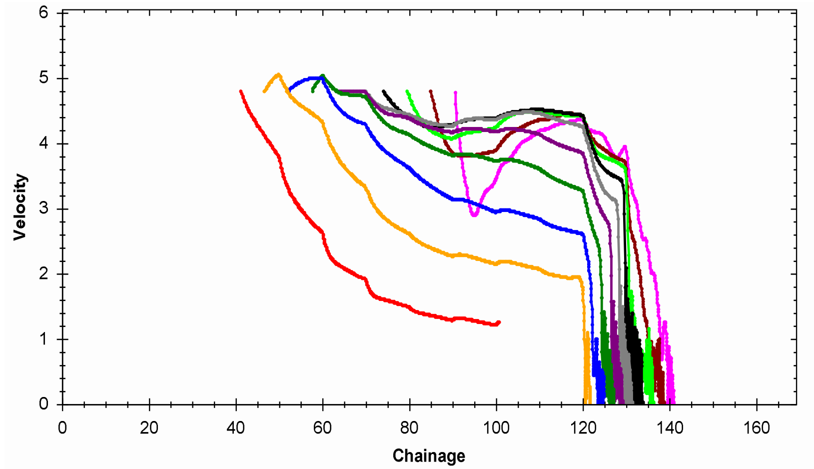
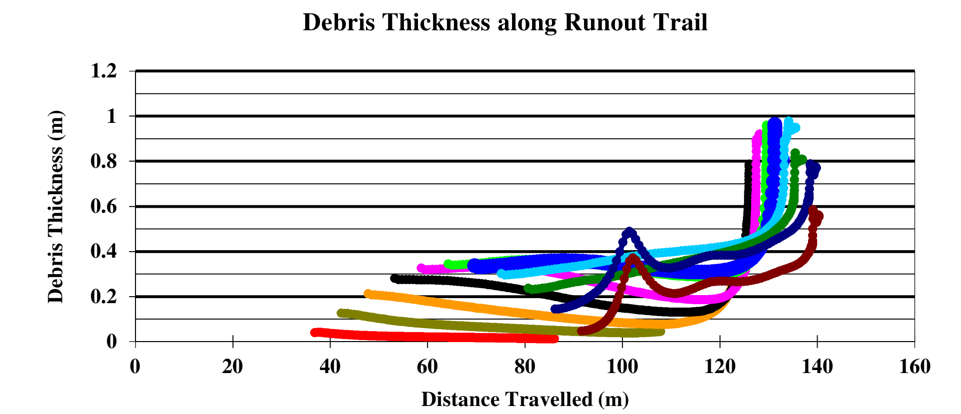
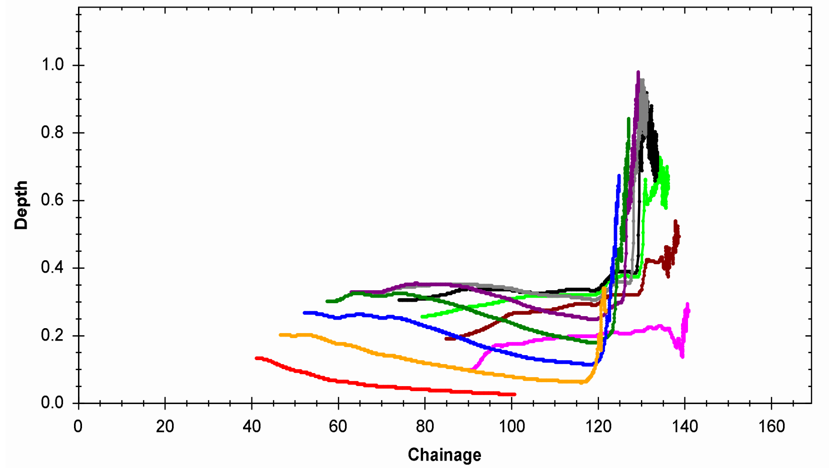




Velocity profile





Thickness profile

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A.8 Validation Case No. 8

Hypothetical Slope Profile A

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Case 8 : Hypothetical Slope Profile A					
Debris Properties		Section 1			
Density (kg/m^3)	1,800	Friction angle (°)	25	Entrainment start location (m)	0
Volume (m^3)	400	Turbulent coefficient (m/s^2)	0	Entrainment end location (m)	0
Initial horizontal length of flow mass (m)	20	Pore pressure for friction	0	Entrainment rate (m^3/s)	0
K_a	0.8	Section 2			
K_0	1	Start location of section 2 (m)	200	Entrainment start location (m)	0
K_p	2.5	Friction angle (°)	25	Entrainment end location (m)	0
Pore pressure ratio, R_u	0.33	Turbulent coefficient (m/s^2)	0	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	0	Pore pressure for friction	0		
Initial Velocity (m/s)	0			Threshold entrainment depth (m)	0

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Summary - Case 8 Hypothetical Slope Profile A			
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference
Runout distance (m)	199.91	198.40	-0.76%
Max. debris velocity (m/s)	13.59	13.76	1.25%
Max. debris thickness (m)	0.85	0.80	-5.88%

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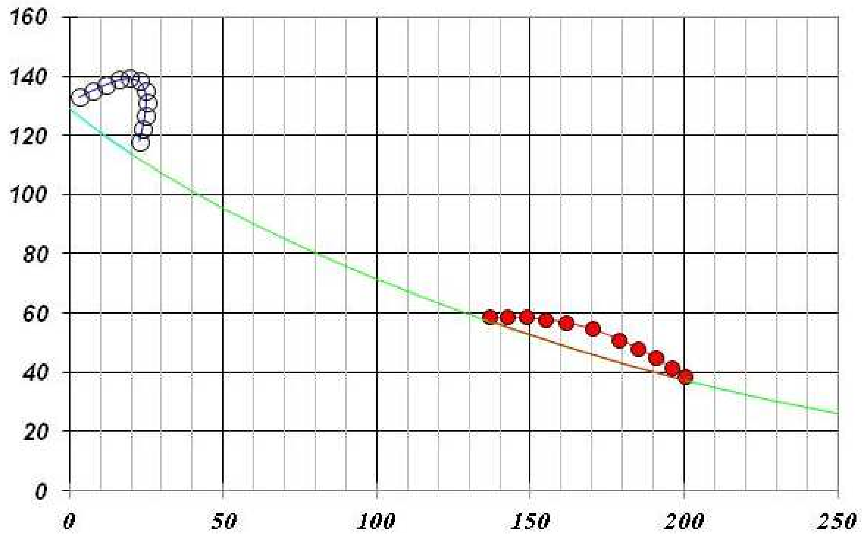

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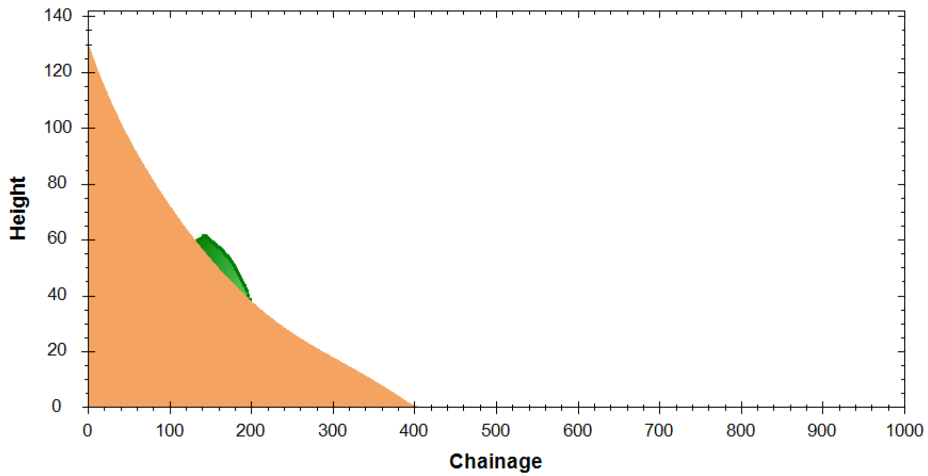

