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Triggering Mechanism and characteristic of Debris Flow in Peninsular Malaysia

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Abstract: *Forensic investigations have been carried out at eight (8) selected debris flow locations in Peninsular Malaysia in order to determine the mechanism and characteristic of debris flow. Comprehensive studies on the available records of past debris flow have been carried out in order to describe the fundamental characteristics of debris flow events. Site investigation and laboratory tests of particular debris flow sites were carried out to evaluate the causes of the debris flow triggering factors such as topographical, geotechnical and geological characteristics. Rainfall records are collected from the nearest meteorological station in order to analyse the reasonable correlation of rainfall with the occurrence of debris flow. Geological study shows that debris flow is prone to occur at granitic areas. The gradient of the initiation areas are above 20□ and the debris tends to deposit in the areas with gradient between 2□ to 15□ . Laboratory tests show that the soil type at the debris flow areas consists predominantly of silty sand classified as SM according to the Unified Soil Classification System. The relation between rainfall patterns and the possible occurrences of debris flow indicated that the trigger thresholds are found to be generally high in most cases.*

Keywords : *Characteristic, Debris flow, Peninsular Malaysia, triggering mechanism*

I. INTRODUCTION

Debris flow is a phenomenon of rapidly moving [1] saturated sediment which contains large boulders, woods, soils and trees that blended together with water. The sediment flows through the mountainous torrent and being deposited at the alluvial fan. The triggered process depends on several characteristics, including the hydrologic, morphometric, geological and geotechnical features of the slopes [2]. The debris flow event usually triggers during intense and localised rainfall [3,4] Heavy precipitation can cause robust force for the mass movement. The catastrophes often cause fatalities, road blockage and intense damage to property which results in economic losses.

A number of recent studies have demonstrated that rainfall induced landslide can transform into debris flow as the run out moves downslope (e.g. [5-8]). Generally, heavy precipitation increases water content and water pressure of the ground and decreases the shear strength within the slope stratum. These activities cause the slope to be unstable and thus triggering landslide. The sediments that become loose during the initial failure of the slope eventually mix with the runoff and initiating the debris flow.

Observation on morphological and geological characteristics of the area shall enable to reveal the triggering mechanism and geomorphological evolution of landslide and debris flow. Geological and morphological information such as mass movement, volume of the deposited debris and their occurrence or contributing factors form a vital component of natural hazard planning [9].Without the knowledge of expected occurrence intervals, debris flow peak discharge and total volumes, neither hazard zonation nor mitigates structures can be designed with high level of confidence [10]

Presently, research on debris flows in Malaysia is still limited to post disaster within the areas of debris flow where disasters had occurred [11]. In the occurrence of calamitous event of debris flow, forensic investigation will be carried out to determine the causes or factors that initiate the debris flow to occur and to recommend immediate and long term remedial measures to overcome the problems. The aim of the present study is to understand and evaluate the triggering mechanism and to recognize the characteristics of debris flow in Peninsular Malaysia in order to evaluate the extent of the risk and predict the occurrence of debris flow in Peninsular Malaysia.

II. METHOD AND STUDY AREA

In this study, eight debris flow occurrences in Peninsular Malaysia were selected (Figure 1). The selection of the sites was made due to the ample data available that includes landslide type, location and time of the landslide occurrences. Furthermore the choice of events also considers the need to focus the events that can provide the widest possible range variation of significant parameters such as duration, intensity, critical rainfalls (maximum) and the number of induced landslides available that includes landslide type, location and time. Table 1 tabulates the eight particular locations of the debris flows events.

