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Assessment of hydrological safety of Mae Sruai Dam, Thailand

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Abstract

Mae Sruai Dam was completed in 2003; it was built across Mae Sruai river in Chaing Rai province, Thailand. This study is done to assess the hydrological safety aspect of the dam for spillway adequacy of the dam to accommodate probable maximum flood inflow (PMF). The hydrological assessment was done by estimating the probable maximum precipitation (PMP) over Mae Sruai River Basin. The two approaches of PMP estimates namely (1) statistical approach and (2) storm maximization and transposition approach were adopted to calculate the 1-day, 2-day and 3-day PMPs. The 1-day PMP of the two approaches were compared with the regional 1-day PMP of Mekong River Basin estimated by U.S. Weather Bureau and U.S. Corps of Engineers in 1970. From the comparison, the storm maximization and transposition approach was finally selected and the 1-day, 2-day and 3-day PMPs were transformed to the continuous 4-day PMP by a regional approach. The HEC-HMS model was applied to transform PMP to PMF and to route the PMF through the reservoir to check if dam-crest had flow overtopping. The continuous 4-day PMP was transformed to PMF with peak reservoir inflow discharge of 1,013 m^3/s and corresponding peak outflow of 886 m^3/s. This outflow was less than the design spillway capacity of 1,160 m^3/s. Thus, the dam safety in hydrological aspect was assured. Furthermore, flood routing study in the flood plain downstream of the dam indicated that flooding in Mae Sruai District floodplain especially in urbanized area would occur due to PMF inflow and hence flood control measures should be adopted.

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Keywords: Dam safety; Mae Sruai Dam; Hydrological safety assessment; Probable maximum precipitation; Probable maximum flood

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1. Introduction

Originated in northern mountainous area of Chaingrai Province, Mae Sruai River runs its 55-km long and converges into Mae Lao River at Mae Sruai District. The Mae Sruai Dam was constructed across Mae Sruai River at Ban Teen Doi, Mae Sruai District, Chiang Rai Province, Thailand as shown in Figure 1. Mae Sruai Dam was completed in Jan 2003 which consists of two types of dam; the Roller-Compacted Concrete (RCC) Dam and the Earth-fill Embankment Dam. The catchment area of Mae Sruai Reservoir is 434 km^2 which contributes 184 MCM of average annual runoff whereas the reservoir capacity is only 73 MCM. The design spillway capacity of Mae Sruai Dam can release the maximum runoff discharge 1,160 m^3/s [1]. The elevations of the spillway crest are +507.000 m MSL and the dam crest is +511.000 m MSL. The 1.30-m diameter of river outlet pipe can release water a maximum of 33 m^3/s There are two channel outlet pipes to release water to irrigate 320 ha of downstream agricultural area.

