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Behaviour of Channelised Debris Flow in the Crocker Range of Sabah, Malaysia: A Case Study at Ulu Moyog, Penampang

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Debris flow remains as a damaging natural hazard in the Crocker Range of Sabah, Malaysia. This is due to the fact that it can move at high velocity and longer travel distance, bringing huge volume of sediment. One of the most severely affected area due to debris flow in the Crocker Range is KM 38.80 of Jalan Penampang-Tambunan in Ulu Moyog, Penampang. Recurring events of the debris flow from the year 2012 until 2014 have rendered the major road trunk between the west coast and interior region and traffic disturbance. The study on its behaviour in terms of velocity, discharge, and travel distance is still limited. Therefore, this study was conducted to identify the behaviour of the localised case of channelised debris flow at Jalan Penampang-Tambunan KM 38.80. Based on site inspection along the channel and computation of flow behaviour based on an established equation, the study found that the velocity, discharge, and travel distance are controlled by the various channel parameters such as the elevation, width, depth, and longitudinal gradient.

Keywords: channel; debris flow; discharge; travel distance; velocity

I. INTRODUCTION

Debris flow constitutes one of the most destructive geological hazards as it can move at high speed and travel at longer distance. It can also severely destroy any objects which stay within its path and poses great fatalities as well as loss of properties due its high velocity and discharge (Iverson *et al.,* 2010; Jianbing *et al.,* 2015). Debris flow consisted of a mixture of rock, mud, organic material, and water that flows down a channelised watershed onto deposition area (Giraud, 2005).

The behaviour of debris flow relating to its velocity, discharge, and travel distance are important aspects to be studied as they serve as references to assess the extent of damage and to determine the effective approach in mitigating debris flow disaster (Chen *et al.,* 1983; Jianbing *et al.,* 2015; Rickenmann, 1999; 2005). On the other hand, previous debris flow incidents in the Crocker Range of Sabah have caused cut-off of major road trunks such as that at Jalan Penampang-Tambunan KM 38.80 (Edgar *et al.,* 2018).

This perennial issue has posed difficulty to daily lives of the public. Despite the recurring incidents, comprehensive study on the debris flows has been lacking. Thus, this study aims to identify the behaviour of the channelised debris flow at the selected locations.

II. STUDY AREA

The study area at Jalan Penampang-Tambunan KM 38.80 is located in Ulu Moyog area within the district of

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Penampang which lies on the Crocker Range of Sabah as shown in Figure 1. The mountainous terrain of Crocker Range with an average elevation of 2,000 m high above mean sea level (AMSL), exhibits a width of more than 40 km and extends about 200 km along the west coast of Sabah. Meanwhile, the road serves as a major link between Penampang and Tambunan town, i.e. between the west coast and interior region of the state. It is bounded by latitude between 5°51'30" N to 5°51'45" N, and a longitude between 116°15'30" E to 116°16'00" E. The affected road section is about 100 m long and 20 m wide, which extends 0.33 km from north to south and 0.21 km from west to east. Geologically, the site is underlain by the Crocker Formation of Eocene-Miocene age which comprised of sedimentary rock units of interbedded sandstone and shale.

