STORM RAINFALL ANALYSIS : AN IMPORTANT FACTOR IN DESIGNING MINE DEWATERING FACILITIES IN TROPICAL REGION

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ABSTRACT

Due to the high rainfall rate, runoff is identified as the main mine water problem in most surface mines in Indonesia. The design criteria of mine dewatering facilities should be based on the rainfall-runoff characteristics at the mining area and its surrounding. Therefore, a continuous and long-term rainfall data is necessary to identify the rainfall-runoff characteristic.

In most area in Indonesia where the mines will be developed, because it is usually located in a remote area, such requirement is not available. In this paper the storm rainfall analysis for designing mine dewatering facilities for such constraint including the frequency analysis will be discussed. Data from Bukit Asam Coal Mine in South Sumatra is used for case study.

INTRODUCTION

Indonesian islands spread along the equatorial line between two continents, Asia and Australia, and two oceans, Pacific and Indian. The climate is influenced by the monsoon that controls the dry or rainy season. Dry season is characterised by less rainfall compare to the rainy season. The average annual rainfall rate in most mining areas lies between 2000 mm and more than 4000 mm.

There are hundreds of mines operating in all over Indonesia, vary from large scale using modern equipment to small scale mines which operate traditionally. Most of them (more than 95%) are extracting near surface mineral deposit applying surface mining method.

Considering the relatively high rainfall rate, runoff from rain water will be the significant mine water in the surface mines. Even in several pits runoff water is the main mine water problem that strongly influence the productivity of the pit.

Therefore, the understanding of rainfall characteristics in the mining area and its surrounding is necessary. Storm rainfall analysis should be identified using the historical data for a better rainfall intensity prediction for the future. But, the sufficient data for identifying the rainfall characteristics is, in most cases, not available. Rainfall gauging in a potential mining area is just started as early as during exploration phase.

On the other hand, the need of mine drainage facilities should be from the beginning of mining operation, i.e. when excavation starts. Although the rainfall data is limited, the appropriate rainfall intensity should be defined to be used in designing mine/pit drainage infrastructure.

STORM RAINFALL ANALYSIS

Rainfall is considered as a random event and it varies geographically, temporally and seasonally. Such variations are very important in the planning and designing mine drainage infrastructures, which require better prediction of rainfall event during the lifetime of drainage infrastructure.

Methods of statistical analysis have been developed to identify the rainfall characteristics. They provide ways to reduce and summarize observed data, to present information in meaningful form as well as to make predictions concerning future behaviour.

The mine drainage facilities should be properly designed to handle extreme rainfall events during its design life. Therefore, for design purpose, rainfall data should be analysed to produce design rainfall values which represent the rainfall characteristics of the area in term of extreme rainfall intensity, its frequency of occurrence and the risk. The method of frequency analysis is used to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distribution.

1. Return Period

Suppose that an extreme event is defined to be occurred if a random variable X is greater than or equal to some level x_T. The recurrence interval τ is the time between occurrences of $X \geq x_T$. The return period T of the event $X \geq x_T$ is the expected value of τ, $E(\tau)$, its average value measured over a very large number of occurrences or it can be defined as the average recurrence interval between events equalling or exceeding a specified magnitude.

If $p=P(X \geq x_T)$ is the probability of occurrence of the event $X \geq x_T$ in any observation, the return period T or $E(\tau)$ is defined as (Viessman, Jr. et al, 1972) :

$$T = E(\tau) = 1/p$$

It means that the probability of occurrence of an event is the inverse of its return period :

$$p = P(X \geq x_T) = 1/T$$

The probability that $X \geq x_T$ will not occur in any year :

$$P(X < x_T) = 1 - P(X \geq x_T) = 1 - 1/T$$

The probability that $X \geq x_T$ will occur at least once in *N* successive years :

$$P(X \geq x_T \text{ at least once in } N \text{ years}) = 1 - (1 - p)^N = 1 - (1 - 1/T)^N$$