Table 1: Eight Significant Debris Flow Occurrences in Peninsular Malaysia

Date of Occurrence	Location	Catchment area (km^2)
30 June 95	Km 38.6 Kuala Lumpur-Karak Highway, Selangor (Genting Sempah)	0.20
28 Dec. 01	GunungPulai, Kulai , Johor (GunungPulai)	3.50
10 Nov. 03	Section 23.3 to 24.10, Kuala KubuBaru - Gap Road, Selangor (Kuala KubuBaru)	0.20
02 Nov. 04	KM 52.4 Kuala Lumpur-Karak Highway, Pahang (Lentang)	0.60
10 Nov. 04	KM 302 North South Expressway, Perak (GunungTempurung)	0.10
12 Apr. 06	Km 33 SimpangPulai - Cameron Highland Road, Perak (SimpangPulai)	0.60
15 Nov. 07	Km 4 to 5 Gap-Fraser's Hill Road, Pahang (Fraser's Hill)	0.40
03 Jan. 09	Section 62.4, Lojing -GuaMusang Road, Kelantan (Lojing)	0.20

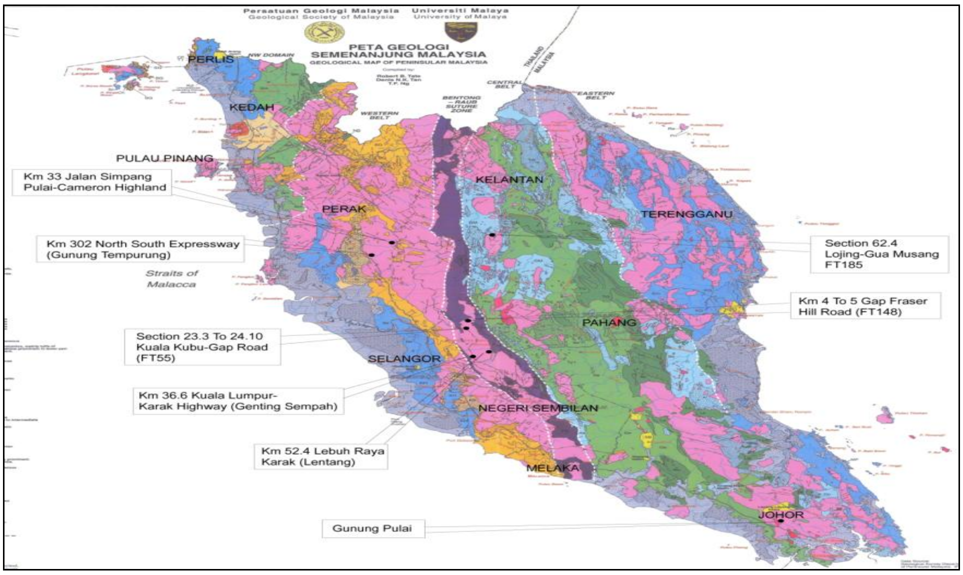


Figure 1: Location of Eight Major Debris Flow Events in Peninsular Malaysia [12]

Comprehensives studies on the available records of past debris flow that include investigation/forensic reports, aerial photographs, geological maps, topographical surveys, newspaper cutting and other relevant sources have been carried out in order to describe the fundamental characteristics of debris flow events. Arial observation of the sites has been used to observe the overall characteristics of the topography and vegetation of the sites. Results obtained from the observation were used in preparing the site investigation plan.

Site visits have been carried out to observe the particular debris flow sites and to estimate the remaining sediment in order to earmark the route map which is to map the debris flow terrain in the existing contour map. Site investigations were conducted by utilizing mackintosh probe in order to determine the ground profile and also by using hand auger to collect soil samples. Laboratory tests are carried out to analyse the coarse grain distribution using disturbed samples as well as to determine moisture content, specific gravity, atterberg limit, and particle size distribution. During the site visit, morphological and geological conditions are also being observed to determine the characteristic of debris flow event in Peninsular Malaysia.