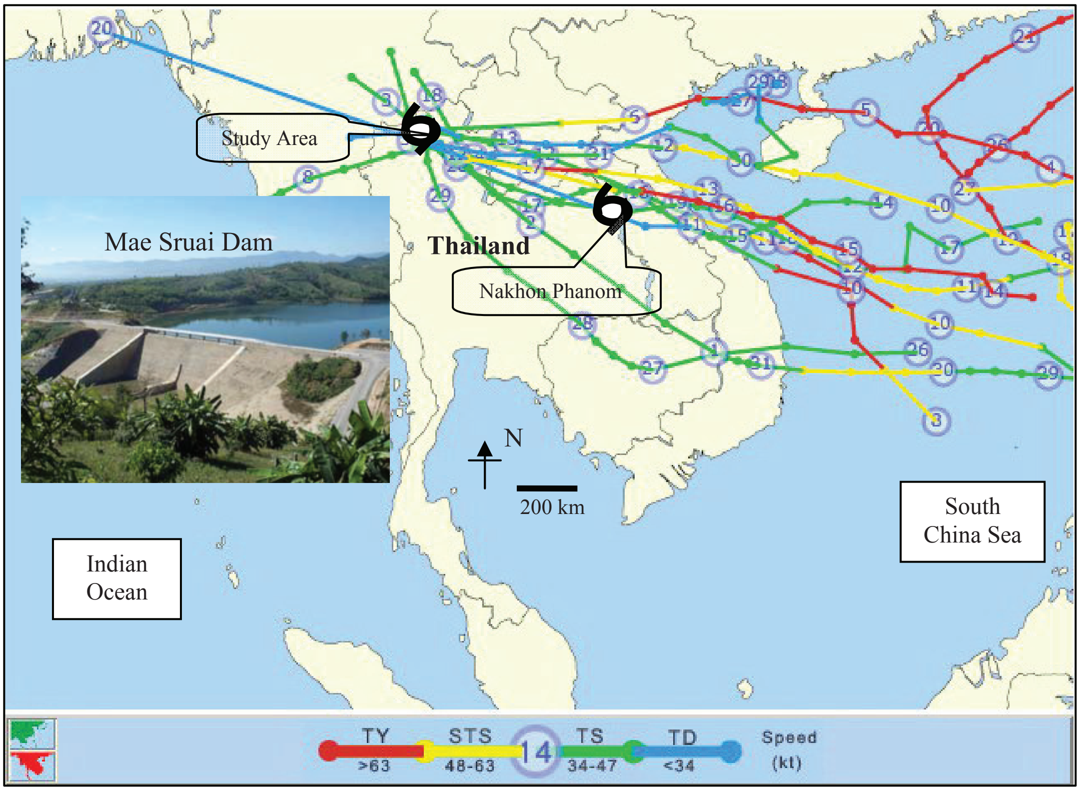

Fig. 1. Mae Sruai Dam picture, location map of study and storm directions over the study area (1951-1995)

2. Method of Analysis

For the hydrological assessment, an analysis is done to check whether the dam has adequate spillway capacity to safely handle the Probable Maximum Flood (PMF) in order to avoid dam crest overtopping. To find out PMF against the dam, the Probable Maximum Precipitation (PMP) over study area is required. There are various models that can be used for estimation of PMP. In this study, two approaches of PMP estimates were adopted to analyze and compare the results with a 24-h PMP value determined by the application of regional PMP of Mekong River Basin [2].

1st Approach: ***The statistical approach***. The annual maximum rainfalls for the durations of 1, 2 and 3 days were abstracted from data archive of each station. The PMP points at each station can be estimated from the following equation [3]:

$$X_{PMP} = \overline{X}_n + K_m \cdot \sigma_n \tag{1}$$

where X_{PMP} is the PMP for a given station for a specific duration, $\overline{X}_n$ and σ_n are the mean and standard deviation for a series of n annual maximum rainfall values of a given duration respectively. K_m is the frequency factor and is the largest of all the calculated K values for all stations in a given area. The value of K is calculated using the following equation:

$$K = \frac{\left(X_1 - \overline{X}_{n-1}\right)}{\sigma_{n-1}} \tag{2}$$

where X_1, $\overline{X}_{n-1}$ and σ_{n-1} are the highest, mean and standard deviation respectively excluding the X_1 value from the series.

2nd Approach: ***The storm maximization and transposition*** [4] was widely used in Thailand because the records of severe storms in Thailand are available. Majority of recorded storms since 1951 to 1995 originated from South China Sea and passed over the north-east region to the study area as shown in Fig.1. One of the most severe storms was the 1962-storm at Nakhon Phanom province situated near the Mekong River's bank in the north-east region of Thailand. A total of 544.6 mm of rainfall occurred within 3 days (June 16-18, 1962), in which 459.2 mm (84%) was measured on the 17th of June. The maximum persisting 12-h dew point temperature associated with this storm was 25.2 ^{o}C. The severe storm or extreme values of precipitable water were approximated by estimates based on surface dew point, assuming saturation and pseudo-adiabatic conditions. Surface dew point representative of the moisture inflows into the storm identifies the storm saturation adiabat. The moist adiabat corresponding to either the highest recorded dew point observed over a period of 50 or more years for the location and season or the dew point for the specific return period, e.g. 100-year, is considered sufficiently close to the probable warmest saturation adiabat. The maximum value of atmospheric water vapor used for storm maximization is usually estimated from maximum persisting 12-h 100-kPa (or 1000- mb air pressure) dew point. Frequency distribution was used for dew point records which was shorter than 50 years to find out the100-year return period maximum annual dew point temperature corresponding to the maximum persisting 12-h dew point temperature. In the storm moisture maximization, it is assumed that rainfall can be determined from the product of available moisture and storm mechanism. The maximum dew point temperatures both for theoretical maximum and for historical storm for different duration were reduced pseudo-adiabatically to the 1000 mb level (equivalent 0 m MSL) by using Pseudo-Adiabatic Chart given in the Manual for Estimation of Probable Maximum Precipitation [5].

