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# Estimation of Probable Maximum Flood

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## Abstract:

The Probable Maximum Flood (PMF) is one of a range of conceptual flood events used in the design of hydrological structures. The main objective of this paper is the estimation of probable maximum flood for Shwegyin Hydropower Project and Yeywa Hydropower Projects. Other objectives of this study are to provide systematic procedures that will consistently produce a reasonable PMF hydrograph and appropriate reservoir flood levels for evaluation of project safety, apply probable maximum flood (PMF) in spillway design of large projects and reduce severe flood damage. In evaluation Probable Maximum Flood (PMF), Unit hydrograph method is used for Shwegyin Project. For Yeywa Project, statically approach and meteorological approach is used In evaluation Probable Maximum Precipitation (PMP). Probable Maximum Flood (PMF) is estimated by Snyder's Unit hydrograph method for Yeywa Project.

***Keywords*—**pmf, pmp, flood estimation, extreme flood, probableflood, maximum flood.

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## I. INTRODUCTION

Myanmar has water power resources of approximately 108,000 MW. In the present year the electrical system of Myanmar has an installed capacity of 1100 MW. It indicates that approximately 2% of hydropower resources have been utilized. Therefore, 98% of hydropower potential remains to be exploited. Electric energy demand has been increasing rapidly over the last few years. The rising demand of energy has prompted the use of renewable sources of energy. Therefore, many new hydropower projects are being constructed in Myanmar. As there are many water resources projects, the safety of these projects against unpredictable flood is more and more important. Estimation of Probable Maximum Flood (PMF) is essential for safety of a water resources project.

For about the last 60 years, the PMF has received general acceptance as the design flood for dams in the United States, whose failure would pose a threat to public safety. More recently, the PMF has received acceptance as the design flood for large dams in many other countries as well.

The Probable Maximum Flood (PMF) is the flood that may occur from the most severe combinations of meteorological and hydrological conditions which are reasonably possible in the region. The estimation of PMF involves a detailed study of storm patterns, storm transposition and various other meteorological phenomena.

Probable Maximum Precipitation (PMP) is defined by the World Meteorological Organization (1986) as 'the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year'. The PMP is usually estimated by maximising the effect of various meteorological factors such as humidity, temperature, and wind.

## II. HYDROLOGIC DATA OF STUDY AREAS

Hydrologic data and project data of Shwegyin Hydropower Project and Yeywa Hydropower Projects are as follows.

### A. Shwegyin Hydropower Project

The Shwegyin Hydropower Project is located near Kyauknaga village, about six miles northeast from Shwegyintown, Bago division. It is constructed across the Shwegyin River which is one of left bank tributaries in the lower Sittaung River, approximately 15 km upstream from the confluence of the Sittaung River and Shwegyin River.

The project area lies in the Southern Torrid Zone. There are the rainy season and the dry season under the influence of the southeast monsoon. The mean annual temperature in the project area being considered is about 26.85°C. The mean monthly temperature of the hottest month (April) is 31.1°C and that of the coldest month (December) is 23°C. The mean annual evaporation in the project area is about 1.66 mm. The mean monthly evaporation has a maximum and minimum 230

  

mm and 102 mm in April and December respectively. The mean annual rainfall measured at Shwegyin DMH (Department of Meteorology and Hydrology) station amounts to 3.700 mm. Monthly mean inflow converted from rainfall data by multiplying annual mean runoff coefficient of 0.78 is 80 $m^3/s$.

The project site has the catchment area of approximately 878 $km^2$. It is located some 30 km ESE (East to South-East) to Nyaunglebin Township on the Shwegyin River.

B. Yeywa Hydropower Project

Yeywa Hydropower Project is located on the Myitnge River which is one of the largest left bank tributaries of the Irrawaddy River. It is situated 50 km south-east from Mandaly. Nam Tu River is originated from mount Loi Swang at an elevation of 1460 m on the northern Shan plateau. It flows on a general direction of north-east to south-west and joints the Ayeyarwaddy River at the about 15 km to the south-west of Mandalay. The main river course length is 530 km and the catchment area for dam site is 28206 $km^2$.