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<tr><td colspan="2">Final Result</td></tr>
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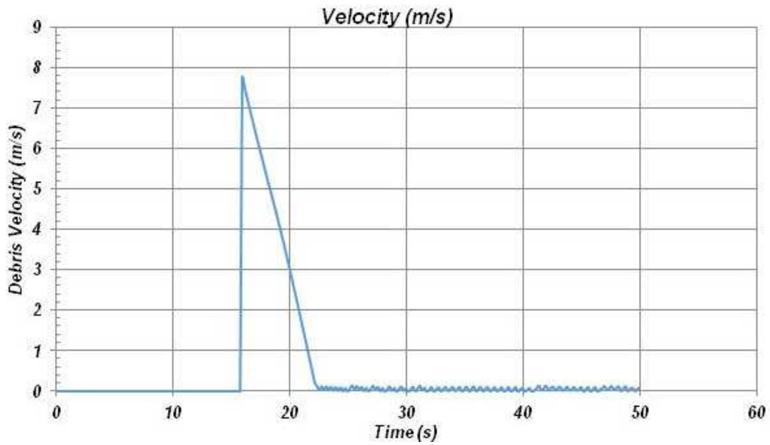
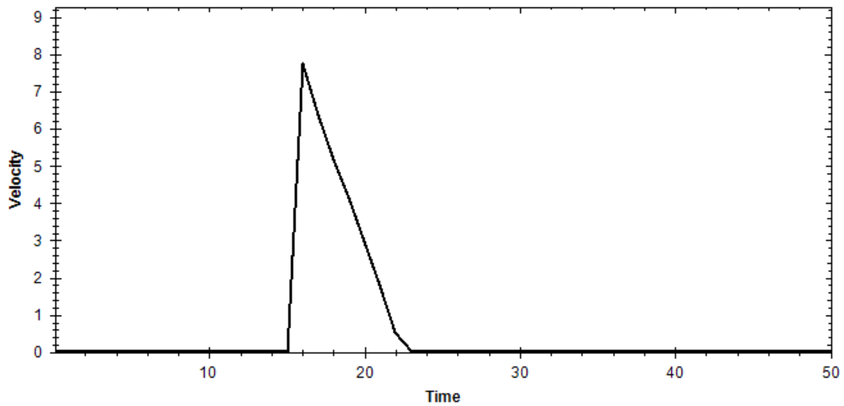
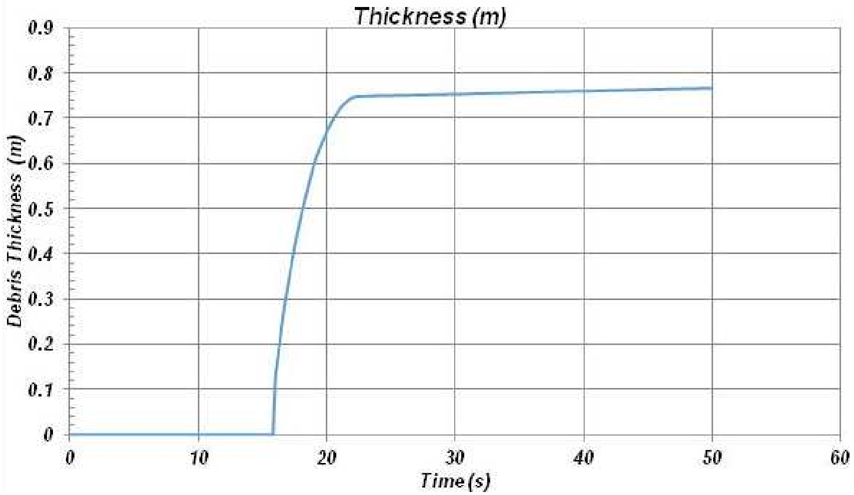
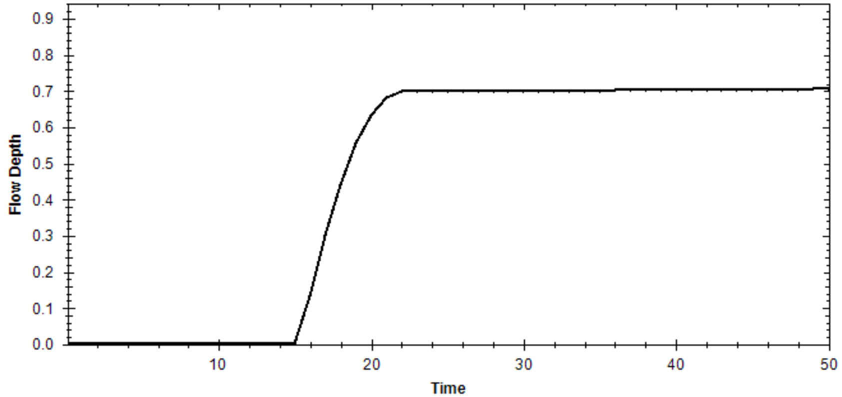
 (At x = 175)	 (At x = 175)
Velocity Hydrograph	
 (At x = 175)	 (At x = 175)
Thickness Hydrograph	

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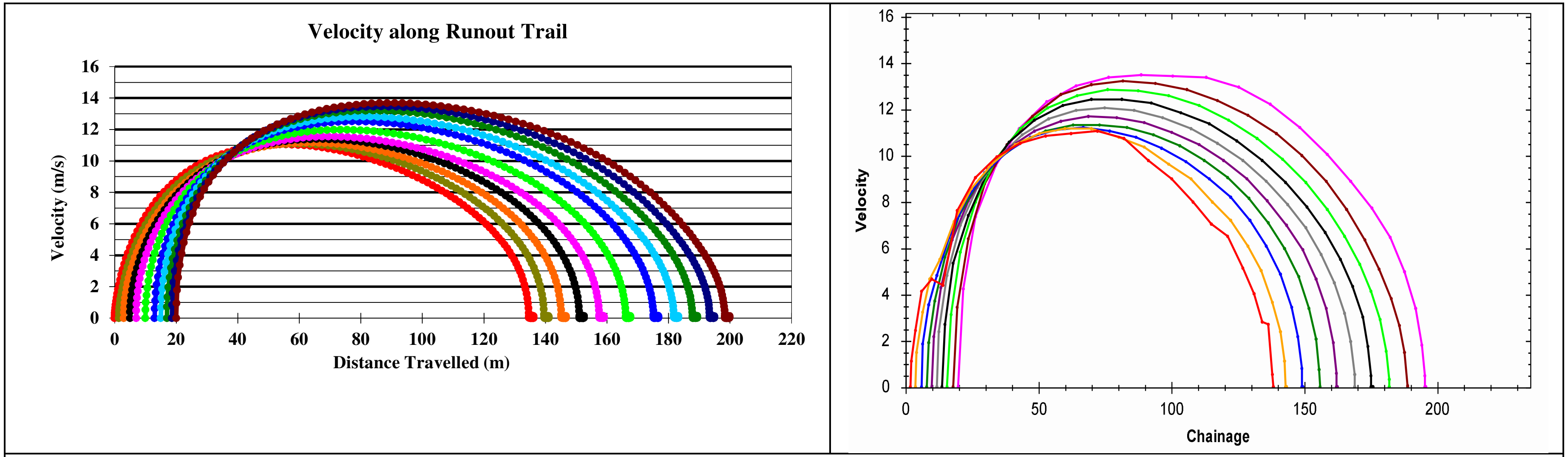
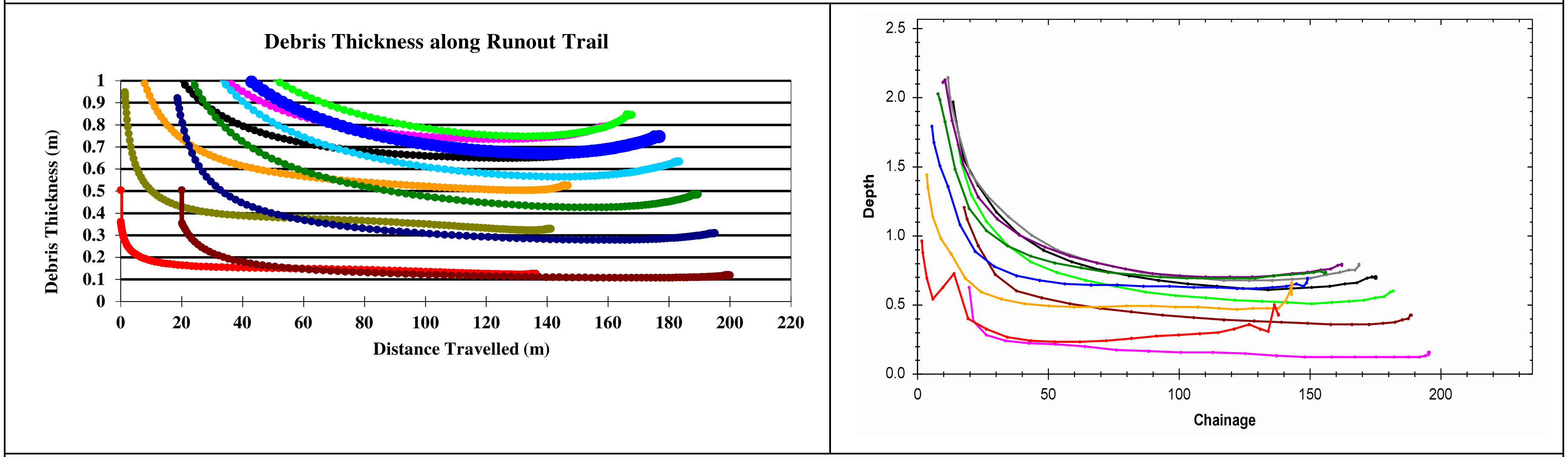