This expression in the design of hydrologic structures is usually called *hydrological risk.*

2. Rainfall Data Series

To calculate the return period of the rainfall event $X \geq x_T$ sets of extreme rainfall data are required. There are two types of data series. An *annual series* data takes one highest event from each year of record. A disadvantage of this abstraction is that the second or the third, etc., highest events in the particular year may be higher than the maximum event in another year and yet they are totally disregard. A series of *partial duration* data is a series of data that are selected so that their magnitude is greater than a predefined *base value.*

The recurrence interval of the annual series means the average number of years between the occurrence of an event of a given magnitude as an annual maximum. In the partial duration series the recurrence interval carries no implication of annual maximum.

3. Extreme Value Distribution

The extreme value distribution in hydrology involves the selection of a sequence of the extreme (largest or smallest) observations from sets of data. In storm rainfall analysis, just the largest rainfall intensity recorded are being used.

The probability distribution function (Chow et al (1988), Kite (1977)), is

$$P(x < x_T) = F(x) = \exp(-\exp[-(x-u)/\alpha])$$

$$\alpha = \sqrt{6}\ .\ s / \pi$$

$$u = \bar{x} - 0.5772\alpha$$

The parameter u is the mode of distribution, $\bar{x}$ and s are the mean and standard deviation from the sample.

A reduced variate y can be defined as :

$$y = (x-u)/\alpha$$

$$y = -\ln[\ln(1/F(x))]$$

Since $P(X < x_T) = 1 - P(X \geq x_T) = 1 - 1/T$ and $P(X < x_T) = F(x_T)$:

$$F(x_T) = (T-1)/T$$

and

$$y_T = -\ln[-\ln\{(T-1)/T\}]$$

$$x_T = u + \alpha y_T$$

CORRELATION BETWEEN PARTIAL DURATION AND ANNUAL SERIES

Rainfall characteristic in an area can be only well defined if long-term rainfall data is available. It means that the number of annual maxima data is suitable enough for an extreme value distribution analysis. In this case two kinds of analysis using annual and partial duration series can be conducted and a better understanding on the storm rainfall probability of occurrence can be achieved.

In most cases in the developing mining area such condition can not be met. Rainfall station is just erected few years back and consequently only small number of annual maxima data is available. In this case the only analysis can be done is using partial duration data series.

Some studies had been conducted to identify the relationship between the recurrence intervals or return periods of partial duration and annual series and their corresponding probability. The relationship after Chow (1964, in Kite, 1977), which is adapted by the US Department of Transportation (1984, in Wanielista, 1990), is :

$$T_P = \frac{1}{\ln T_A - \ln(T_A - 1)}$$

where T_P and T_A are the recurrence intervals of partial-duration and annual series respectively.

Using data from Bukit Asam Mine in South Sumatra, the return periods between partial duration and annual data series have been analysed. Defining the intensity-duration-frequency relationship between two types of data series leads to the certainty using partial duration data series if only short period rainfall data available. This is the condition occurred in most of newly developed mining areas in Indonesia.

Data from weather station of Bukit Asam Mine consist of rainfall intensity data from 1986 to 1995 recorded by an automatic rainfall recorder. Longer data period is not available because this equipment was installed in 1985. The relationship between partial duration and annual series for different return periods (T=2 years, T=5 years, T=10 years and T=25 years) are shown in Table 1.

In general the analysis using partial duration series gives higher value than annual series. Small differences have been shown for the longer rainfall duration, i.e. the 120 to 1440-minutes rainfall duration and also 10-minutes duration. For 5-minutes, 15-minutes, 30-minutes and 60-minutes duration the differences are significant where the intensities of partial duration data are 8.5 to 28.3% higher than annual series.

