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Flood in Mekong River & Simultaneous Failure of a Dam Situated on its Tributary

Neha B. Nandiwale[1*], Snehal A. Sutar[2], Ashish A. Doshi[3] & Amey U. Kumbhar[4]
[1]*Assistant Engineer, Infraplan Hydraulic Laboratory, Pune, India*
[2]*GIS Engineer, Infraplan Hydraulic Laboratory, Pune. India*
[3]*Director, Infraplan Hydraulic Laboratory, Pune, India*
[4]*Assistant Engineer, Infraplan Hydraulic Laboratory, Pune, India*
E-mail: neha.nandiwale@infraplan.co.in, snehal.sutar@infraplan.co.in , ashishdoshi@infraplan.in , amey.kumbhar@infraplan.co.in*

Abstract:

This paper presents a case study conducted to identify the hydraulic parameters and to assess the water levels & discharges in Mekong River, Laos during various floods and simultaneous breach of 34m high dam across one of its tributary. Mathematical model studies were undertaken for estimation of probable maximum discharge, velocities, arrival times and assessment of the water levels during floods & simultaneous dam break. The analysis was carried out to assess the breach flood wave impinging on the confluence and backwater effect along the tributary of Mekong River. The present paper describes the dam break simulation carried out for 15 MW Hydropower project located on a tributary, 6 km upstream of its confluence with Mekong River. Reservoir is extending up to 12 km upstream of dam. Bathymetry survey & LIDAR data was converted to digital elevation model using Quantum GIS software. The dam breach study was carried out using a HEC-RAS 2D software. The paper presents the outcome of the simulation for four different cases of dam failure at;

1. *Fair-weather condition (without flood) and Full Reservoir Level*
2. *PMF impinging on tributary dam reservoir along with lean flow in the Mekong River*
3. *PMF impinging on tributary dam reservoir while Mekong River is at high flood*
4. *Backwater effect of PMF flood impinging on tributary dam reservoir with spillway gates stuck and dam overflowing*

The analysis indicated very high velocities were persisting at the confluence of the tributary with the Mekong River. Also, the backwater effect was as high as 15 m. Emergency action plan was prepared based on findings of the study. Evacuation routes & safe zones were identified along with probable hazards to households and hydraulic structures.

Keywords: *Dam Breach, Submergence, Backwater effect, Spillway gate failure, 2D simulation.*

1. Introduction

The Mekong River in Laos has many tributaries and hosts several hydropower projects for generating electricity. This paper investigates the impact of flooding due to failure of the dam in a tributary and its impact on the confluence with Mekong River. The study highlights the extent of flooding much above the normal flood levels due to failure of a dam and its consequences on the confluence of tributary with Mekong River in the event of simultaneous occurrence of flood in Mekong and failure of a dam on the tributary will lead to unexpected fast rise in water levels in river upstream of confluence. The paper highlights the importance of imagining and assessing the extreme events that likely to occur in case of any structure across a tributary or river. Below Figure 1 shows the plan and section of the study area.

1.1. Background

A small-sized hydropower development project is located on the small tributary which originates from western Muong Phiang, Xayaboury Province, Lao PDR. It then merges into Mekong River in Xayaboury Province. The project features a concrete gravity dam with 5 radial gates and has an installed capacity of 15 MW. This dam is situated at the lower reaches of the tributary River, about 6 km upstream of its confluence with the Mekong River. The length of the reservoir upstream of the dam is 11.78 km. The Dam is 34 m high and of reinforced concrete type whereas the spillway has a crest length of 235 m. The elevation of river bed at the dam site is 248 to 252 m.asl. The crest level for radial gates is at 258 m.asl. The high-water level (HWL) of reservoir is 272.00 m.asl, the water depth in front of the dam is about 22.0 m. The low water level (LWL) of reservoir is at 264.67 m.asl. The river catchment area is comprised of the high mountains and the deep valleys. The natural gradient of the river is about 1.67% i.e. 1 in 600. Annual rainfall varies from 1,000 to 3,500 mm. Rainfall is strongly seasonal with over 90% of rain brought by the South West monsoon in the wet season lasting from April to October. Many ravines are discharging into the River and V-shaped valleys are predominant. The local area is covered by the dense tropic plants. There are two towns along the right bank of reservoir on the upstream of Hydropower project, one located around 12 km upstream of the dam and another city located at around 22 km upstream. Also, near confluence of the tributary with Mekong, one village is located. Further, there are two major hydropower projects located on Mekong River, at about 8 km upstream and one is proposed at

about 100 km downstream from the said confluence. A two-dimensional mathematical model was prepared using Hec-RAS 6.4 latest version software released by Hydrologic Engineering Centre of U.S. Army Corps of Engineers.