Rainfall records are acquired from the nearest meteorological station that are relevant to the past events of debris flow managed by Drainage and Irrigation Department and also by the Malaysia Meteorology Department. The distances form the rain gauges to the sites vary between 2 km to 30 km and the elevations range from 10 m to 2000 m. The relationship between rainfall patterns that are characterized by their intensity and duration is analysed to determine the reasonable correlation of rainfall with the occurrence of debris flow. The maximum hourly rainfall depths and durations that correlate with the debris flows are plotted together with the intensity against duration criteria to see which criterion can approximate the threshold of the failure events.

III. TRIGGERING MECHANISM

Intense and heavy rainfall increases the water content and pore water pressures within the residual soil that could trigger landslides. The landslide eventually will be transformed to debris flow due to muddy water moving downslope. Debris flow initiations certainly will begin because of the existence of heavy surface run off. Surface run off or groundwater along the catchment provides water integration into beginning failure [4,12]. The appearance of water mix with accumulated regressive collapse sedimentation from source area of the landslide constitutes the formation of debris flow [7,14].

Based on the analysis and field investigation of the study areas, it has been revealed that the triggering mechanism of the debris flow occurred initially at upper stream, in the gravitational and hydraulic action flowing down the torrent driven by the weight of accumulated sediments. The effect of gravity increases the momentum of the debris flow, consequently increases the intensity of the scouring activities and rapidly scraping the bed. The scouring materials flow down into the channel, following the surface running water and deposited on the alluvial fan. In some other cases, debris flow may occur due to erosion of the sediment in the channel. The activities transform the moving materials to debris flow.

Debris flow is commonly triggered due to the increasing in pore water pressures on the sedimentation. The rapid increase in pore water pressures and decrease in the shear strength however may not always be attributable to infiltration precipitation [15]. The collapse occurred and expanded backward of the collapse. This type of collapse is regressive. Moreover, the debris of the collapse is assumed to change into debris flow after heavy rain.

IV. RESULTSAND DISCUSSION

4.1 Morphologic changes

The area affected by debris flow is divided into three different subareas which are the source area, flow area and depositional area. Source area is the initiation area which is usually the scar of landslide that had occurred causing debris flow. Flow area is where the sediment flowing down the torrent, but then some of the debris flow sediment was deposited along the stream. Depositional area is an alluvial fan. The deposited debris flow sediment is made up of boulders, woods, fallen trees, and soils.

The identification of the morphologic changes described based on the result of aerial photographs and detail field surveys. Even though it is subjective, morphologic field is intended to estimate of debris flow volumes that give the important contribution to the assessment of debris magnitude. Debris flow volume is defined as a total material such as boulders, debris, fines and organic material transport from source area to the deposited area. As the same procedure used by Iversion et al [16] debris flow volume was computed by measuring area and average thickness of the deposited material in the field. The profiles analyses of the source area, flow area and deposition area of the gully area were used to identify the morphologic changes. The metamorphic changes showed that the gully had been undercut and denuded at both lateral sides. On site investigation showed that most of the gully wall had been eroded. Consequently, the estimation of the respective morphologic changes of eight debris flow study areas in Malaysia helps in interpretation of the debris flow. Table 2 shows the morphometric parameter of the eight debris flow study areas in Malaysia.

Gradient of the slope influenced the occurrence and impact of debris flow. The gullies originally had not contributed to a large amount of deposited materials, the higher gradient of slope speed up the moving materials and increase the force. From the field surveys, in the case of eight sites in Malaysia (Table 2), the gradient of the initiation areas are above 20^o and the debris tends to deposit in the areas with gradient between 2^o to 15^o. Only fine particles may travel beyond 2^o. This result correspond with previous study i.e., Osanai et al, [17] explained that source of debris flow are typically found in area of the slopes stepper than 20^o and the sediments tend to deposit in the area where the gradient less than 10^o.