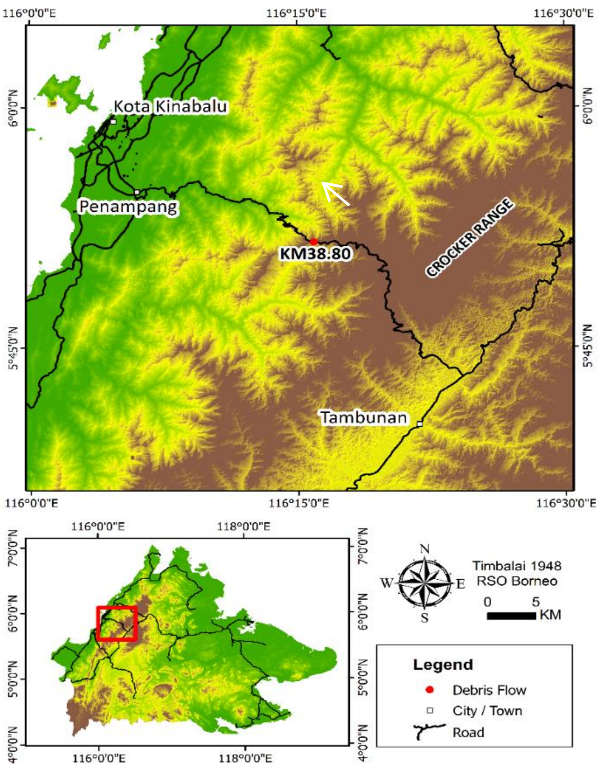


Figure 1. Location of study area at Jalan Penampang-Tambunan KM 38.80, Ulu Moyog, Penampang.

Series of debris flow events have been recurring in the year 2012 to 2014 at the study area. The incidents have not only caused disruption in traffic flow due to road closure for several hours, but also has detrimental effect to social and economic aspects of the public. The worst debris flow incident at Jalan Penampang-Tambunan KM 38.80 occurred on 16th January 2015 as shown in Photograph 1. The road was impassable to traffic for more than 17 hours as big loose boulders and mud were deposited along the pavement.

Photo 1. Debris flow at Jalan Penampang-Tambunan KM 38.80 on 16th January 2015.

III. MATERIALS AND METHODS

The characterisation of debris flow behaviour at the study area was carried out based on site inspection and calculation of its flow parameter pertaining to the velocity, discharge, and travel distance.

Site inspection along and within the channel was conducted to trace the debris flow path starting from the initiation zone at the upper reach down to the deposition zone at the road level. The field work gathered and recorded information on the debris flow mechanism, as well as to obtain data which were used in the calculation of flow parameter and analysis of the material property. The data were collected at every 20 m interval along the stream path in consideration that similar channel traits are generally observed within the distance. Total numbers of 12 channel sections were inspected at Jalan Penampang-Tambunan KM 38.80. The channel parameters measured on site involved maximum (upper mouth level) and minimum (bed level) width, depth on both wall sides of the channel, depth of observed mud trace, and lastly the longitudinal gradient of the channel bed. Then, the velocity and discharge of the debris flow at each channel section were computed by using the formula recommended by Lo (2000) in equation 1 and 2 respectively.

$$V_c = K_c H_c^{2/3} I_s^{1/5} \quad (1)$$

$$Q_c = W_c V_c \quad (2)$$

Where V_c is sectional velocity of debris flow (m/s); K_c is factor related to debris flow depth according to Table 1; H_c is measurement of debris flow depth marked by mud trace (m); I_s is longitudinal slope gradient of channel bed (%); Q_c

is the sectional discharge of debris flow (m³/s); and W_c is the cross sectional area of channel (m²).

Table 1. Relationship between the velocity coefficient (K_c) and debris flow depth (H_c) (Source: Chen *et al.,* 1983)

H_c (m)	<2.5	2.75	3	3.5	4	4.5	5	>5.5
K_c	10	9.5	9.0	8.0	7.0	6.0	5	4.0

On the other hand, the travel distance was calculated by applying equation 3 as proposed by Rickenmann (1999).

$$L = 1.9V^{0.16}H^{0.83} \quad (3)$$

where L is travel distance (m); V is total volume (m³); and H is height difference between initiation and deposition (m).

IV. RESULTS AND DISCUSSION

The results pertain to the distribution of debris flow, channel profile, discharge and velocity, and lastly the travel distance.

A. *Distribution of Debris Flow*

Based on field inspection, the sub-region of debris flow can be divided into three zones namely initiation, runout, and deposition. As explained in Figure 2, the initiation zone is marked in Section 1, the runout zone comprises Section 2 to Section 11, and the deposition is indicated in Section 12.