Velocity profile



Thickness profile

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A.9 Validation Case No. 9

Hypothetical Slope Profile A

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Case 9 : Hypothetical Slope Profile A					
Debris Properties		Section 1			
Density (kg/m^3)	1,800	Friction angle (^{o})	25	Entrainment start location (m)	0
Volume (m^3) :	400	Turbulent coefficient (m/s^2)	0	Entrainment end location (m)	0
Initial horizontal length of flow mass (m)	65.6	Pore pressure for friction	0	Entrainment rate (m^3/s)	0
K_a	0.8	Section 2			
K_0	1	Start location of section 2 (m)	200	Entrainment start location (m)	0
K_p	2.5	Friction angle (^{o})	25	Entrainment end location (m)	0
Pore pressure ratio, R_u	0.33	Turbulent coefficient (m/s^2)	0	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	82.67	Pore pressure for friction	0		
Initial velocity (m/s)	10.68			Threshold entrainment depth (m)	0

Remarks: Initial velocity is set to 10.7 m/s.

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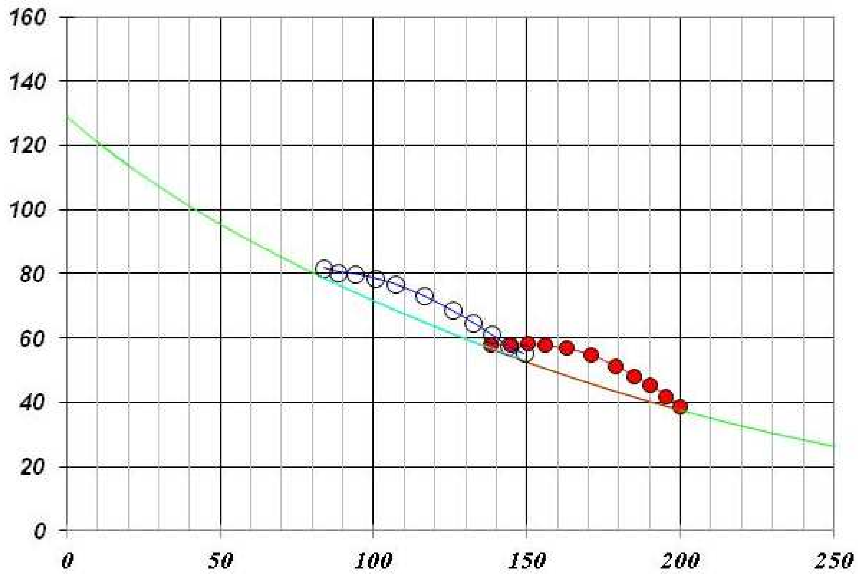
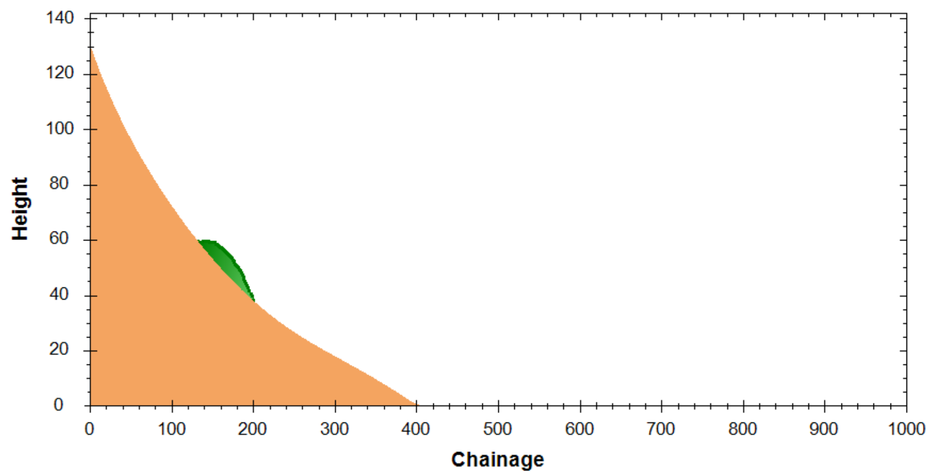
Summary - Case 9 Hypothetical Slope Profile A			
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference
Runout distance (m)	199.47	199.60	0.07%
Max. debris velocity (m/s)	10.68	10.70	0.19%
Max. debris thickness (m)	0.88	0.81	-7.95%

2d-DMM (Version 1.2)	2d-DMM (Version 2.0)
	
Final Result	

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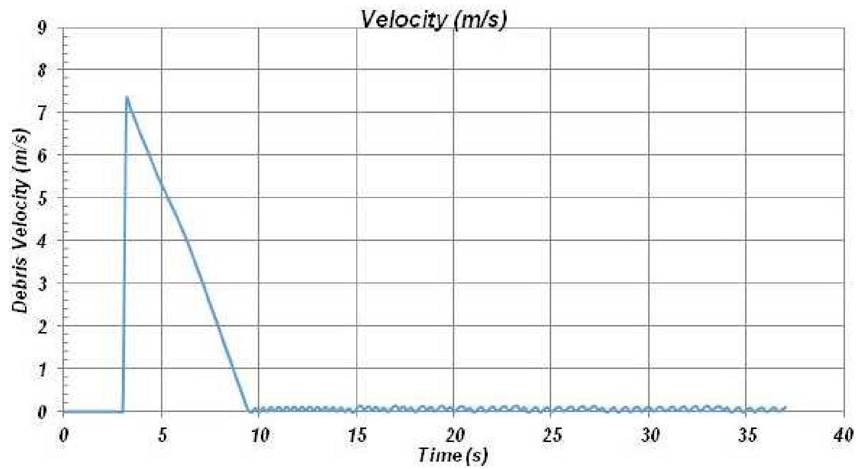
<td>

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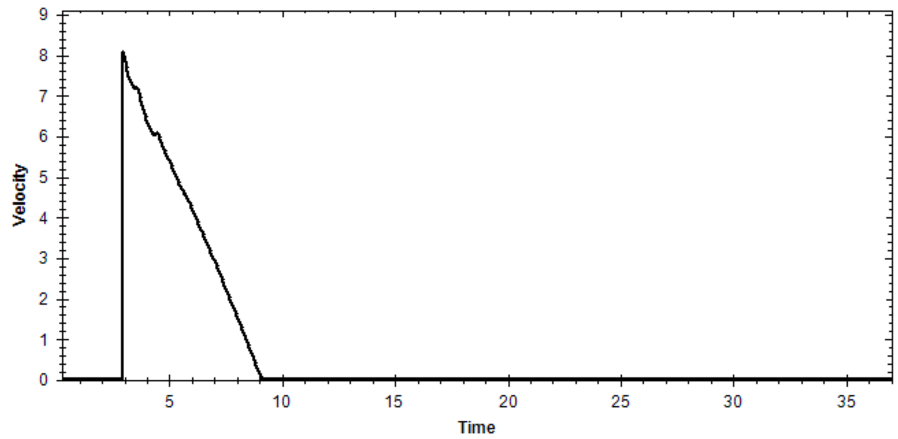
<td>