Table 1
Rainfall Intensity (mm/hr) calculated using partial duration and annual series

Return Period (year)	Data Series	Rainfall Duration 5 min	10 min	15 min	30 min	60 min	120 min	360 min	720 min	1440 min
2	P	164.58	129.97	114.97	85.61	56.71	28.36	14.05	7.30	3.66
	A	150.78	129.80	100.58	75.19	48.20	28.30	14.00	7.25	3.60
	Δ %	9.2	0.1	14.3	13.8	17.7	0.2	0.4	0.7	1.7
5	P	207.67	155.96	133.97	105.55	68.00	34.00	16.90	8.84	4.13
	A	185.31	155.00	122.21	85.20	53.00	34.00	17.00	9.00	4.10
	Δ %	12.1	0.6	9.6	23.9	28.3	0	-0.6	-1.8	0.7
10	P	236.20	173.17	146.54	118.74	75.46	37.73	18.79	9.86	4.44
	A	207.70	170.05	130.26	99.00	68.30	37.50	18.75	9.75	4.25
	Δ %	13.7	0.2	12.5	19.9	10.5	0.6	0.2	1.1	4.5
25	P	272.25	194.91	162.43	135.42	84.90	42.45	21.18	11.15	4.84
	A	235.20	192.25	149.65	110.92	75.20	42.50	21.00	11.00	4.75
	Δ %	15.8	0.1	8.5	22.1	12.9	-0.1	0.8	1.4	1.9

P = Partial Duration Series; A = Annual Series

CORRELATION BETWEEN DAILY RAINFALL AND RAINFALL INTENSITY

The correlation between intensity of short time rainfall duration and 24-hour rainfall follows the Mononobe's equation (Sosrodarsono & Takeda, 1983) :

$$I_t = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^m$$

where I_t is the rainfall intensity in mm/hour for a rainfall duration t, R_{24} is the 24-hour rainfall and m is 2/3.

Using data from weather station at Bukit Asam Mine the correlation is being analysed to see whether it is still valid for the mining area. There are two data arrays being correlated. The first array contains rainfall intensities of several duration (5, 10, 15, 30, 60, 120, 360, 720,1440 minutes) calculated from daily rainfall data using Mononobe's equation. The second array consists of rainfall intensities summarized from automatic rainfall recorder (ARR) measurement. The data of both arrays is ranked. Partial duration data series are selected from both arrays then extreme value distribution analysis is applied to calculate the intensity-duration-frequency (IDF) relationships of both arrays.

Figures 1,2 and 3 show the comparison between IDF curves generated from ARR data and the data calculated from daily rainfall using Mononobe's equation for 2, 5, and 10 years of recurrence period.