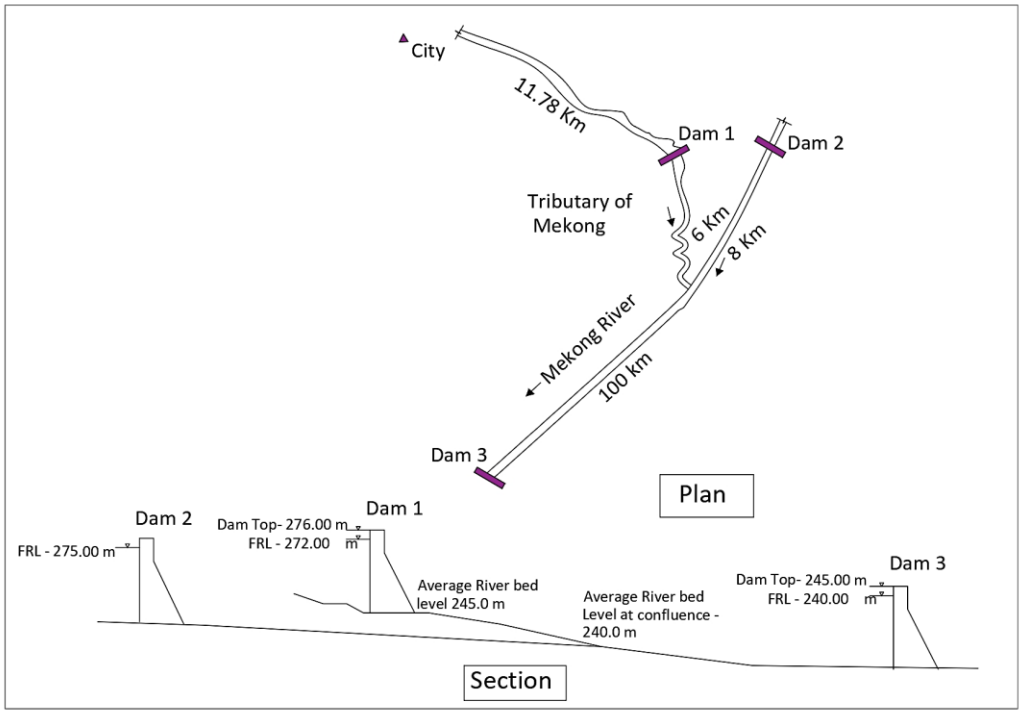


Figure 1. Plan and section of the study area

2. Data Required

The following data was received from the project authorities.

- Salient features of the Hydropower project.
- Topographic survey for the study area in CAD format with 1 m contour interval.
- The cross sections/ bathymetry data for the 6 km length from dam to the confluence with Mekong River.
- Design floods along with return periods.
- General Arrangement Drawings and typical cross sections for Dam and powerhouse.
- General information of Major Dams on the Mekong River at 8 km upstream and 100 km downstream from the confluence.

2.1.1. Hydrology Data

The Max storage volume (At HWL – 272.00 m.asl) is 16,72,0000 m^3 and the active storage volume is 12,16,0000 m^3. The storage volume and reservoir water level relationship correlated from the available data was adopted in the mathematical model as input for storage area. Probable maximum flood is 4,431 m^3/s. Inflow hydrograph was supplied by the authorities for 48 hours duration having its peak at PMF flood which is used for the simulation.

2.2. Model Setup

A two-dimensional model was set up in the latest version of HEC-RAS software. The contour data obtained from Lidar survey having 5 m contour interval, was received covering upstream length of 11.78 km of dam except for water impounding area under reservoir. For downstream length of 6 km from dam upto the confluence of Mekong River,

the bathymetry survey data was provided having cross sections with centre-to-centre distance of 300 m. Total 19 cross sections were provided. With the help of bathymetry data further contours were drawn for entire downstream area with 5 m interval using GIS software. In order to reproduce an accurate digital terrain, it would have been more appropriate to have lesser c/c spacing for bathymetric cross sections. However, to establish a fairly precise terrain model, the bathymetric cross sections were interpolated using GIS processes and also with the help of satellite image. Digital Elevation Model was prepared in GIS software based on this data.