## III. SELECTION OF DESIGN FLOOD

For Design flood in the design of service spillway, 1000 year flood is used. Design flood for auxiliary spillway is Probable maximum flood (PMF). When the flood exceeds the designed capacity of the main spillway, the auxiliary spillway comes into operation and the total flood is passed by both the spillways. An auxiliary spillway cannot be provided alone without the main spillway. Selection of Design flood for hydraulic structures is as shown in Table I.

Table I
Selection of Design Flood for Hydraulic Structures

| Structure | Storage (M $m^3$) | Design Flood |
|---|---|---|
| Dams / Barrage (Large projects) | >60 | (a) PMF from PMP or<br>(b) Flood with return period of 1000 years or more |
| Permanent Barrage/ Small Dams | <60 and >10 | (a) SPF from SPS<br>(b) Flood with return period 100 years<br>(c) a or b whichever is higher |
| Small Structures (minor projects) | C.D. works<br>Culverts/ bridges<br>Dams up to 10 M $m^3$ storage,<br>Pickup barrages | (a) Flood of return period of 50 or 100 years depending on the importance of the structure |

## IV. METHODS OF ESTIMATION OF MAXIMUM FLOOD

For proper design of hydraulic structures, a reliable estimate of the flood discharge is essential (Technical Board Committees 1997). But adequate data for design flood computation may not be available for all specific streams and at this situation; it can be estimated by indirect methods or empirical methods. The methods for the estimation of the maximum inflow flood discharge are:

(a) Past flood marks method
(b) Empirical methods
(c) Envelope curves method
(d) Concentration time method
(e) Rational method
(f) Unit hydrograph method
(g) Flood frequency method.

In the report, study of probable maximum precipitation (PMP) is based on the hourly rainfall at Shwegyin catchment. For Yeywa Hydropower Project, Probable Maximum Precipitation (PMP) is estimated by statically approach and meteorological approach. Unit hydrograph method is used for the estimation of probable maximum flood (PMF). Synthetic unit hydrograph method is used for Yeywa Hydropower Project. Probable maximum flood (PMF) is determined by applying probable maximum precipitation (PMP) to unit hydrograph.

A. Unit Hydrograph Method

The unit hydrograph is defined as the hydrograph resulting from an isolated storm of unit duration occurring uniformly over the entire catchment area and producing unit (i.e. 1 cm) depth of direct runoff. Theunit duration is usually expressed in hours and it is prefixed to the unit hydrograph. Thus a 6-hr unithydrograph indicates the hydrograph which gives 1 cm depth of direct runoff when a storm of 6-hourduration occurs uniformly over the catchment. The unit hydrograph is also called the unit graph.

The design flood is obtained from the unit hydrograph and the design storm. The following procedure is commonly used:

- Obtain the hyetograph of the effective rainfall from the design storm. Select the lowest initial loss and the lowest infiltration index to obtain the maximum rainfall excess.
- Develop the hydrograph of direct runoff from the unit hydrograph and the hyetograph of the effective rainfall.
- Add the base flow to the direct runoff flood hydrograph to obtain the design flood.

The design storm for the estimation of the probable maximum flood (PMF) is the maximum probable precipitation (PMP). Similarly, for the standard project flood (SPF), the standard project storm (SPS) is required. For other design floods, a smaller design storm is suitably selected.

## V. ESTIMATIONOF PROBABLEMAXIMUM FLOODFORSHWEGYINHYDROPOWER PROJECT

The unit hydrograph method has become useful and powerful tool for the flood calculation. Application of the unit hydrograph to obtain a flood hydrograph assumes that the storm rainfall is uniformly distributed over the catchments.