In hydro-meteorological work, the atmosphere is usually assumed to contain the same amount of water vapor as saturated air with saturation pseudo-adiabatic temperature rapes rate. The precipitable water in various layers of saturated atmosphere also can be obtained from Manual for Estimation of Probable Maximum Precipitation [5]. By assuming the cloud top height at 12,000 m MSL (200 mb air pressure), the depth of precipitable water in a column of saturated air can be approximated by subtracting the precipitable water at the cloud top by precipitable water at elevation of station with base at 0 m MSL (or 1000 mb). The point PMP at any particular location and storm duration can be calculated as

$$PMP = P_o \cdot F_m \cdot F_t \cdot F_{at} \quad (3)$$

Where P_o is the observed precipitation (mm) during 1962 storm at Nakhon Panom of 459.2, 517.2 and 544.6 mm for 1-day, 2-day and 3-day durations, respectively. F_m is the moisture maximization factor $=W_{pm} / W_{ps}$, in which W_{pm} is precipitable water for maximum dew point temperature at storm location and W_{ps} is precipitable water for dew point temperature during storm over elevation of the storm site [6]. F_t is the storm transposition factor = W_{pt}/ W_{pm} , in which W_{pt} is precipitable water for maximum dew point temperature at transposed location over elevation of the storm site. F_{at} is the transportation adjustment factor = W_{pe}/ W_{pt} , in which W_{pe} is precipitable water for maximum dew point temperature at transposed location over elevation of transposed site.

3. Results and Discussions

The point PMP values at Chiang Rai and Chiang Mai stations are calculated and averaged aerially for the Mae Sruai watershed and the results are shown in Table 1.It was found that the PMP values determined by the statistical approach were significantly underestimated, because the available records of daily rainfall data were not long enough to cover the extreme rainfall. The PMP values of the storm maximization and transposition approach were selected to be representative PMP over the study area because its 1-day PMP value was consistent with a 24-h PMP value determined by the application of regional PMP of Mekong River Basin [2].

Table 1. Summary of PMP (mm) over Mae Sruai watershed [7]

Approaches	1-day PMP	2-day PMP	3-day PMP
1. Statistical Approach	193.1	243.7	296.6
2. Storm Maximization and Transposition Approach	427.9	482.0	507.5
3. Regional PMP of Mekong River Basin Approach	407-430	-	-

To find out the short duration PMP, the regional approach described by [8] was adopted to develop rainfall Intensity-Duration-Frequency (IDF) curve for the closest rainfall station (representative station) at Amphoe Mae Sruai.Using the IDF curves, it is possible to build up a design storm profile for durations up to 96 hours (4 days) and return periods up to 1,000 years including PMP. The design IDF curves can be applied to point rainfall within catchment and derived catchment storm profile for design PMF computation. The PMP is the input to calculate PMF for the basin.

In general, the transformation of PMP to PMF requires the estimation of retention losses, the derivation of unit hydrographs, the convolution of rainfall excess and unit hydrograph, the flood routings through the channel and reservoir and the selection of antecedent and subsequent floods.