Table 2 Morphometric parameter of eight debris flow location in Peninsular Malaysia

Study area	Parts	Elevation (m asl)	Slope gradient (^{o})
Genting Sempah	Source area	720-670	25
	Flow area	670-540	18
	Deposited area	540-520	9

GunungPulai	Source area Flow area Deposited area	654-400 400-152 152-96	42 2 8
Kuala Kubu – Gap	Source area Flow area Deposited area	780-680 680-550 550-510	34 22 9
GunungTempurung	Source area Flow area Deposited area	810-640 640-290 290-240	32 19 10
Lentang	Source area Flow area Deposited area	590-410 410-160 160-150	35 24 9
SimpangPulai	Source area Flow area Deposited area	1650-1550 1550-840 840-825	28 18 12
Fraser's Hill	Source area Flow area Deposited area	1200-1060 1060-702 702-640	27 24 8
Lojing	Source area Flow area Deposited area	1700-1590 1590-1110 1110-1050	31 22 15

4.2 Geological Survey

Based on the Peninsular Malaysia Map of Geology and Selangor Geological Map as depicted in Figure 1, most of the debris flow study areas are located within the Main Range of Granite, part of the granite body which is grouped in the Mesozoic late Orogenic granite. Detail observation of geological features on site reveal that the sites are mainly underlain by granite with various weathering grades.

From the site visits, it has been noticed that most of the upstream area is covered with granite rocks, while the downstream is covered with metamorphic rocks. Table 3 shows that 6 out of 8 sites investigated in Malaysia are abundant with granite, which implies weathering grade of granite is one of the important factors to be assessed in Malaysia.

Table 3: Geology of sources of debris flow in Malaysia

Site Location	**Geology of source Area**	**Weathering Condition**
Genting Sempah	Contact of Metamorphic rock and Igneous Rock	Grade Ⅲ～Ⅳ
GunungPulai , Johor	Completely weathered granite	Grade V
GunungTempurung	Granite or Metamorphic Rock	Grade IV～V
SimpangPulai	Granite	Grade III～IV
Lentang	Upstream area is granite	Grade II～III
Kuala KubuBharu	Completely weathered granite	Grade IV～V
Fraser Hill	Near surface is residual soil and completely weathered granite	Grade IV～VI
Lojing , GuaMusang	Upstream area Coarse Granite & downstream area is residual soil	Grade III～V

4.3 Geotechnical Investigation

A set of samples at different sites and location along the slope from the sources area to deposited area was collected. The samples of the debris flow material were tested for its grain-size distribution. Sediment samples for particle analysis were taken in debris flow area (Table 4). Most of the observed sampled material consists predominantly of silty sand classified as SM according to Unified Soil Classification System. Consequently, debris flow started with granular flow cooperating with water along the torrent through scouring processes and then transformed into muddy debris flow.

Since the materials are predominantly consisted of sand, it is quite difficult to take undisturbed samples to reconstruct samples in laboratory in order to evaluate the geotechnical parameter. Atterberg limits of the soil samples classify as slightly plastic (Plastic Index equals 3-15%) to medium plastic (Plastic Index equals 15-30%) silty sand. Specific gravity (SG) of the soil sample range from 2.55 – 2.66 prove that the sediment soil type dominant of sand.