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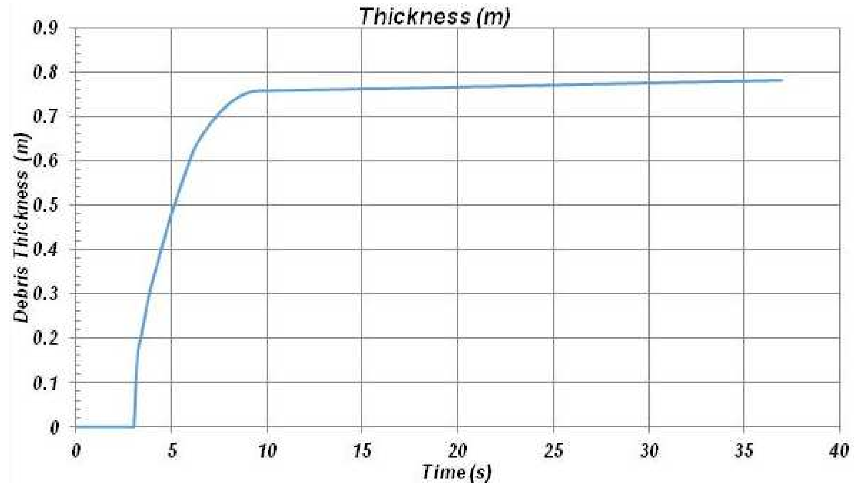
<td>

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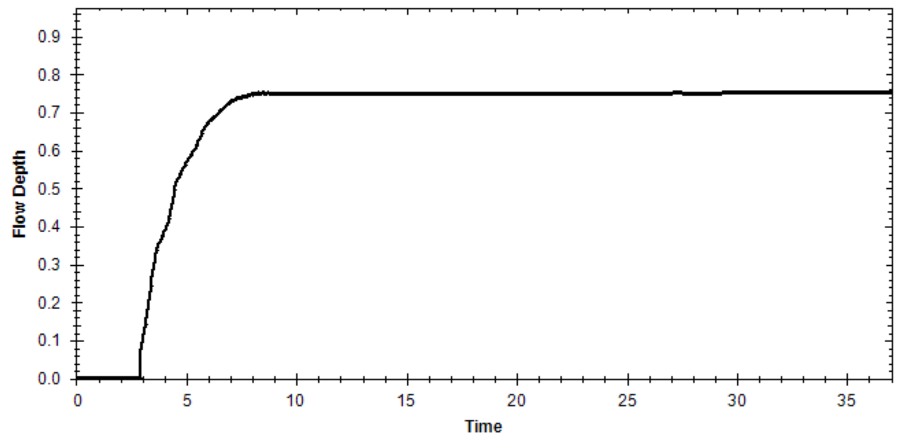
<td>

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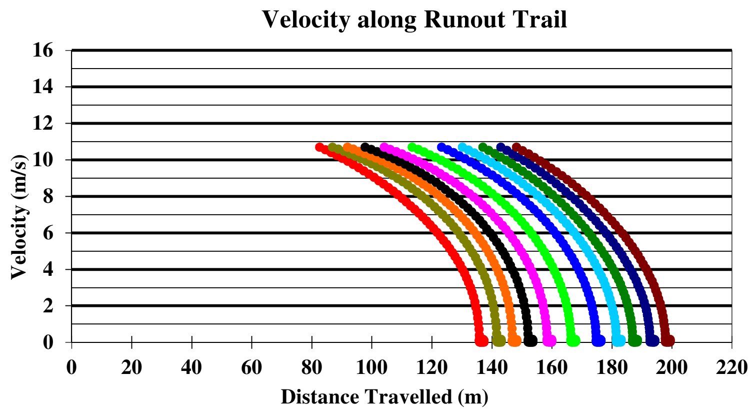
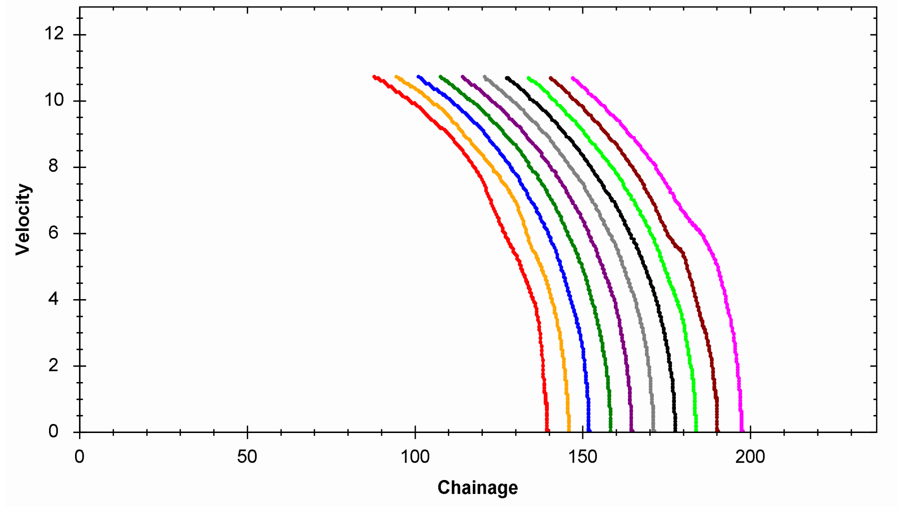
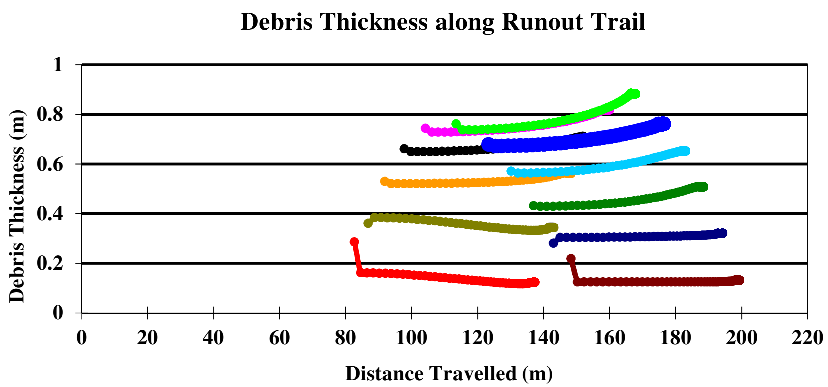
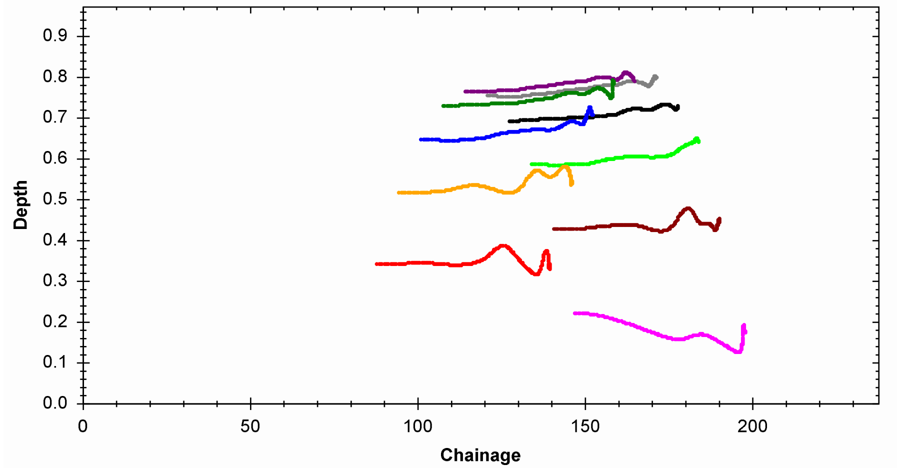




Velocity profile





Thickness profile

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A.10 Validation Case No. 10

Hypothetical Slope Profile B

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Case 10 : Hypothetical Slope Profile B					
Debris Properties		Section 1			
Density (kg/m^3)	1,764	Friction angle (º)	17.5	Entrainment start location (m)	0
Volume (m^3) :	150	Turbulent coefficient (m/s^2)	0	Entrainment end location (m)	0
Initial horizontal length of flow mass (m)	12	Pore pressure for friction	0	Entrainment rate (m^3/s)	0
K_a	0.3	Section 2			
K_0	1	Start location of section 2 (m)	1000	Entrainment start location (m)	0
K_p	3	Friction angle (º)	17.5	Entrainment end location (m)	0
Pore pressure ratio, R_u	0	Turbulent coefficient (m/s^2)	0	Entrainment rate (m^3/s)	0
Initial location of landslide debris (m)	0	Pore pressure for friction	0		
Initial velocity (m/s)	0			Threshold entrainment depth (m)	0

Remarks: Both rectangular and trapezoidal sections are tested, i.e. the side angles are set as 45° and 90° respectively.