A. Unit Hydrograph Derivation

  

According to the basic assumptions of the unit hydrograph theory, it is most desirable to select a hydrograph resulting from an isolated, intense, short duration storm of nearly uniform distribution in space and time for derivation of a unit single peak hydrograph from the records. If no ideal storm is available, it is necessary to develop the unit hydrograph from a complex storm. Unit hydrograph derivation mainly consists of four procedures as shown below:

Firstly, an obtained hydrograph, which is converted with the Q-h curve at the dam site, is separated into direct runoff and baseflow.

Secondly, a part of rainfall contributing to direct runoff, which is called effective rainfall, is extracted from observed hyetograph so that the amount of effective rainfall over the catchment area is equal to that of the corresponding direct runoff.

Thirdly, the hydrographs of direct runoff are divided by the corresponding effective rainfall, and then several unit hydrographs are collected.

Finally, three unit hydrographs with the first to third peak discharge are extracted from the collected unit hydrographs. The average unit hydrograph is sketched to conform to the shape of the other graphs, passing through the computed average peak and having a unit depth of one centimeter. The compiled effective rainfall data show duration time of one hour contributing to the unit hydrograph. Then, the ordinates of a representative unit hydrograph are plotted and the results are shown in Fig. 1.

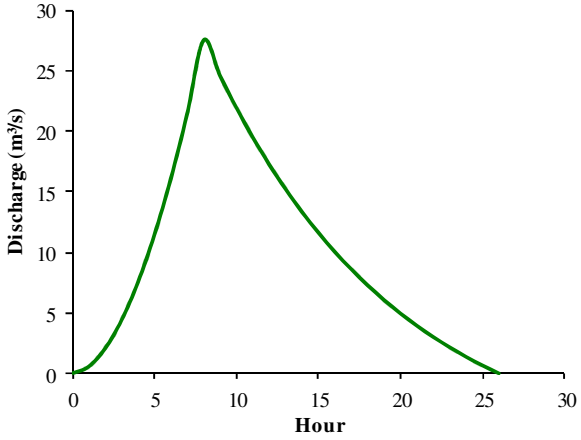


Fig.1 Representative Unit Hydrograph

B. Determination of Probable Maximum Precipitation

Probable maximum precipitation (PMP) is the depth of precipitation which for a given area and duration can be reached but not exceeded under known meteorological condition (Technical Board Committees 1997). Statistical techniques applied to the measurements of extreme rainfalls. PMP as shown in Table II is estimated with a statistical approach such as Hershfield's method. The critical rainfall excess sequences are 26.1, 53.1, 110.7, 44.1 and 22.5 mm respectively.

Table II
Probable Maximum Precipitation

| Duration Time (hour) | Rainfall Intensity (mm/hour) | Frequency Factor ($K_m$) |
|---|---|---|
| 1 | 123 | 5 |
| 2 | 91 | 7 |
| 3 | 77 | 8 |
| 4 | 65 | 9 |
| 5 | 57 | 9 |

C. Development of Probable Maximum Flood

For Shwegyin Hydropower Project, the hydrograph of direct runoff is developed from the unit hydrograph and the hyetograph of the effective rainfall by using critical sequence. The PMF ordinates are obtained by adding the baseflow to the direct runoff ordinates. From the trial critical sequence of the PMF hydrographs, the final result of the PMF hydrograph for Shwegyin Hydropower Project is shown in Fig. 2.

Probable maximum flood for Shwegyin Hydropower Project is estimated to be 6778 $m^3/s$.