Table 4: Physical Property of Debris Flow Sediment

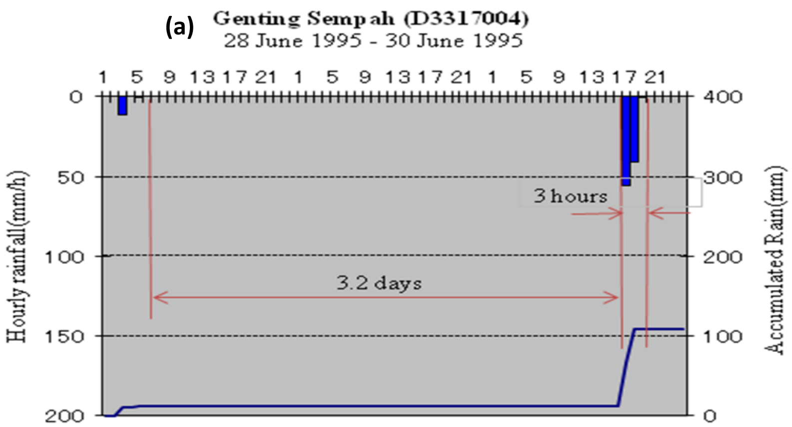
Site	SG	MC (%)	Atterbeg Limits			Mechanical And Hydrometer Analysis				Remarks
			LL %	PL %	PI %	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	
Genting Sempah	2.65	24	42	29	13	12	47	25	16	Silty SAND with litle gravel
GunungPulai , Johor	2.65	25	40	24	16	20	51	21	15	Silty SAND with some gravel
GunungTempurung	2.63	24	40	28	12	47	17	24	12	Silty Clayey GRAVEL
SimpangPulai	2.66	30	53	32	21	17	47	22	14	Silty SAND with litle gravel
Lentang	2.55	18	36	25	11	10	63	19	18	Silty SAND with litle gravel
Kuala KubuBharu	2.64	30	54	32	22	2	52	26	20	Silty SAND with traces gravel
Fraser Hill	2.65	24	53	31	22	11	50	27	13	Silty SAND with litle gravel
Lojing , GuaMusang	2.66	22	36	26	10	15	56	20	9	Silty SAND with some gravel

4.4 Rainfall Condition

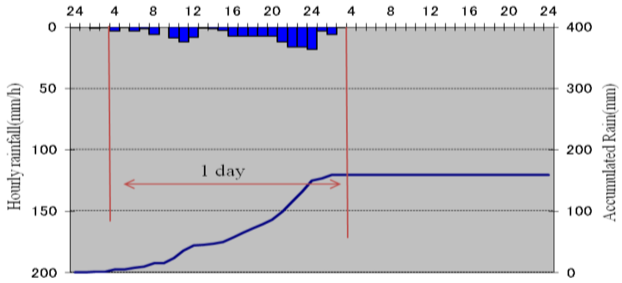
Malaysia is a tropical country situated near the equatorial latitudes, and has tropical climate with high temperature and abundant rainfall throughout the year. Numerous researchers that studied slope failures in tropical regions had concluded that rainfall has been one of the most recognized triggering factors of slope failures in these regions which experience heavy rainfalls almost throughout the year [18-20]. The rainfall is frequently short and intense, while prolonged rainfall occurred during two monsoon seasons, namely Southwest Monsoon that occurs from May to September and Northeast Monsoon from November to March each year. Annual rainfall distribution in Malaysia is about 3000 mm. Intense and heavy rainfall are known to be the most significant triggering factor that causes landslides which eventually transform to debris flow [16, 21]. The debris flow events occurred during the period of maximum rainfall generally during April – May and October – November due to the influence of the monsoon (see Table 1).

Table 5 Calculated and recorded critical intensity for given duration

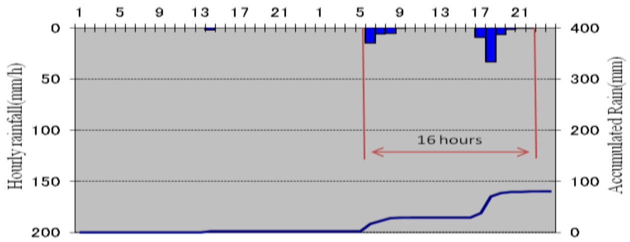
Location	Duration (hr)	Calculated Intensity (mm)	Recorded Max. Intensity (mm)
Genting Sempah	3	62	55
GunungPulai	24	18	20
Kuala KubuBaru	16	22	33
GunungTempurung	17	22	15
Lentang	3	38	57
SimpangPulai	46	12	16
Fraser’s Hill	15	23	38
Loging	28	21	43

(a)