The initiation of the debris flow refers to the source area of the main landslide which is located at a height of 1,065 m AMSL. The landslide was measured about 50 m long, 40 m wide and 25 m high. Its landform exhibits steep scarp of approximately 70° and concave slope towards the runout zone.

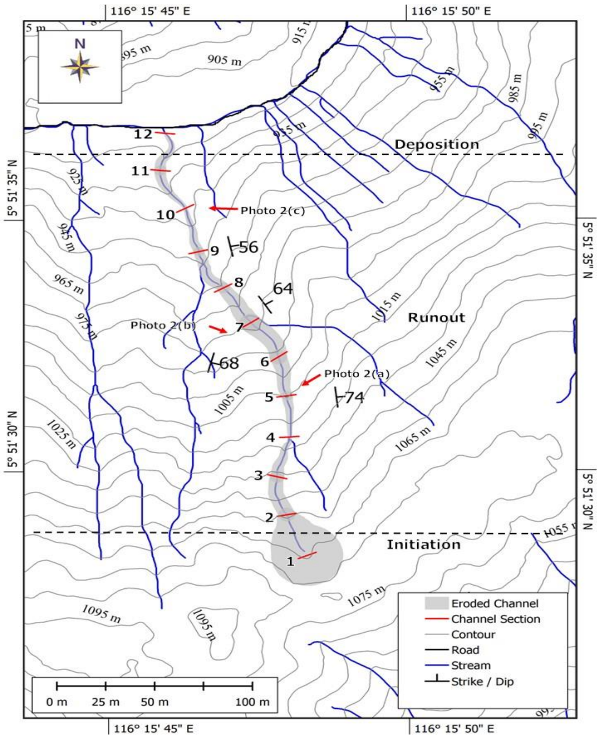


Figure 2. Sub-region of debris flow at Jalan Penampang-Tambunan KM 38.80.

As the crest was overburdened and weakened by water surcharge due to rainfall, materials consisted of loose colluvium and highly weathered sandstone have slide in a translational mode which have been pushed down to the compressive zone on the starting point of runout.

The materials are then transported to the runout zone by the connecting stream. The runout zone traversing down the stream at an *elevation from 1,053 m to 916 m AMSL. As most* of the sediment supplies and entrainment process occur within the channel, the runout zone displays intensification of debris flow volume. Increase in the volume is also contributed by the presence of colluvium and talus at secondary landslide locations which take place at Section 5, Section 7, and Section 10 as shown in Photograph 2. Accumulations of the loose rocks within the runout zone may act as a temporary dam for further landslide.

The debris ceases to flow at deposition area which is elevated at 910 m AMSL, concurrent with the road level as the channel loses its confinement and achieves gentler gradient.

(a)

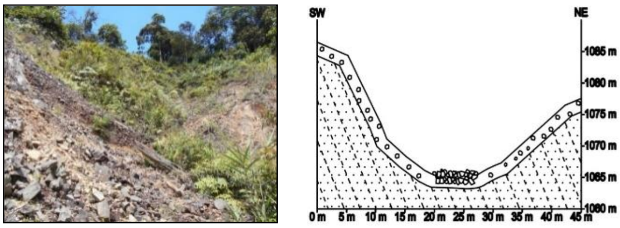
(b)

(c)

Photo 2. Secondary landslides at Jalan Penampang-Tambunan KM 38.80: (a) Section 5; (b) Section 7; (c) Section 10.

B. *Channel Profile*

The channel profiles from the initiation to the deposition zone are shown in Figure 3, while the observed channel parameter is explained in Table 2. The bedding of the sedimentary rock is mostly oriented NW-SE and dips at steep gradient between 56° to 74°. As the bedding on the channel wall at southwest, west, and northwest sides daylighting with the slope face and create a weaker plane, more supplies of sediments are contributed by the southwest, west, and northwest sidewalls compared to that at the northeast, southeast, and east sidewall. The channel width and depth vary from 1.5 m to 37 m and 0.3 m to 3.9 m respectively. Meanwhile, the longitudinal gradient ranges between 10° and 50°.