Manning's roughness coefficient (n value) represents the frictional characteristics of the river reach and is significant parameter in predicting the water levels and velocities. It is advisable to consider appropriate 'n value' with due consideration for uncertainty in fluctuations of water levels for dam breach simulation. The tributary is located in a mountainous ranges having a steep slope gradient. At some places, the river portion has medium to large size boulders having diameters of 1 to 2.5 m and the side slopes of river banks are quite steep with medium to dense vegetation cover. In view of this, assessment of Manning's n value was undertaken for different portions of the river. The geological data, prototype observations with respect to water levels, vegetation cover and slope of the terrain were considered for arriving the Manning's roughness coefficient. Studies concluded that Manning's roughness coefficient of 0.035 is a good fit for the river portion and a value of 0.060 was will be well suited for the vegetation cover, as seen from the literature.

The reservoir was modeled as a 'storage area' with a stage-volume relationship and an initial water level of 272.0 m at HWL. The downstream river was modeled as a '2D flow area' with a 10m x 10m resolution. A SA/2D connection linked the storage area to the 2D flow area. The dam, with a top elevation of 276.17 m, and five sluice gates (10m x 14m) with an invert level of 258.0 m, were modelled. The mathematical model was run under various scenarios of dam failure. Boundary conditions included data from design flood events (PMF) and gate discharges. The available data indicated that during the dry season, the Mekong River has a minimum flow of 800 to 1,000 m^3/s, with an additional 1,000 to 1,200 m^3/s from upstream Chinese dams, totaling a minimum of 2,000 m^3/s. In the monsoon season (June to October), the flood discharges at the confluence were evaluated based on available data. The analysis of the available data indicated that powerhouse discharge of the upstream dam on Mekong River is of the order of 5100 m^3/s and a dam overflow spillway having 10 radial gates would cater for 47,500 m^3/s. The tailwater rating curve at the downstream boundary of the model at confluence of Mekong River was arrived from the various data supplied by the project authorities. In arriving this tailwater rating curve different flow scenarios for both dry and monsoon season and accounting for dams situated at the downstream of the confluence were also considered. Figure 2 shows the various tailwater rating curves for different scenarios. The large variation in depth can be attributed to variation in discharge during different seasons.

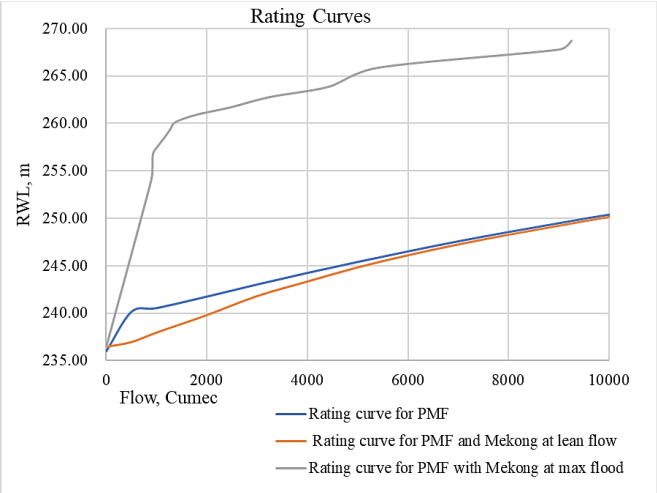


Figure 2. Rating curves for PMF with Mekong flood

3. Dam Failure Scenarios

The dam failure scenarios were discussed in detail with project authorities in the context of the multiple projects in the vicinity. The following four scenarios were adopted for the analysis of dam breach:

1. Dam Breach at Fair-weather condition (without flood) at Full Reservoir Level

2. Dam Breach at PMF impinging on tributary dam reservoir along with lean flow in the Mekong River
3. Dam Breach when PMF impinging on tributary dam reservoir while Mekong River is at high flood
4. Backwater effect of PMF flood impinging on tributary dam reservoir with spillway gates stuck and dam overflowing

3.1. Dam breach parameters

Various breach parameters were necessary as an input for performing dam break simulation. Studies were carried out for estimation of breach parameters. The breach parameters were calculated by various methods represented in Figure 3. The breach parameters adopted for simulation were adopted after evaluating combination of various parameters.