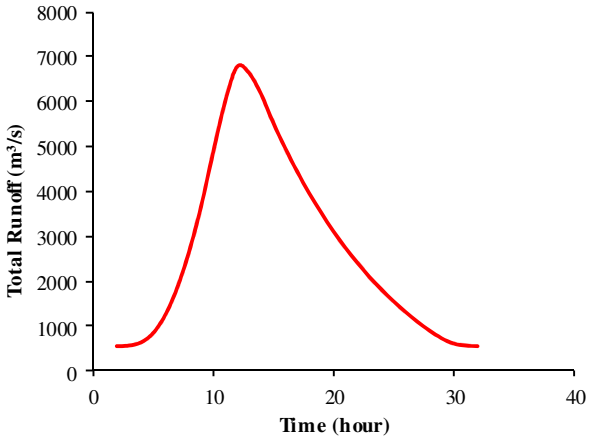


Fig. 2 Probable Maximum Flood Hydrograph for Shwegyin Project

## VI. ESTIMATION OF PROBABLE MAXIMUM FLOOD FOR YEYWA HYDROPOWER PROJECT

In Yeywa Hydropower Project, Probable Maximum Precipitation is estimated by two methods of approach. They are;

- Statistic approach and
- Meteorological approach

For estimation of Probable Maximum Flood, a unit hydrograph is predicted by Snyder's Synthetic Unit Hydrograph Method and Probable Maximum Flood (PMF) is determined by applying Probable Maximum Precipitation (PMP) to unit hydrograph.

  

A. Statistical Approach

Statistical procedures for estimating PMP may be used wherever sufficient precipitation data are available, and are particularly useful for making quick estimates, or where other meteorological data, such as dew point and wind records, are lacking. It is used mostly for making quick estimates for basins of no more than about 1000 km2, but has been used for much larger areas. Its convenience lies in that it requires considerably less time to apply than does the meteorological, or traditional, approach and one does not have to be a meteorologist to use it. A major shortcoming is that it yields only point values of PMP and thus requires area-reduction curves for adjusting the point values to various sizes of area. A second problem is involved in determining the appropriate value to use for K. Different values have been used by various investigators [Dhar and Damte, 1969; McKay, 1965]. Development of Procedure is as follow.

The procedure as developed by Hershfield (1961) and later modified (1965) is based on the general frequency equation [Chow 1961].

$$X_m = \overline{X}_n + K_m S_n \quad (1)$$

where $X_m$ is the rainfall of return period t; $\overline{X}_n$ and $S_n$ are, respectively the mean and standard deviation of a series of n annual maxima; and $K_m$ is the number of standard deviations to be added to $\overline{X}_n$ to obtain $X_m$.

(1)Adjusted PMP: $\overline{X}_n$ and $S_n$are adjusted using adjustment factors. Unadjusted PMP is calculated by using adjusted $\overline{X}_n$ and $S_n$. PMP is adjusted by Adjustment Factor ($F_0$). Adjusted PMP can be calculated by the following equations.

Adjusted $\overline{X}_n = (Fx_1)(Fx_2)\ \overline{X}_n$

Adjusted $S_n = (Fs_1)\ (Fs_2)\ S_n$

Unadjusted PMP,

$$X_m = \overline{X}_n + K_m S_n \quad (2)$$

Adjusted PMP,

$$PMP = F_0 X_m \quad (3)$$

Where, $F_0$ = adjustment factor

For this study,

| | | | |
|---|---|---|---|
| $Fx_1$ | = 99% | $Fx_2$ | = 103.1% |
| $Fs_1$ | = 84% | $Fs_2$ | = 113% |
| $K_m$ | = 13.6 | | |
| $F_0$ | = 100.9% | | |

From Statistical Approach, the estimated PMP is 201.1 mm by using above equations.

B. Meteorological Approach

The assumption is that PMP can be computed from optimum storm maximization by moisture maximization factor depends on the specific humidity that maintains precipitable water in ratio to the storm holding humidity capacity. MMF can be expressed as

$$MMF = \frac{W_{max}}{W_{actual}} \quad (4)$$

Where,

MMF = moisture maximization factor (MMF)

$W_{max}$ = humidity of maximum dew point temperature

$W_{actual}$ = humidity of dew point temperature at the rainstorm area

Humidity can be estimated as

$$ln\ W = 0.06 t_d - 0.02 \quad (5)$$

Where, W = humidity in atmosphere (cm)

$t_d$ = maximum dew point temperature ( °C)

Some dew point was estimated for the maximum flood observed is 22.42°C and maximum 100 years return period dew point is 32.53°C for dam site. From above Equation, moisture maximization factor is obtained as 1.89. Then, PMP can be obtained as 208.8 mm by multiplying one day maximum precipitation of 110.5 with MMF of 1.89.