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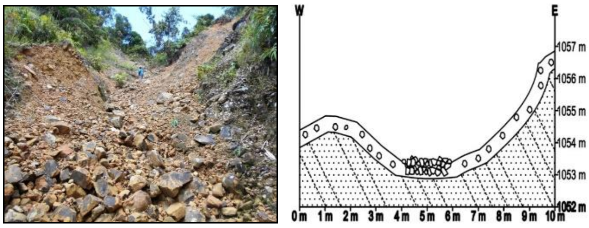

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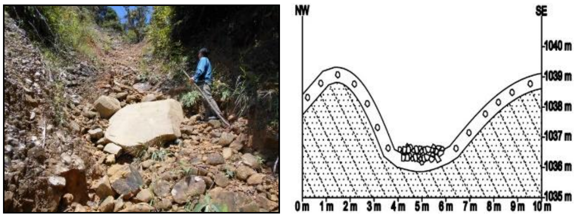

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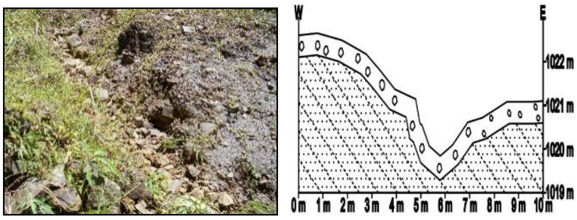

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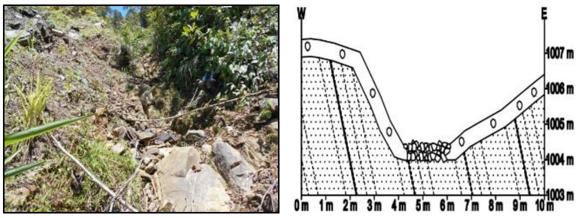

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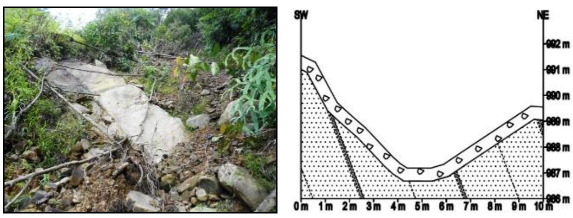

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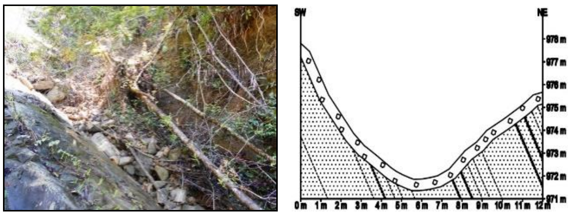

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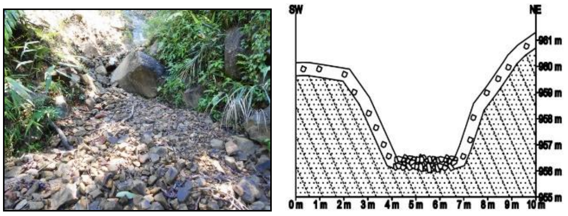

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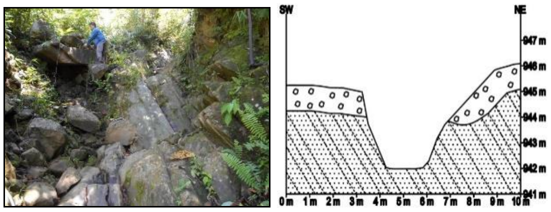

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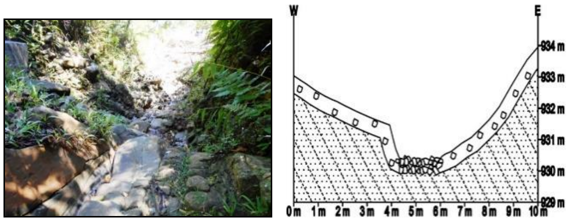