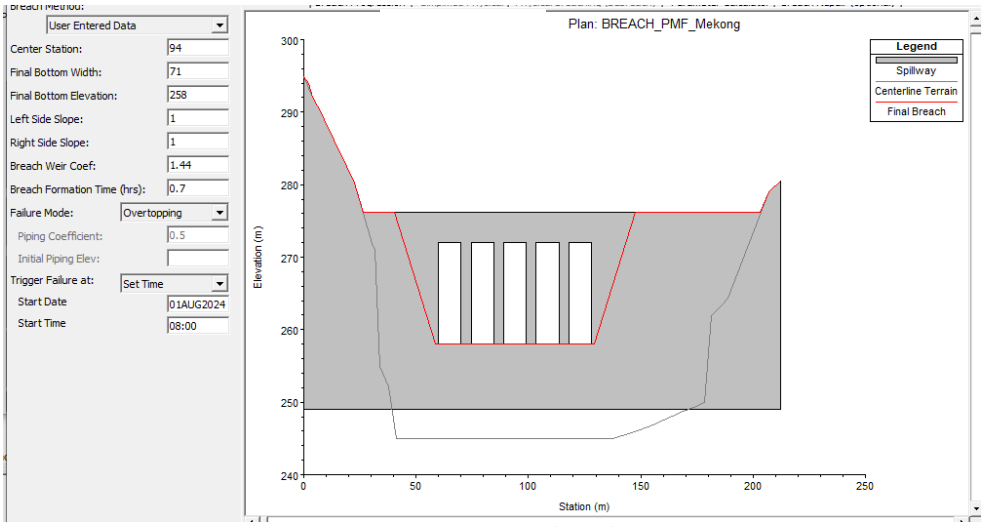


Figure 3. Breach parameters defined for simulation

Simulation was set up in Hec-RAS model with corresponding model inputs and breach parameters as explained above. Unsteady simulation was performed with a dam breach. Based on the data analysis, time period for various scenarios were arrived as shown in the Table 1 below. The computation interval and mapping output interval was kept as of 1 sec and 5 minutes, respectively. Hydrograph and detailed output interval were set to 5 minutes.

Table 1. Time periods for various scenarios

Sr No.	Scenarios	Simulation time, Hrs.	Flood Inflow Hydrograph, Time in Hrs	Dam Break at time, Hrs
1	Dam Breach during dry season without flood	12:00	-	0:0
2	Dam Breach when reservoir is at flood water level with PMF impinging.	72:00	36:00	8:00
3	Dam Breach when reservoir is at flood water level with PMF impinging with Mekong flowing at high flood levels	72:00	36:00	8:00
4	Reservoir is at full storage level at PMF impinging on reservoir and all spillway gates are stuck	48:00	36:00	-

The following paragraphs describe the various observations during the conduct of the studies.

4. Dam Breach Outflow Results

The observations of each of the cases as mentioned above are summarized in following paragraphs.

- Case 1 - Dam Breach during dry season without flood - Dam breach was initiated at 00:00 hrs and the maximum breach flow of around 6,259 Cumec was observed at 00:26 hrs. Subsequently the gated flow of 198 Cumec, which was maximum at 00:09 hrs. just during or before the breach. The maximum breach velocity observed at overtopping mode was little more than 6 m/s at 00:25 hrs. The maximum breach width was achieved at 00:51 hrs. Maximum water level realized just downstream of dam is 264.72 m whereas near the confluence of rivers, it was 247.45 m. The breach flood reached the confluence in about 41 min after initiation of breach.
- Case 2 - Dam Breach with PMF impinging - Dam breach was initiated at 08:00 hrs and the maximum breach flow of around 10,109 Cumec was observed at 08:24 hrs. Subsequently the gated flow of 4,045 Cumec, which was maximum at 08:09 hrs during or before the breach. The maximum breach velocity observed at overtopping mode was little more than 6 m/s at 08:23 hrs. The maximum breach width was achieved at 08:42 hrs. Maximum water level realised just downstream of dam is 268.37 m whereas near the confluence of rivers, it was 250.30 m. The breach flood reached the confluence in about 33 min after initiation of breach.
- Case 3 - Dam Breach during flood season with PMF impinging and Mekong flowing at high flood levels - Dam breach was initiated at 08:00 hrs and the maximum breach flow of around 3,869 Cumec is observed at 08:35 hrs. Subsequently the gated flow of 4,001 Cumec, which was maximum at 08:10 hrs during and before the breach. The maximum breach velocity observed at overtopping mode was little less than 5 m/s at 08:20 hrs. The maximum breach width was achieved at 08:42 hrs. The maximum breach width was achieved at 08:45 hrs. Maximum water level realised just downstream of dam is 267.89 m whereas near the confluence of rivers, it was 265.42 m, due to the high-water level in Mekong River. The breach flood reached the confluence in about 45 min after initiation of breach. Figure 4 shows breach flow hydrograph for all three cases.