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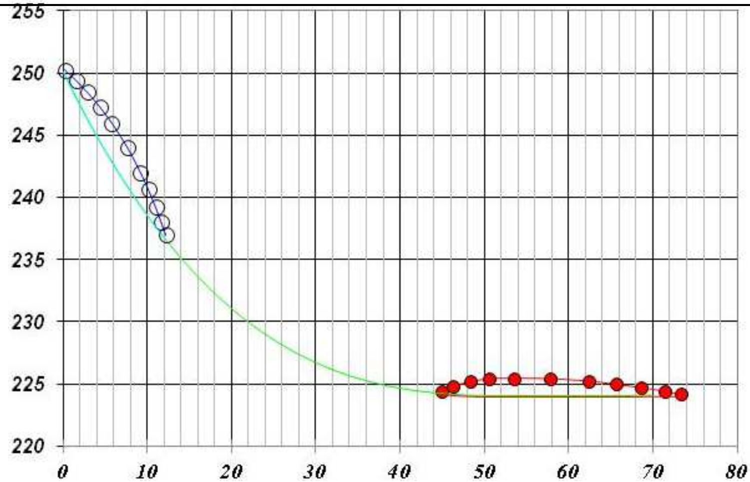
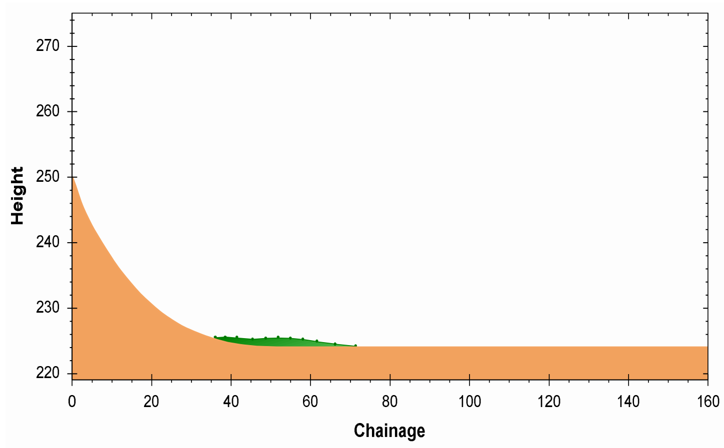
Summary - Hypothetical Slope Profile B (Side angle = 45°)			
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference
Runout distance (m)	73.28	71.78	-2.05%

Summary - Hypothetical Slope Profile B (Side angle = 90°)			
	2d-DMM (Version 1.2)	2d-DMM (Version 2.0)	Percentage Difference
Runout distance (m)	73.23	75.26	2.77%

Side angle = 45°	
2d-DMM (Version 1.2)	2d-DMM (Version 2.0)
	
Final Result	

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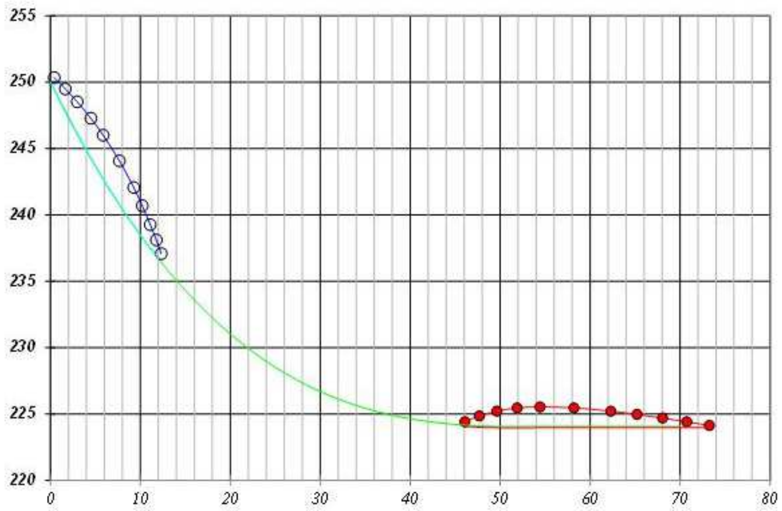
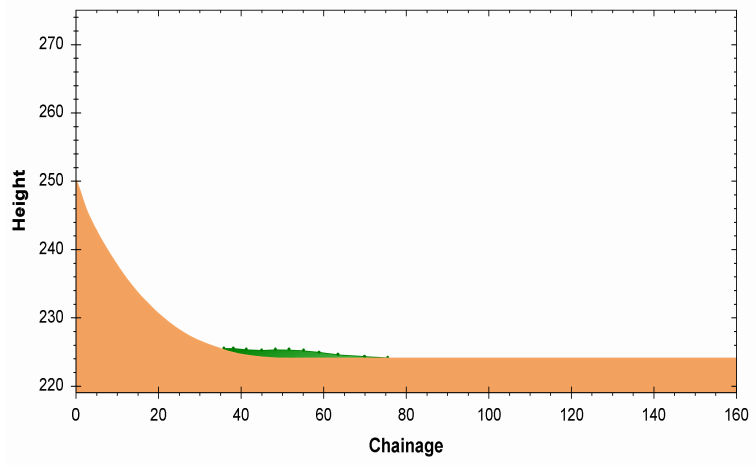
<tr><td>
</td><td>
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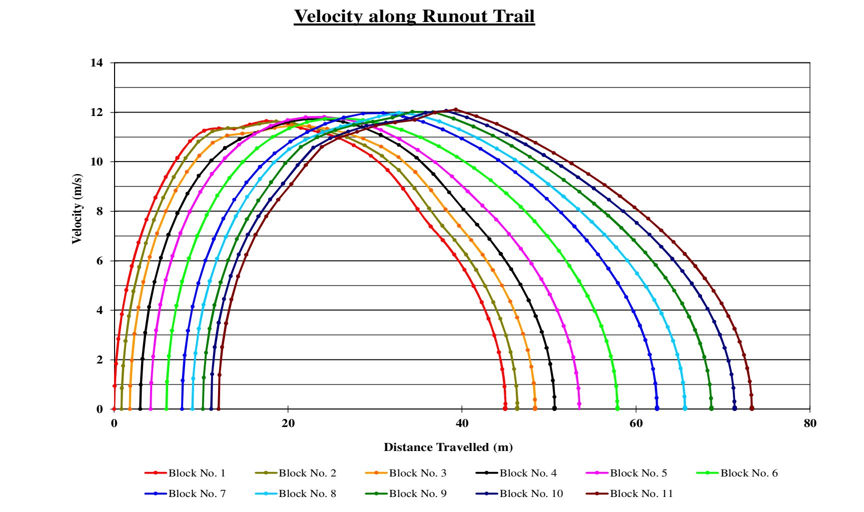
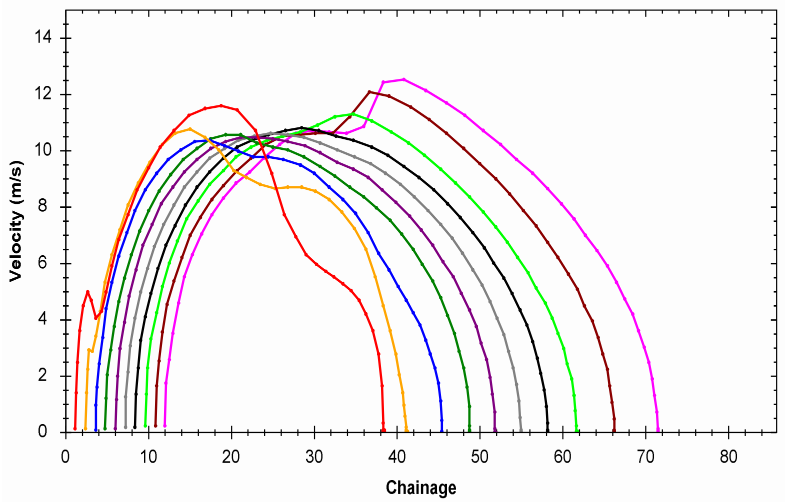
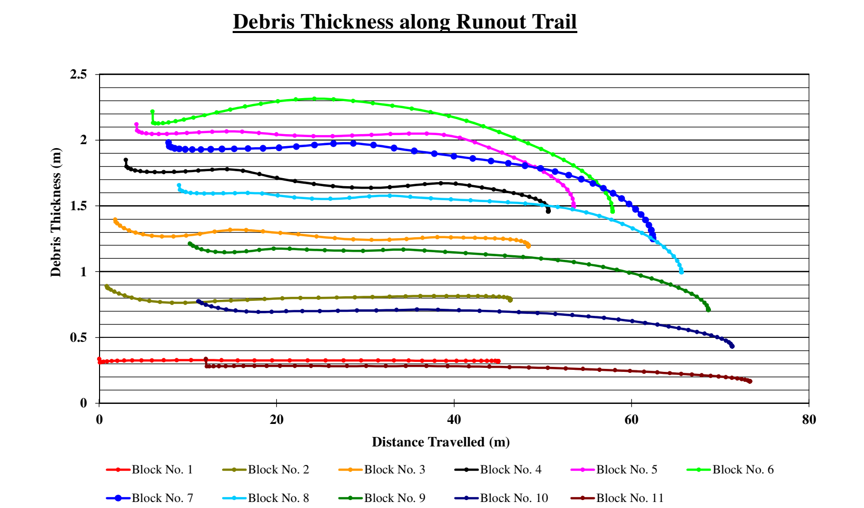
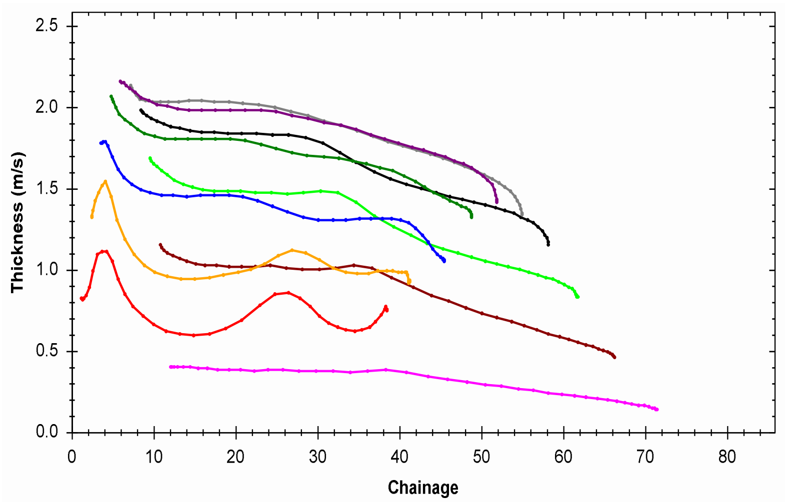