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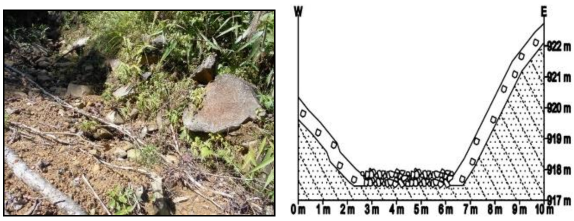

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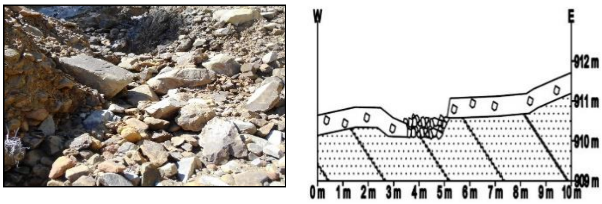

(12)

Figure 3. Channel section at Jalan Penampang-Tambunan KM 38.80.

Table 2. Observed channel parameters at Jalan Penampang-Tambunan KM 38.80.

Section	Elevation AMSL (m)	Width (m)	Depth (m)	Longitu-dinal Gradient (°)
1	1,065	37.0	1.5	22
2	1,053	8.6	2.0	50
3	1,036	7.3	3.0	38
4	1,020	2.0	0.7	28
5	1,004	5.8	1.4	28
6	987	8.9	2.4	44
7	972	11.1	3.7	22
8	956	6.6	3.9	10
9	942	5.6	3.0	10
10	930	2.1	0.5	20
11	916	6.4	1.0	40
12	910	1.5	0.3	20
Average		**8.6**	**2.0**	**30**

C. *Discharge and Velocity*

The discharge and velocity of debris flow along the channel are explained in Figure 4. Their distribution is derived based on the calculation of debris flow parameter as shown in Table 3.

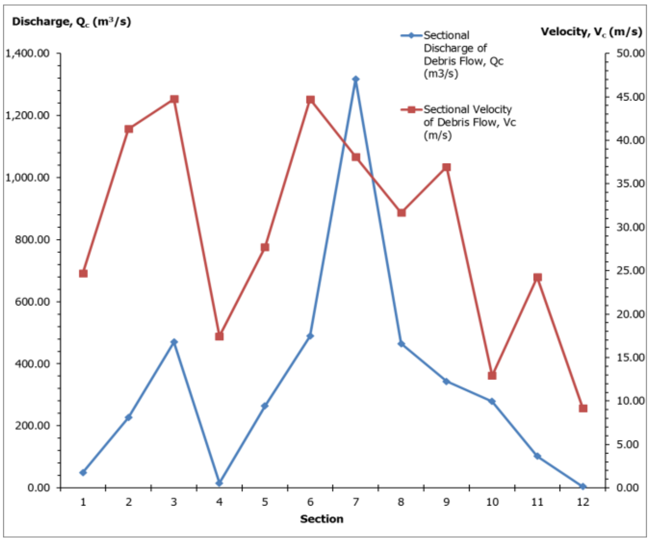

Figure 4. Distribution of discharge and flow velocity along debris flow channel at Jalan Penampang-Tambunan KM 38.80.

Table 3. Calculated result of debris flow parameter along debris flow channel at Jalan Penampang-Tambunan KM 38.80.