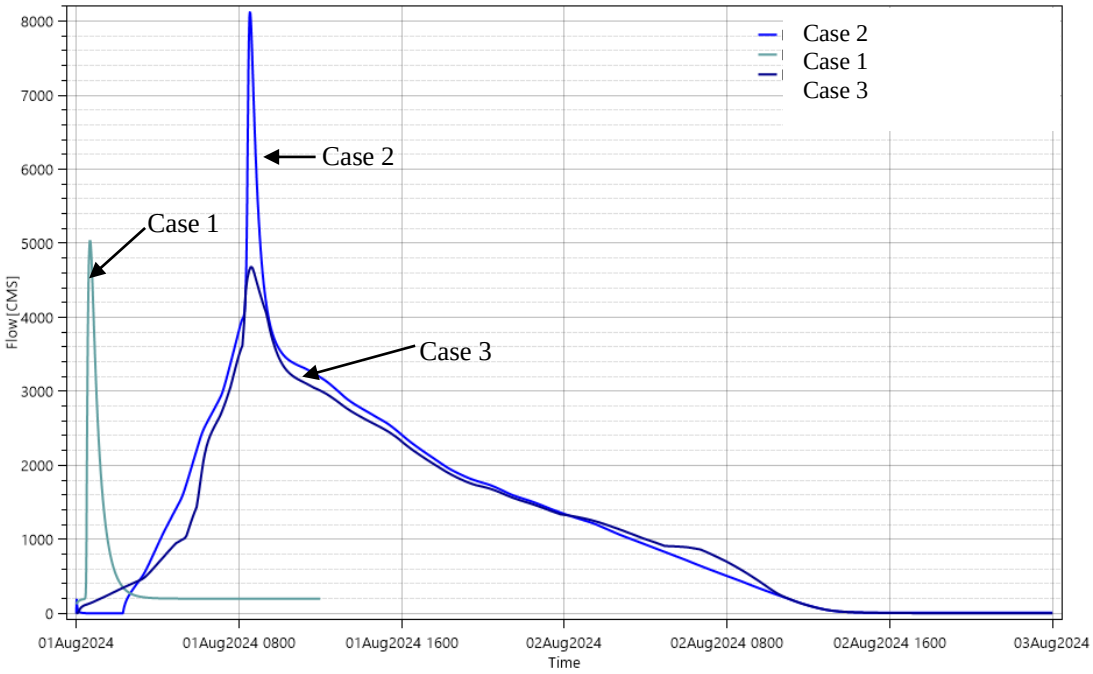


Figure 4. Breach Flow hydrograph for Breach FRL, PMF and With Mekong case

- Case 4 – Reservoir is at Full storage level and gates stuck due to technical error during PMF impinging and Mekong flowing at high flood levels - In this case it was considered that the spillway gates get stuck due to some technical error and while the reservoir water level is at FRL 272 m and 1 in 500-year flood is impinging on the reservoir and also Mekong flowing at high flood levels. This simulation would be helpful in understanding the spread of the reservoir and the maximum water level that can reach in the upstream of spillway during gate failure scenario. The maximum flow of around 3,995 Cumec was observed at 08:15 hrs. as shown in Figure 5. All gates were stuck hence gate flow is zero. Maximum water level realised just downstream of dam is 265.53 m whereas near the confluence of rivers, it was 263.44 m, due to the high-

water level in Mekong River. Maximum water levels at upstream and downstream observed was 281.84 m and 265.53 m respectively.