Therefore, the results from two approaches are

- Statistical estimate of PMP = 201.1 mm
- Meteorological estimate of PMP = 208.8 mm

The result of meteorological analysis is adopted for safety side.

C. Estimation of Probable Maximum Flood

The unit hydrograph method is also used to estimate the probable maximum flood. A unit hydrograph is a hydrograph presenting 1 unit runoff from a rainfall of same unit duration and specific aerial distribution. A unit hydrograph for a given catchment can be calculated either directly by using rainfall runoff data for selected events or indirectly by using a synthetic unit hydrograph formula.

The following procedures are made to estimate the probable maximum flood for the design of proposed dam site.

- Preparation of dimensionless graph at Shwesayan gauging station.
- Prediction of the unit graph at the dam site based on the dimensionless graph at Shwesayan gauging station and topographic condition of the basin.
- Derivation of PMF at the dam site applying the convolution integral for the unit graph and PMP so obtained.

(1)Unit Hydrograph for Yeywa Project:In order to establish a unit hydrograph at the Yeywa dumpsite, the dimensionless graph at Shwesayan gauging station was derived from the recorded floods having maximum discharge of 3296 $m^3$/sec and basin time lag of 108 hours is shown in Fig. 3.

  

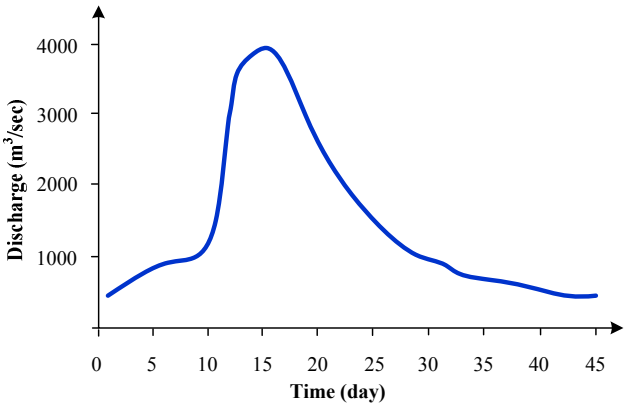


Fig. 3 Observed Flood at Shwesayan Gauging Station

A unit hydrograph is developed for unit rainfall over the Shwesayan gauging station considering the unit duration determined from the dimensionless graph and time lag. A dimensionless unit hydrograph is then developed from the observed flood with base flow of 500 $m^3$/sec and the dimensionless graph is shown in Fig. 4.

To estimate the time lag at the dam site, the Snyder's formula was applied as given below,

$$L_g = C_t \times (LL_c)^{0.3} \quad (6)$$

Where, $L_g$ = basin time lag (hour)
$L$ = length of the longest watercourse from the point of interest to the basin boundary (mile)
$L_c$ = length of watercourse from the point of interest of the centroid of basin boundary (mile)
$C_t$ = Snyder's coefficient