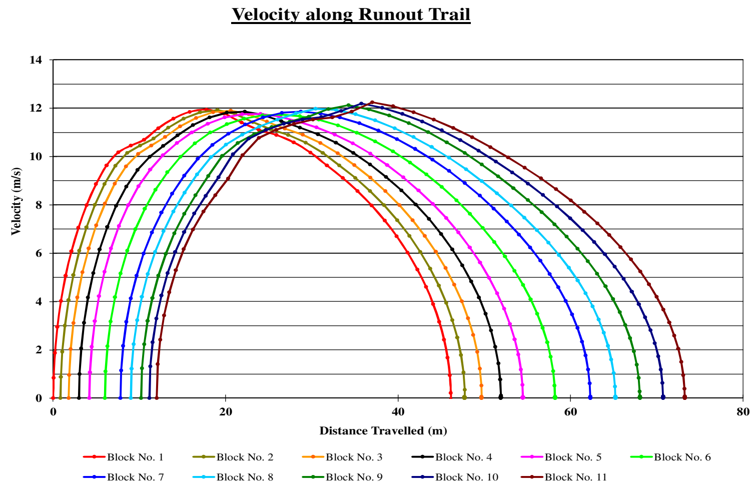


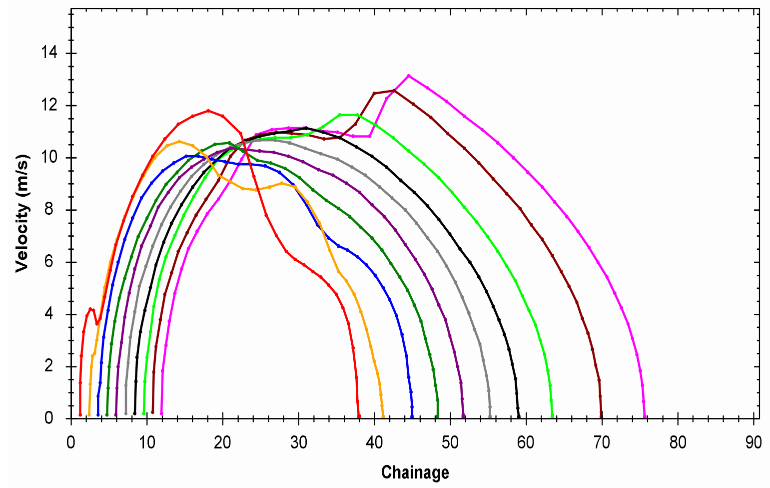
Velocity profile (Side angle = 45°)



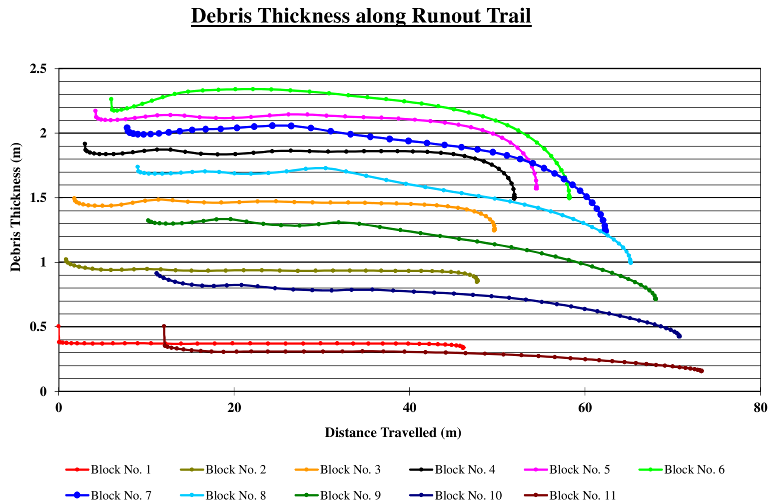


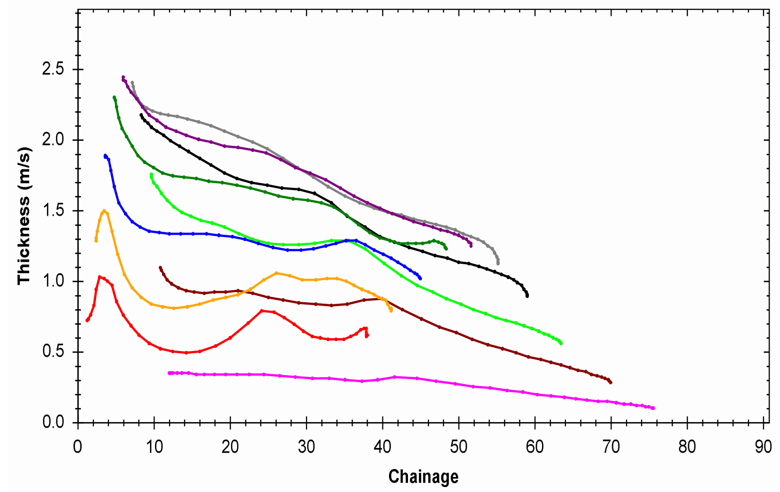
Thickness profile (Side angle = 45°)