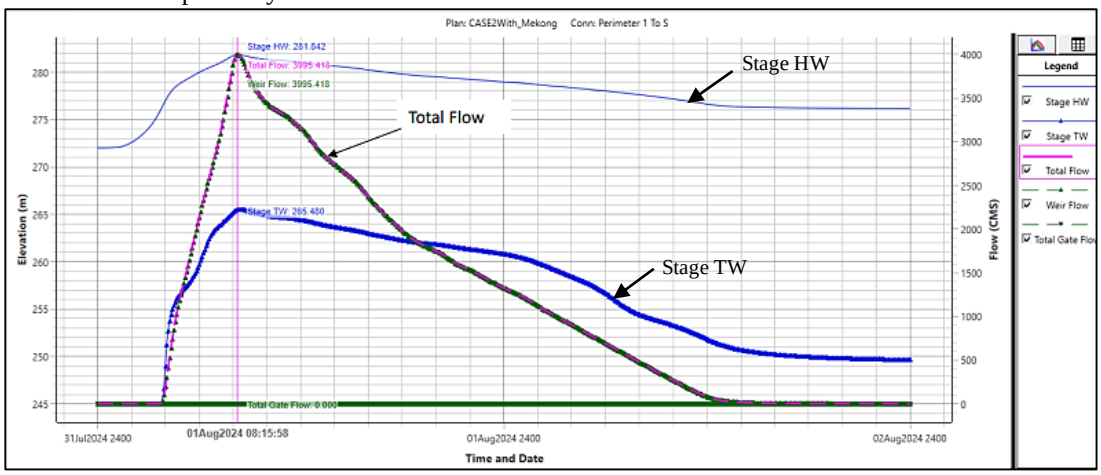


Figure 5. Total flow for case of PMF with Mekong flood and all gate stuck (Case 4)

4.1. Flood Routing

The studies were further carried out to evaluate the propagation of floods in the downstream river and its parameters such as time and discharge at various location along the river. The studies were carried out for four cases as mentioned above. The results of flood hydrographs across different cross section along the river profile for case 2 and 3 are shown in Figure 6 and 7. Water surface elevations along the river profile for case 2 and 3 are shown in Figure 8 and 9.

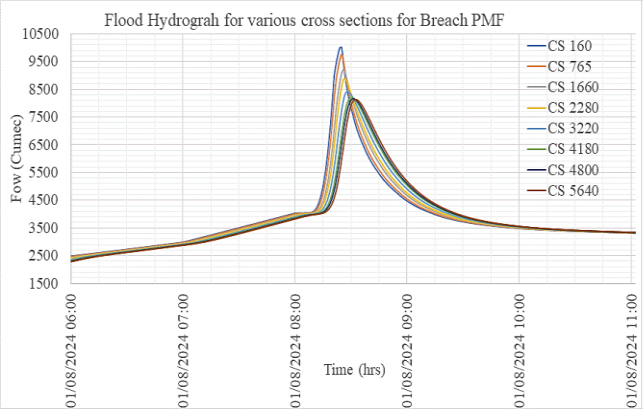


Figure 6. Flood Hydrograph for various cross sections breach PMF case (Case 2)

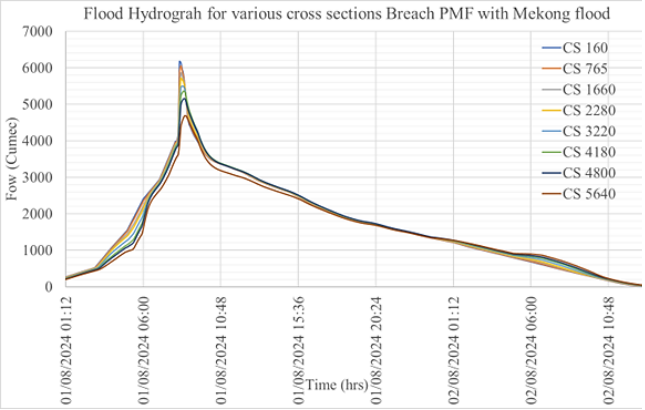


Figure 7. Flood Hydrograph for various cross sections breach PMF with Mekong flood (Case 3)

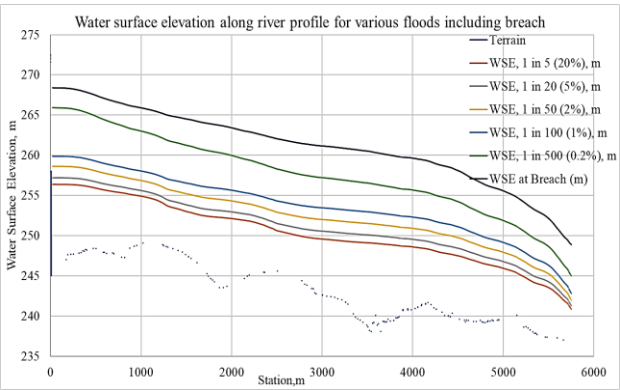


Figure 8. Water surface elevation along river profile for Breach PMF (Case 2)