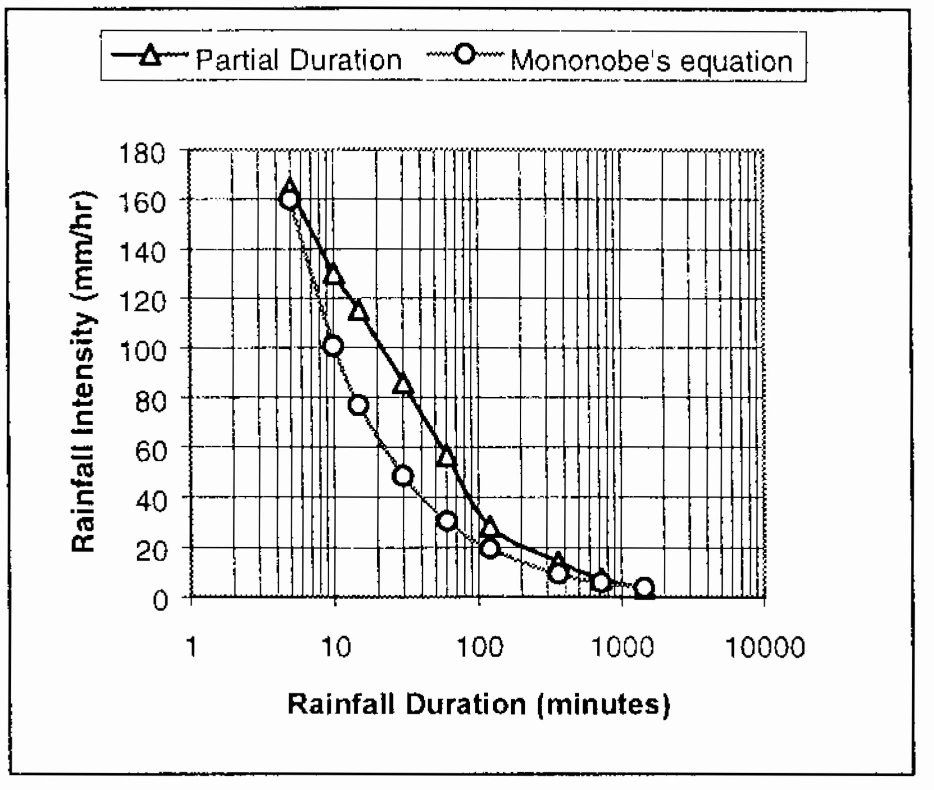

Figure 1 : Intensity-Duration for T = 2 years (ARR vs. daily data)

The results show that the calculated intensities using Mononobe's equation are lower than those summarized from ARR measurement data and the difference is smaller in the longer duration.

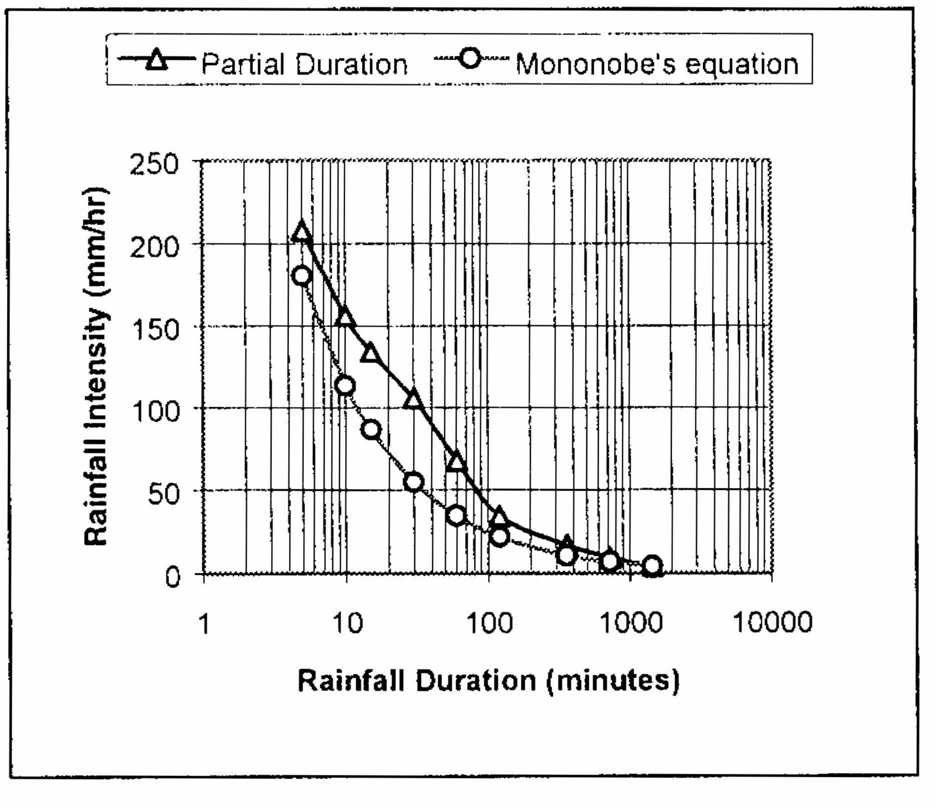

Figure 2 : Intensity-Duration for T = 5 years (ARR vs. daily data)