Cross Section	Velocity Coefficient, K_c	Longitudinal Slope Gradient of Channel Bed, I (%)	Debris Flow Depth Determined by Measurement of Mud Trace at the Cross Section, H_c (m)	Cross Sectional Area, W_c (m^2)	Sectional Velocity of Debris Flow, V_c (m/s)	Discharge along Channel, Q_{c1} (m^3/s)	Discharge from Secondary Landslide, Q_{c2} (m^3/s)	Sectional Discharge of Debris Flow, Q_c (m^3/s)
1	9.00	40.40	1.50	2.00	24.71	49.43	0.00	49.43
2	10.00	119.18	2.00	5.50	41.30	227.14	0.00	227.14
3	9.00	78.13	3.00	10.50	44.76	469.97	0.00	469.97
4	10.00	53.17	0.70	0.89	17.45	15.53	0.00	15.53
5	10.00	53.17	1.40	3.66	27.70	101.40	162.79	264.19
6	10.00	96.57	2.40	10.95	44.71	489.62	0.00	489.62
7	7.60	40.40	3.70	22.13	38.10	843.10	473.83	1,316.92
8	7.20	17.63	3.90	14.67	31.67	464.59	0.00	464.59
9	10.00	17.63	3.00	9.30	36.93	343.42	0.00	343.42
10	10.00	36.40	0.50	0.69	12.93	8.92	270.19	279.11
11	10.00	83.91	1.00	4.23	24.25	102.59	0.00	102.59
12	10.00	36.40	0.30	0.50	9.20	4.60	0.00	4.60

Based on Figure 4, it is observed that the discharge remarkably increases at two stages that occur in Section 1 to 3 and 4 to 7. The discharge initially increases as the sediment is transported from the initiation point to the transportation zone. The subsequent increase in volume happens as material entrainment takes place along the channel due to the erosion of both channel bed and sides.

The scale of the debris is amplified by the supply of sediment in the gully. Section 4 to 5 and 6 to 7 show dramatic discharge increase due to sediment supply from the secondary landslides. The decrease in the discharge happens in Section 3 to 4 and 7 to 12 due to the reduction in the cross-sectional area of the channel which supplies the sediment.

The debris flow generally shows a similar pattern of rapid increase and decrease of velocity with the discharge from Section 1 to 6. Unpredictable velocity trait happens at the later stages from Section 7 to 12. Increase in the velocity initially occurs in Section 1 to 3 as the sediment gains flow momentum from the landslide source and mobilized over a steeper channel with a gradient of 500. The other three stages of increase in the velocity can be seen in Section 4 to 6, 8 to 9, and 10 to 11. The velocity intensification in Section 4 to 6 and 10 to 11 is due to steepening channel gradient from 280 to 440 and 200 to 400 respectively.

Narrowing channel width in Section 8 to 9 governs the velocity increase. On the other hand, velocity decrease is observed at four stages, i.e. Section 3 to 4, 6 to 8, 9 to 10, and 11 to 12. As the channel gradient is decreasing at Section 3 to 4, 6 to 8, and 11 to 12, the velocity is also reducing. Due to velocity decrease at Section 6 to 7, deposition of material at Section 7 is significantly increased. This explains the sharp decrease of discharge after Section 7. Diminishing velocity at Section 9 to 10 is controlled by the decrease of debris flow depth.

Most of the debris flow discharges, which constitute more than 90% of the total volume occurs in the runout zone. Computed sectional discharge in the runout zone can be as high as 27 times more than that in the initiation zone. Findings on the discharge and velocity behaviour in this study generally correspond with those proposed by Giraud (2005) and Jianbing *et al.* (2015).

D. Travel Distance

By applying equation 3, the travel distance of the debris flow from the initiation to deposition zone is calculated as 472 m long. The distance is computed by taking the total volume of 4,027 m^3 and height relief of 155 m.

Compared to the total volume of debris flow, height relief contributes more significant impact on the travel distance. In agreement with Rickenmann (2005), a higher difference in elevation will assist to mobilize debris flow at a further distance due to higher momentum of flow from the upper channel.

V. CONCLUSIONS

In conclusion, the behaviour of channelised debris flow in the Crocker Range can be summarised as follows:

a. The velocity is equivalent to 0.1 to 2.0 times the discharge;
b. More material supplies due to presence of thicker and more loose top soil may increase the total volume of sediment;
c. Higher elevation and more confined channel cause increase in energy and speed of flow; and
d. The travel distance equals to about 3 times the height relief.

VI. ACKNOWLEDGEMENTS

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