Velocity profile (Side angle = 90°)





Thickness profile (Side angle = 90°)

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Appendix B

Summary of Data Points of Channel Geometry

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Contents

B.1 Validation Case No. 1

Liu Pok Landslide

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Validation Case No. 1 Liu Pok Landslide							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	96.09	0.00	15.09	0.00	1.57	0.00	1.57
5.00	92.53	5.00	27.41	194.00	1.57	194.00	1.57
10.00	89.18	10.00	25.25				
15.00	86.00	15.00	21.88				
20.00	82.94	20.00	19.19				
25.00	79.96	25.00	15.92				
30.00	77.05	30.00	11.99				
35.00	74.18	35.00	9.02				
40.00	71.34	40.00	6.99				
45.00	68.53	45.00	7.28				
50.00	65.74	50.00	7.34				
55.00	62.99	55.00	7.12				
60.00	60.28	60.00	6.85				
65.00	57.62	65.00	6.64				
70.00	55.01	70.00	6.58				
75.00	52.46	75.00	6.67				
80.00	50.00	80.00	6.89				
85.00	47.62	85.00	7.21				
90.00	45.34	90.00	7.57				
95.00	43.16	95.00	7.91				
100.00	41.09	100.00	8.18				
105.00	39.14	105.00	8.34				
110.00	37.29	110.00	8.37				
115.00	35.57	115.00	8.25				
120.00	33.95	120.00	8.01				
125.00	32.44	125.00	7.67				
130.00	31.03	130.00	7.28				
135.00	29.71	135.00	6.92				
140.00	28.47	140.00	6.65				

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Validation Case No. 1 Liu Pok Landslide							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
145.00	27.30	145.00	6.55				
150.00	26.18	150.00	6.70				
155.00	25.11	155.00	7.17				
160.00	24.06	160.00	7.97				
165.00	23.02	165.00	9.12				
170.00	21.99	170.00	10.57				
175.00	20.96	175.00	12.18				
180.00	19.91	180.00	13.76				
185.00	18.84	185.00	14.99				
190.00	17.76	190.00	15.45				
194.00	16.89	194.00	14.88				

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B.2 Validation Case No. 2

Cloudy Hill Landslide

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Validation Case No. 2 Cloudy Hill Landslide

Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	35.85	0.00	5.68	0.00	1.57	0.00	1.57
5.00	34.14	5.00	5.76	130.00	1.57	130.00	1.57
10.00	32.59	10.00	5.69				
15.00	31.18	15.00	5.57				
20.00	29.86	20.00	5.43				
25.00	28.59	25.00	5.32				
30.00	27.35	30.00	5.25				
35.00	26.09	35.00	5.22				
40.00	24.80	40.00	5.23				
45.00	23.45	45.00	5.26				
50.00	22.03	50.00	5.32				
55.00	20.54	55.00	5.37				
60.00	18.99	60.00	5.43				
65.00	17.38	65.00	5.49				
70.00	15.75	70.00	5.55				
75.00	14.12	75.00	5.61				
80.00	12.52	80.00	5.68				
85.00	10.99	85.00	5.77				
90.00	9.57	90.00	5.88				
95.00	8.29	95.00	6.03				
100.00	7.18	100.00	6.19				
105.00	6.26	105.00	6.36				
110.00	5.53	110.00	6.50				
115.00	4.98	115.00	6.56				
120.00	4.57	120.00	6.46				
125.00	4.24	125.00	6.07				
130.00	3.88	130.00	5.23				

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B.3 Validation Case No. 3

Cloudy Hill Landslide

Validation Case No. 3 Cloudy Hill Landslide							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	35.85	0.00	3.40	0.00	0.87	0.00	0.52
5.00	34.14	5.00	3.29	5.00	0.87	5.00	0.50
10.00	32.59	10.00	3.31	10.00	0.87	10.00	0.50
15.00	31.18	15.00	3.41	15.00	0.87	15.00	0.53
20.00	29.86	20.00	3.57	20.00	0.87	20.00	0.58
25.00	28.59	25.00	3.73	25.00	0.86	25.00	0.64
30.00	27.35	30.00	3.89	30.00	0.84	30.00	0.71
35.00	26.09	35.00	4.01	35.00	0.82	35.00	0.77
40.00	24.80	40.00	4.09	40.00	0.79	40.00	0.84
45.00	23.45	45.00	4.13	45.00	0.76	45.00	0.89
50.00	22.03	50.00	4.12	50.00	0.73	50.00	0.93
55.00	20.54	55.00	4.08	55.00	0.71	55.00	0.94
60.00	18.99	60.00	4.03	60.00	0.70	60.00	0.92
65.00	17.38	65.00	4.00	65.00	0.70	65.00	0.87
70.00	15.75	70.00	4.01	70.00	0.73	70.00	0.77
75.00	14.12	75.00	4.10	75.00	0.79	75.00	0.62
80.00	12.52	80.00	4.27	80.00	0.86	80.00	0.59
85.00	10.99	85.00	4.04	85.00	0.74	85.00	0.51
90.00	9.57	90.00	3.88	90.00	0.65	90.00	0.45
95.00	8.29	95.00	3.80	95.00	0.57	95.00	0.40
100.00	7.18	100.00	3.79	100.00	0.51	100.00	0.36
105.00	6.26	105.00	3.87	105.00	0.47	105.00	0.34
110.00	5.53	110.00	4.02	110.00	0.44	110.00	0.33
115.00	4.98	115.00	4.25	115.00	0.43	115.00	0.34
120.00	4.57	120.00	4.56	120.00	0.45	120.00	0.36
125.00	4.24	125.00	4.94	125.00	0.48	125.00	0.41
130.00	3.88	130.00	5.41	130.00	0.52	130.00	0.47

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B.4 Validation Case No. 4

Lei Pui Street Landslide

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Validation Case No. 4 Lei Pui Street Landslide							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	234.85	0.00	4.97	0.00	1.57	0.00	1.57
5.00	227.54	5.00	9.36	340.00	1.57	340.00	1.57
10.00	220.85	10.00	12.74				
15.00	214.72	15.00	15.37				
20.00	209.07	20.00	17.41				
25.00	203.87	25.00	19.01				
30.00	199.06	30.00	20.25				
35.00	194.60	35.00	21.19				
40.00	190.45	40.00	21.86				
45.00	186.57	45.00	22.29				
50.00	182.93	50.00	22.47				
55.00	179.51	55.00	22.41				
60.00	176.29	60.00	22.10				
65.00	173.23	65.00	21.56				
70.00	170.32	70.00	20.79				
75.00	167.54	75.00	19.81				
80.00	164.89	80.00	18.65				
85.00	162.35	85.00	17.36				
90.00	159.90	90.00	15.98				
95.00	157.54	95.00	14.58				
100.00	155.27	100.00	13.23				
105.00	153.07	105.00	12.01				
110.00	150.94	110.00	10.99				
115.00	148.88	115.00	10.26				
120.00	146.89	120.00	9.88				
125.00	144.96	125.00	9.91				
130.00	143.09	130.00	10.40				
135.00	141.27	135.00	11.34				
140.00	139.52	140.00	12.73				

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Validation Case No. 4 Lei Pui Street Landslide

Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
145.00	137.81	145.00	14.49				
150.00	136.17	150.00	16.50				
155.00	134.57	155.00	18.57				
160.00	133.03	160.00	20.45				
165.00	131.53	165.00	21.77				
170.00	130.08	170.00	20.75				
175.00	128.68	175.00	15.56				
180.00	127.32	180.00	12.41				
185.00	126.00	185.00	10.70				
190.00	124.72	190.00	9.95				
195.00	123.48	195.00	9.81				
200.00	122.26	200.00	9.98				
205.00	121.08	205.00	10.28				
210.00	119.91	210.00	10.57				
215.00	118.77	215.00	10.77				
220.00	117.64	220.00	10.84				
225.00	116.53	225.00	10.79				
230.00	115.42	230.00	10.65				
235.00	114.32	235.00	10.44				
240.00	113.21	240.00	10.23				
245.00	112.10	245.00	10.05				
250.00	110.99	250.00	9.97				
255.00	109.86	255.00	10.03				
260.00	108.73	260.00	10.26				
265.00	107.58	265.00	10.68				
270.00	106.42	270.00	11.30				
275.00	105.26	275.00	12.10				
280.00	104.08	280.00	13.06				
285.00	102.90	285.00	14.14				