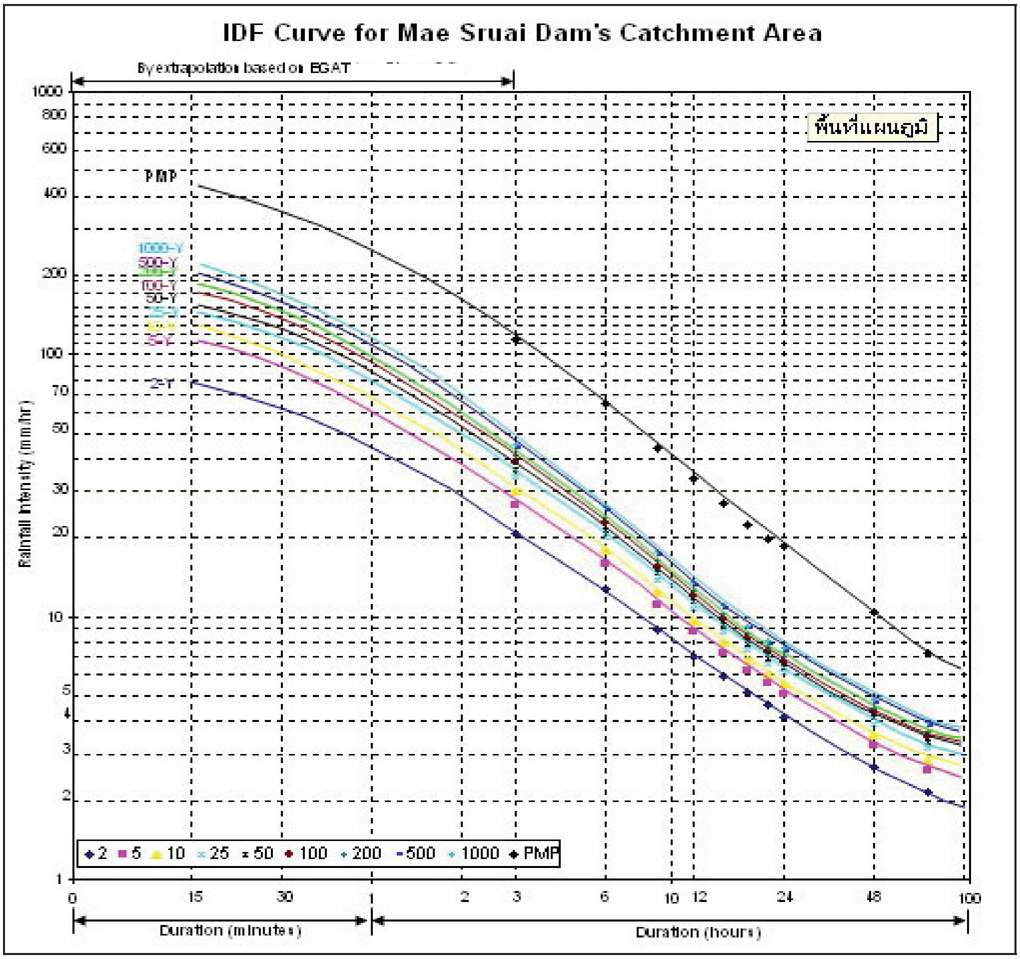

Fig. 2. Rainfall Intensity-Duration-Frequency Curve for Mae Sruai dam's catchment

The HEC-HMS model [9] required the following input data: 1) time-series data: precipitation data and discharge data of selected durations for calibrations and verification, 2) reservoir elevation-storage relationship and elevation-spilled discharge relationship, 3) local evapo-transpiration data. In model calibration and verification, the extreme historical events used for calibration are considered. The raw data of daily discharge for Station G.9 upstream of reservoir and Mae Sruai Dam were validated by plotting. Then the three events were selected as follows: 1) 20-30 July 2003 for the first model calibration, 2) 9-20 August 2005 for the second model calibration, and 3) 17-28 September 2006 for the model verification. The Optimization Manager in HEC-HMS model is used to estimate fitted parameters for model calibration based on difference between computed discharges and observed discharges. The average parameters of two model calibrations were used to verify the model. In order to gain the accurate result of model application, the HEC-HMS model calibrations and verification were done in three time steps: (1) 1-day, (2) 1-hour, and (3) 15-minute time steps. The 1-hour and 15-minute input rainfall data were re-distributed from daily data by assuming that rainfall intensity was uniform. Similarly, the discharge data for 1-hour and 15-minute were re-distributed by interpolating daily value day-by-day. In the model application for extreme event simulations, the same time step as calibration was used. In HEC-

HMS model application, the short duration precipitation values (accumulated rainfalls) were required for three cases of extreme precipitations: (1) 500 years of return period, (2) 1000 years of return period, and (3) PMP. All the short duration rainfalls of three extreme events were taken from IDF curve analysis and summarized in Table 2.