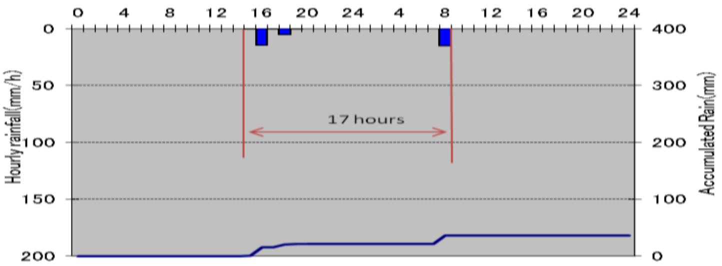
(b) Gunung Pulai (D173200)
27 December 2001 - 28 December 2001



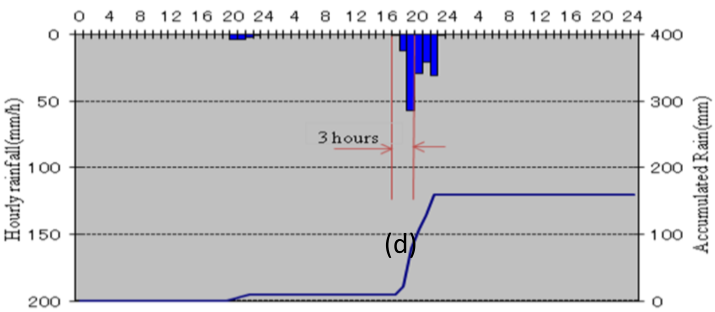
(c) Kuala Kubu Baru (D3516022)
9 November 2003 - 10 November 2003



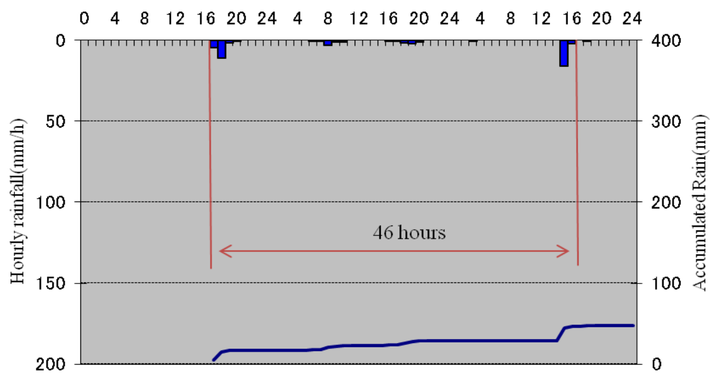
(d) Gunung Tempurung (M48625)
9 November 2004 -10 November 2004