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Validation Case No. 4 Lei Pui Street Landslide							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
290.00	101.73	290.00	15.28				
295.00	100.57	295.00	16.41				
300.00	99.43	300.00	17.48				
305.00	98.32	305.00	18.39				
310.00	97.26	310.00	19.08				
315.00	96.28	315.00	19.48				
320.00	95.38	320.00	19.56				
325.00	94.60	325.00	19.29				
330.00	93.96	330.00	18.68				
335.00	93.50	335.00	17.80				
340.00	93.25	340.00	16.74				

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B.5 Validation Case No. 5

Tip No.7 Flow Slide of 1966 at Aberfan, South Wales

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Validation Case No. 5 Tip No.7 Flow Slide of 1966 at Aberfan, South Wales							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	319.85	0.00	76.49	0.00	1.57	0.00	1.57
20.00	306.53	20.00	75.00	868.00	1.57	868.00	1.57
40.00	294.27	40.00	74.43				
60.00	282.99	60.00	74.44				
80.00	272.62	80.00	74.80				
100.00	263.09	100.00	75.31				
120.00	254.32	120.00	75.84				
140.00	246.25	140.00	76.31				
160.00	238.82	160.00	76.64				
180.00	231.96	180.00	76.82				
200.00	225.63	200.00	76.86				
220.00	219.77	220.00	76.78				
240.00	214.32	240.00	76.62				
260.00	209.25	260.00	76.43				
280.00	204.51	280.00	76.29				
300.00	200.06	300.00	76.24				
320.00	195.86	320.00	76.38				
340.00	191.87	340.00	76.75				
360.00	188.07	360.00	77.42				
380.00	184.43	380.00	78.44				
400.00	180.92	400.00	79.86				
420.00	177.53	420.00	81.73				
440.00	174.23	440.00	84.05				
460.00	171.01	460.00	86.84				
480.00	167.86	480.00	90.10				
500.00	164.76	500.00	93.83				
520.00	161.72	520.00	97.98				
540.00	158.73	540.00	102.54				
560.00	155.79	560.00	107.45				

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Validation Case No. 5 Tip No.7 Flow Slide of 1966 at Aberfan, South Wales							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
580.00	152.90	580.00	112.65				
600.00	150.07	600.00	118.08				
620.00	147.32	620.00	123.67				
640.00	144.65	640.00	129.36				
660.00	142.09	660.00	135.07				
680.00	139.64	680.00	140.74				
700.00	137.34	700.00	146.31				
720.00	135.21	720.00	151.73				
740.00	133.28	740.00	156.97				
760.00	131.58	760.00	162.01				
780.00	130.15	780.00	166.89				
800.00	129.03	800.00	171.63				
820.00	128.25	820.00	176.33				
840.00	127.86	840.00	181.11				
860.00	127.92	860.00	186.14				
868.00	128.07	868.00	188.28				

B.6 Validation Case No. 6

ENTLI Case No. 03SEA2011E

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Validation Case No. 6 ENTLI Case No. 03SEA2011E							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	478.12	0.00	12.00	0.00	1.57	0.00	1.57
10.00	466.87	141.00	12.00	141.00	1.57	141.00	1.57
20.00	454.65						
30.00	442.74						
40.00	431.86						
50.00	422.27						
60.00	413.89						
70.00	406.43						
80.00	399.47						
90.00	392.64						
100.00	385.67						
110.00	378.50						
120.00	371.44						
130.00	365.21						
140.00	361.08						
141.00	360.85						

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B.7 Validation Case No. 7

ENTLI Case No. 03SEA2011E

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Validation Case No. 7 ENTLI Case No. 03SEA2011E							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	478.12	0.00	12.00	0.00	1.57	0.00	1.57
10.00	466.87	141.00	12.00	141.00	1.57	141.00	1.57
20.00	454.65						
30.00	442.74						
40.00	431.86						
50.00	422.27						
60.00	413.89						
70.00	406.43						
80.00	399.47						
90.00	392.64						
100.00	385.67						
110.00	378.50						
120.00	371.44						
130.00	365.21						
140.00	361.08						
141.00	360.85						

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B.8 Validation Case No. 8

Hypothetical Slope Profile A

Validation Case No. 8 Hypothetical Slope Profile A							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	129.13	0.00	10.00	0.00	1.57	0.00	1.57
10.00	121.14	400.00	10.00	400.00	1.57	400.00	1.57
20.00	113.91						
30.00	107.30						
40.00	101.20						
50.00	95.54						
60.00	90.24						
70.00	85.24						
80.00	80.50						
90.00	75.98						
100.00	71.66						
110.00	67.52						
120.00	63.55						
130.00	59.75						
140.00	56.10						
150.00	52.61						
160.00	49.28						
170.00	46.11						
180.00	43.10						
190.00	40.25						
200.00	37.56						
210.00	35.02						
220.00	32.64						
230.00	30.40						
240.00	28.29						
250.00	26.31						
260.00	24.43						
270.00	22.64						
280.00	20.93						

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Validation Case No. 8 Hypothetical Slope Profile A							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
290.00	19.27						
300.00	17.64						
310.00	16.02						
320.00	14.40						
330.00	12.75						
340.00	11.07						
350.00	9.33						
360.00	7.55						
370.00	5.70						
380.00	3.82						
390.00	1.90						
400.00	0.00						

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B.9 Validation Case No. 9

Hypothetical Slope Profile A

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Validation Case No. 9 Hypothetical Slope Profile A

Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	129.13	0.00	10.00	0.00	1.57	0.00	1.57
10.00	121.14	400.00	10.00	400.00	1.57	400.00	1.57
20.00	113.91						
30.00	107.30						
40.00	101.20						
50.00	95.54						
60.00	90.24						
70.00	85.24						
80.00	80.50						
90.00	75.98						
100.00	71.66						
110.00	67.52						
120.00	63.55						
130.00	59.75						
140.00	56.10						
150.00	52.61						
160.00	49.28						
170.00	46.11						
180.00	43.10						
190.00	40.25						
200.00	37.56						
210.00	35.02						
220.00	32.64						
230.00	30.40						
240.00	28.29						
250.00	26.31						
260.00	24.43						
270.00	22.64						
280.00	20.93						

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Validation Case No. 9 Hypothetical Slope Profile A							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
290.00	19.27						
300.00	17.64						
310.00	16.02						
320.00	14.40						
330.00	12.75						
340.00	11.07						
350.00	9.33						
360.00	7.55						
370.00	5.70						
380.00	3.82						
390.00	1.90						
400.00	0.00						

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B.10 Validation Case No. 10

Hypothetical Slope Profile B

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Validation Case No. 10 Hypothetical Slope Profile B

Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	250.05	0.00	3.50	0.00	0.79	0.00	0.79
3.00	244.85	100.00	3.50	100.00	0.79	100.00	0.79
6.00	241.46						
9.00	238.48						
12.00	235.87						
15.00	233.60						
18.00	231.66						
21.00	230.00						
24.00	228.62						
27.00	227.48						
30.00	226.58						
33.00	225.87						
36.00	225.24						
39.00	224.77						
42.00	224.43						
45.00	224.22						
48.00	224.10						
51.00	224.05						
80.00	224.05						

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Validation Case No. 10 Hypothetical Slope Profile B							
Topography		Width		Side Angle (Left)		Side Angle (Right)	
Chainage (m)	Elevation (m)	Chainage (m)	Width (m)	Chainage (m)	Angle (radian)	Chainage (m)	Angle (radian)
0.00	250.05	0.00	5.00	0.00	1.57	0.00	1.57
3.00	244.85	100.00	5.00	100.00	1.57	100.00	1.57
6.00	241.46						
9.00	238.48						
12.00	235.87						
15.00	233.60						
18.00	231.66						
21.00	230.00						
24.00	228.62						
27.00	227.48						
30.00	226.58						
33.00	225.87						
36.00	225.24						
39.00	224.77						
42.00	224.43						
45.00	224.22						
48.00	224.10						
51.00	224.05						
80.00	224.05						

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