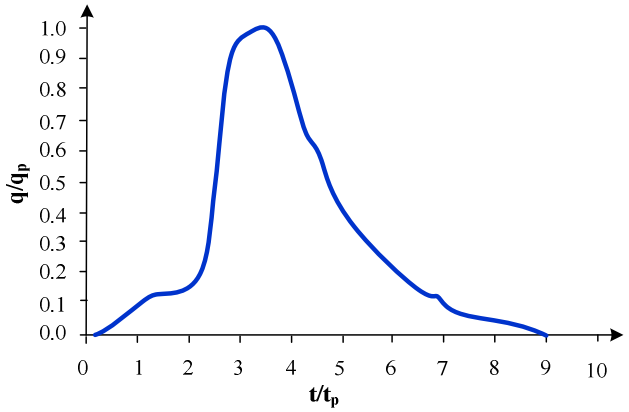


Fig. 4 Dimensionless Unit Hydrograph at Shwesayan Station

Snyder's coefficient for Shwesayan station, $C_t$ = 4.975 is computed by using

$L_g$ = 108 hours
$L$ = 260.00 miles = 420 km
$L_c$ = 109.36 miles = 176 km

For the dam site, applying

$C_t$ = 4.975,
$L$ = 242.33 miles = 390 km
$L_c$ = 90.72 miles = 140 km
$L_g$ = 99.87 hours
$L_g + D/2$ = 111.87 hours
$D$ = the rainfall duration 24 hours

A unit hydrograph at dam site is estimated by using above basin characteristics is shown in Fig. 5.

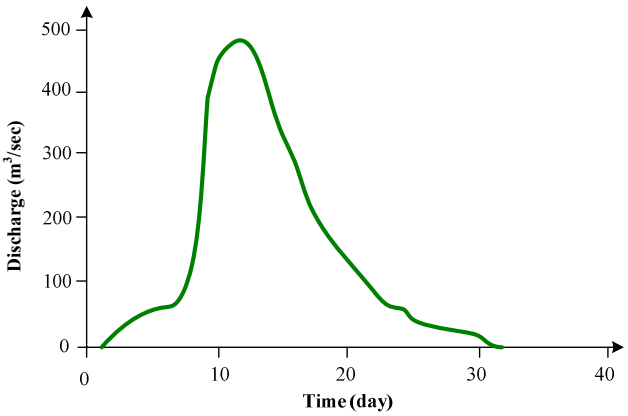


Fig. 5 Estimated Unit Hydrograph at Dam Site

(2)Probable Maximum Flood for Dam Site:The PMP is converted to PMF using unit graph. The peak discharge of PMF is more than 1.9 times the 10000year probable flood of 6500 $m^3$/sec. Fig. 6 shows PMF hydrograph at dam site.

Probable maximum flood for Yeywa Hydropower Project is estimated to be12470 $m^3$/sec.

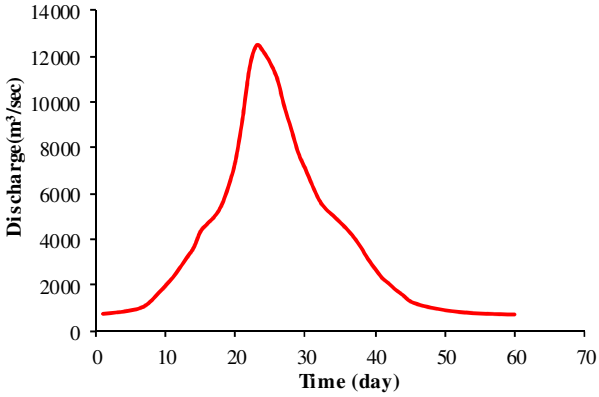


Fig. 6PMF Hydrograph for Yeywa Project

## VII. CONCLUSIONS

For Shwegyin Hydropower Project, estimation of probable maximum precipitation (PMP) is based on the hourly rainfall at Shwegyin catchment. For Yeywa Hydropower Project, PMP is estimated byStatistic approach andMeteorological approach as Yeywa catchment is complex. Simple unit hydrograph is used for Shwegyin and Synthetic unit hydrograph methods is used for Yeywa. For both

projects, PMF is determined by applying probable maximum precipitation (PMP) to the unit hydrograph.In large dam spillway design, PMF is necessary.This research can be taken as general reference for determination of PMF for ongoing hydropower projects.

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