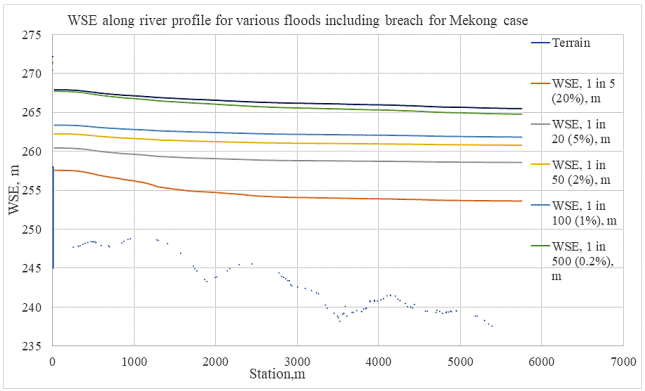
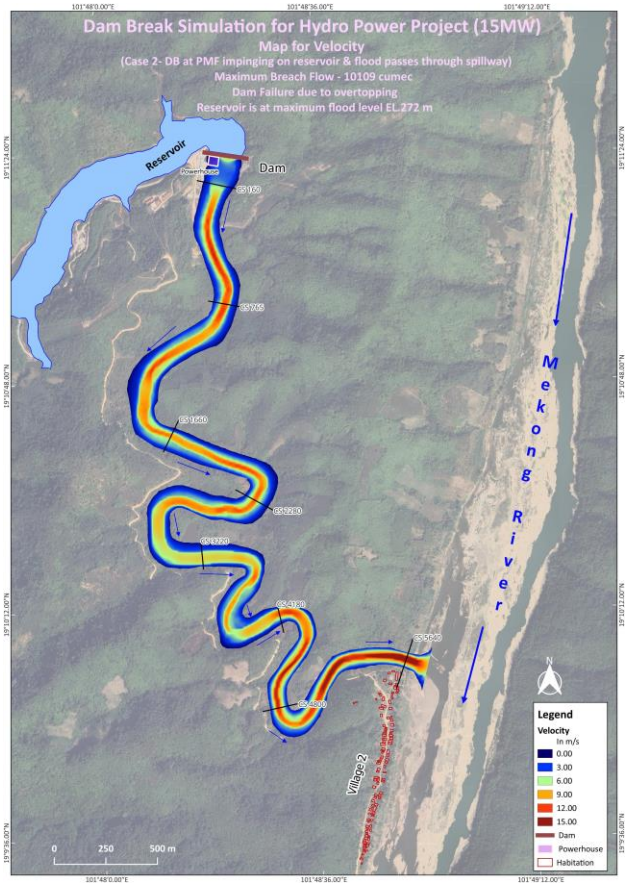


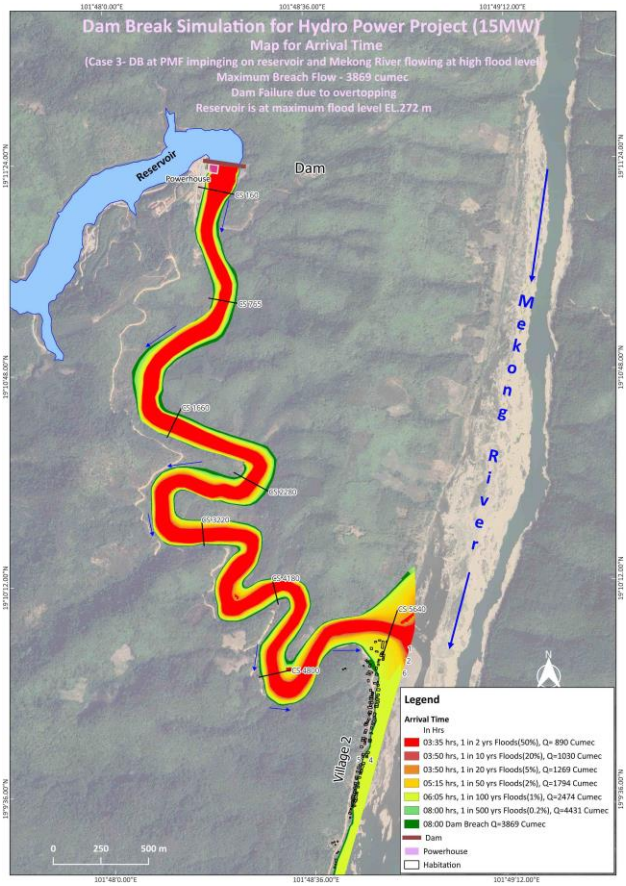
Figure 9. Water surface elevation along river profile for Breach PMF with Mekong flood (Case 3)