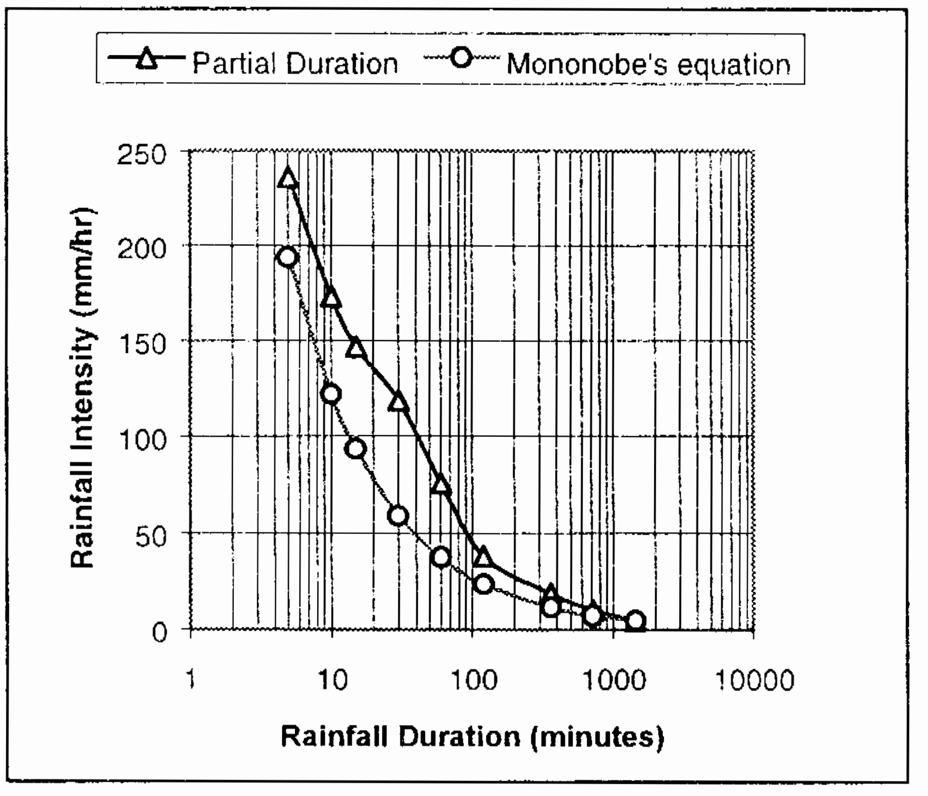

Figure 3 : Intensity-Duration for T = 10 years (ARR vs. daily data)

APPLICATION IN THE MINE DEWATERING ANALYSIS

In most surface mines in Indonesia runoff of rainwater is the most important mine water problem. The tropical area influenced by the monsoon is characterised by high rainfall intensity. This should be considered in designing the mine dewatering facilities. Therefore, the design requirement is the capability to predict the storm rainfall in the future, at least, as long as the life time of the dewatering facilities.

Because most of the mines in Indonesia are developed in a remote and undeveloped area, there is sometimes no stations available in the surrounding area or the mine is located very far away from the nearest rainfall station. Another problem is the length and type of rainfall data. In most stations rainfall rate is measured daily using ordinary rainfall gauge and the measurement is just started a few years back. Only very few stations are equipped with a continuous automatic rainfall recorder.

On the other hand, for the design of drainage infrastructures to handle the runoff water, the rainfall-runoff relationship in the mining area should be characterised. The design storm rainfall intensity is calculated using historical rainfall data from weather stations in the mining and surrounding area. Therefore, a significant rainfall intensity data should be available, which, of course, can not be provided from an ordinary manual rainfall gauge alone.

When there is only short-term rainfall data available, the result of analysis has shown that using partial duration series of data in defining design storm rainfall is still allowable particularly for shorter recurrence period. It gives higher value of storm rainfall than the result using annual series of data which means that the risk of exceedence is smaller.

In the case when only daily rainfall available the application of Mononobe's approximation to determine rainfall intensities for shorter rainfall duration tends to be under estimate. Big differences shown particularly for short duration (< 120 minutes) should be considered carefully by the design engineer in defining design storm rainfall intensity.

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