(e) Lentang (D3519125)
1November 2004 - 2 November 2004



(f) Simpang Pulai (M48632)
10 April 2006 - 12 April 2006



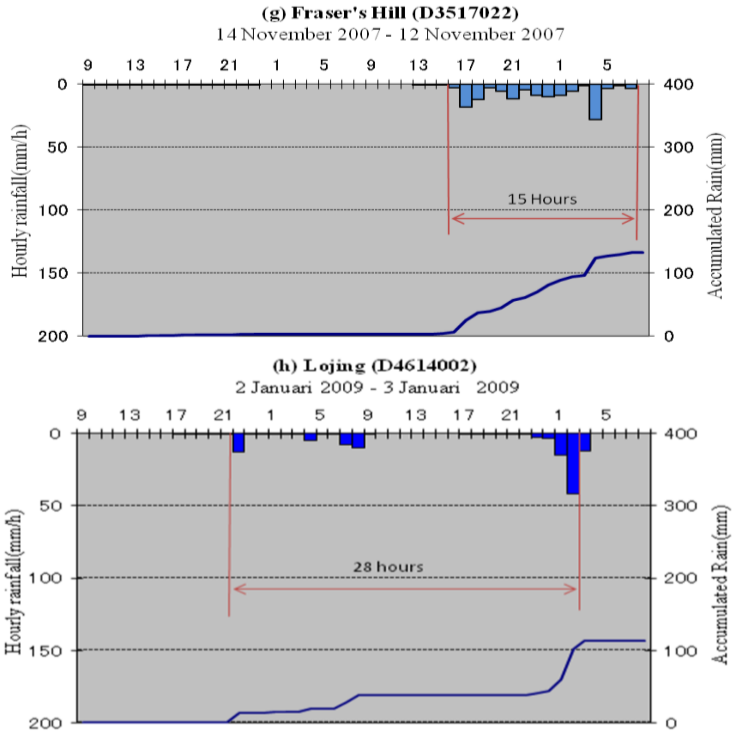


Fig. 3 Duration of rainfall and accumulated rainfall depth of (a)GunungPulai (b)GunungPulai (c)Kuala KubuBaru (d)GunungTempurung (e)Lentang (f)SimpangPulai (g) Fraser's Hill (h) Loging

In order to derive empirical critical thresholds for mass movements, many mass movement studies have focused on rainfall parameters such as rainfall intensity, duration, cumulative rainfall, and antecedent rainfall (see [22-23] for detailed reviews). The relationship between rainfall intensity (I) and duration (D) is most commonly used to estimate rainfall thresholds (e.g., [22-23, 24-26]). Caine [24] first established worldwide rainfall threshold values for landslides.Figure 4 indicates worldwide rainfall thresholds by various researchers compiled by Jakob et al [27] using method established by Caine [24] These eight (8) events plotted together with the intensity against duration criteria to see which criterion can approximate the threshold of failure events. It has shown that the series of points, given by Wilson et al [28] are close to those of the eight events in Malaysia. Comparison between worldwide threshold data compiled by Jakob et al [27] and Peninsular Malaysian data carried out shows that the trigger thresholds are generally higher.
The equation that represents the Wilson's et al [28] data point is expressed as:

$$I_p = 121.4 \times D^{-0.602} \qquad (1)$$

Where I_p: Highest rainfall intensity during the rainfall event, D: Duration of the rain in hours.

The critical intensities are calculated for each sites using equation (1) as shown in Table 3. Further studies to investigate hydrological response and influence of antecedent rainfall, if there is any, should be incorporated in such study.

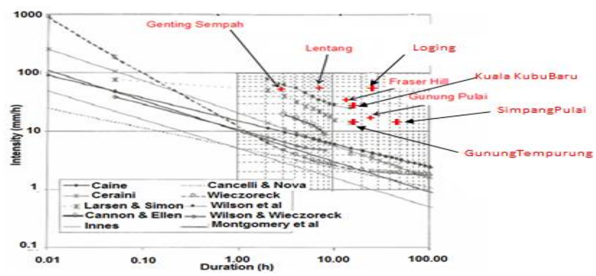


Fig. 4: Rainfall intensity and duration associated with eight debris flow event in Peninsular Malaysia and curve proposed by various researchers for similar case (Jakob et al [26]). From the data of debris flow events, rainfall thresholds intensity for Peninsular Malaysia nearly follows the threshold proposed by Wilson et al [27]

V. CONCLUSION

Comprehensive understanding of mechanisms and factors controlling the intensity and likelihood of debris flow will provide access to the fundamental hazard and provide proper planning for non-structural and structural measures. The investigation emphasized that the study of topography of debris flow areas is necessary in order to understand the nature of the event. Studies indicate that ignition site were located in the granitic regions. Consequence indicates that the weathering grade of granite is one of the important factors of debris flow to be assessed in Malaysia. Other than that, a morphologic change also helps in interpretation of the debris flow in Malaysia. The study highlighted that debris flow is often triggered by the high intensity of rainfall. Comparison between worldwide threshold data compiled by Jakobet al [27]and Peninsular Malaysia data carried out in this study shows that the trigger thresholds are generally higher. The higher thresholds may be due to thicker soil layers that require more rains for extensive localized failures to occur.

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