Table 2. Accumulated rainfall for HEC-HMS application based on 3 cases of extreme events [7]

Durations (hours)	0.25	1	2	3	6	12	24	48	96
500-Y Acc. Rainfall (mm)	49.5	101.0	124.0	131.1	151.5	159.0	177.4	226.5	316.8
1000-Y Acc. Rainfall (mm)	52.5	109.0	130.0	136.3	157.0	164.2	182.7	233.1	326.4
Acc. PMP (mm)	103.8	225.0	304.0	340.6	389.1	403.5	445.1	501.3	576.0

From the results of reservoir routing by 500-year, 1000-year return period of rainfalls and PMP over Mae Sruai watershed area, results based on 1-hour and 15-minute time steps were consistent and more realistic than the result based on 1-day time step. The duration 1-day time step was too wide for peak discharge to be incorporated accurately. The peak discharge, thus, was less than the results of 1-hour and 15-minute time steps. The result of 15-minute time step simulation was finally used for further analysis. The computed inflow peak discharge values corresponding to PMP, 1000-year and 500-year return periods of rainfall based on 15-minute time step were 1013, 381 and 366 m^3/s. Compared to the design spillway capacity of 1,160 m^3/s [1], it can be stated that the dam and its spillway can safely handle the PMF without dam crest overtopping flow as shown in Fig. 3.

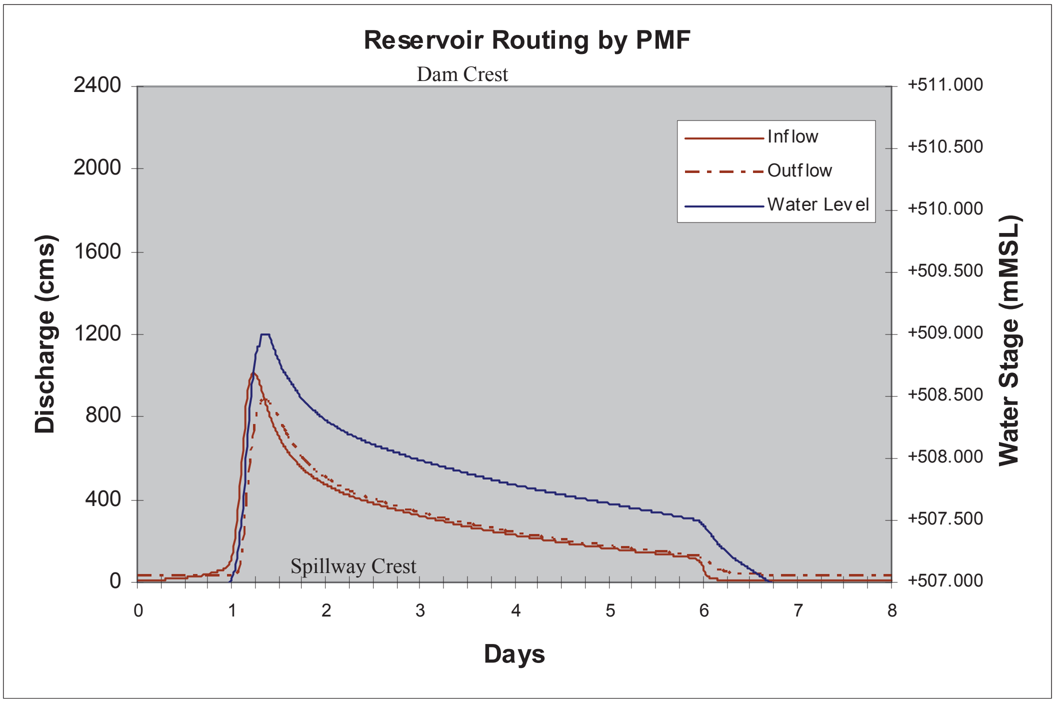

Fig. 3. Computed PMF inflow, corresponding outflow and reservoir level of Mae Sruai Dam

4. Conclusions and Recommendations

On the assumption that the PMP occurred during the reservoir at full of storage with fully operable outlet discharge, the existing spillway capacity was found capable to safely handle PMF without dam crest overtopping. The simulated peak water level was only +509.000 m MSL while the dam crest elevation was +511.000 m MSL. Although Mae Sruai Dam is safe in hydrological assessment, the downstream floodplain especially downstream urbanized area of Mae Sruai District was in high risk of flood and should be protected. A 2-dimensional flood routing model [7] was applied in downstream flood plain area of the dam. It was found that the simulated flood due to PMF covered 383 ha area of downstream flooding for 4 day duration. The extreme floods can be decreased in magnitude by suitable reservoir operation. Decreasing reservoir water level to accommodate extreme inflow should be done properly before rainy seasons.

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