4.2. Flood Mapping

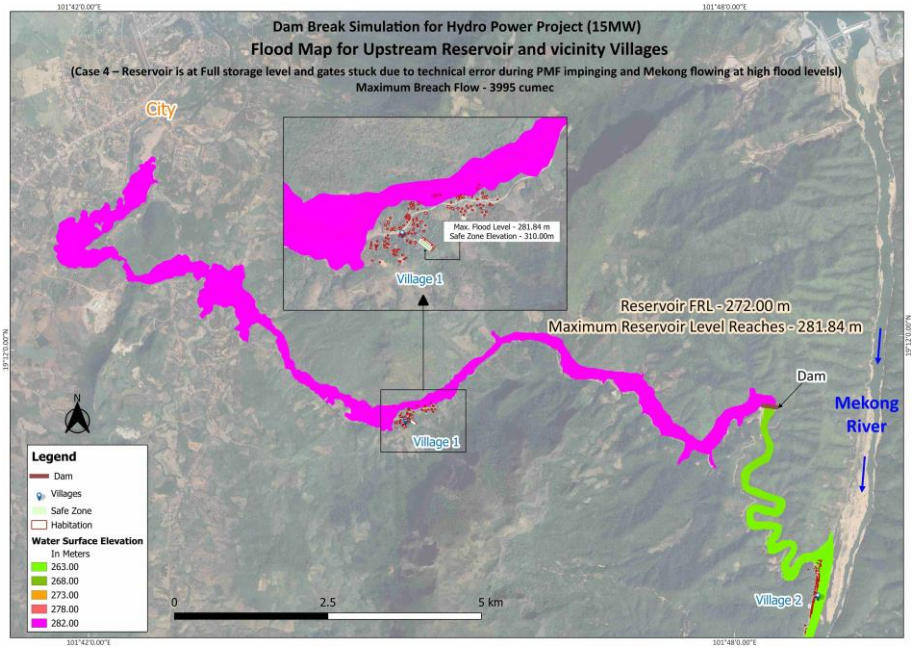
The results of dam breach were exported in GIS software and the maps were prepared for various scenarios. The water surface elevations, velocities, arrival times, receding times and the affected habitations are shown in Map 1 to 4.



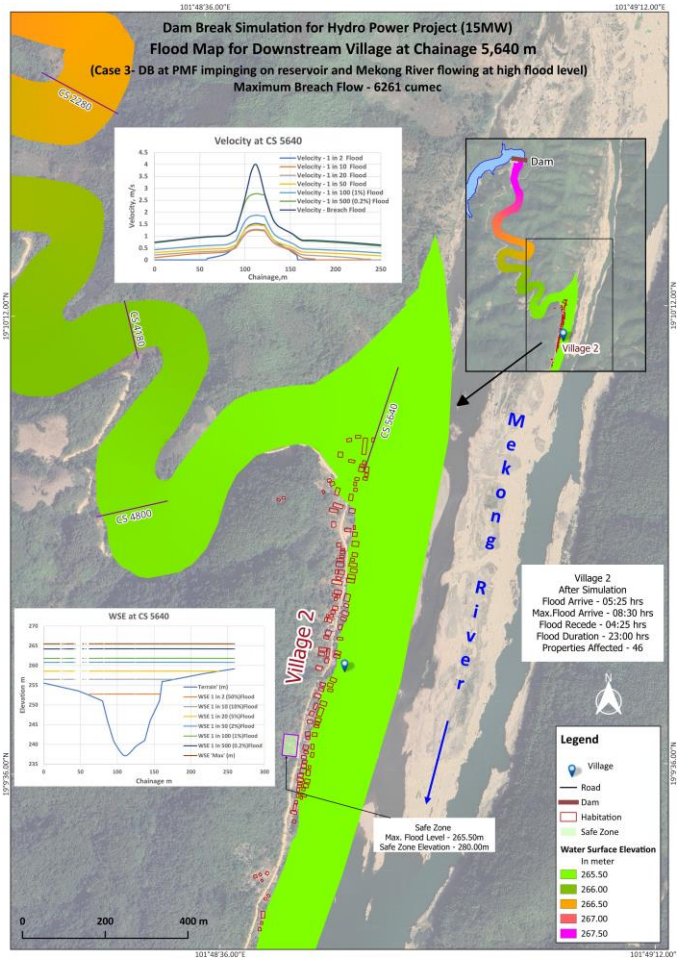
Map 1. Dam break at PMF during flood condition – Surface velocities in the river - Case 2



Map 2. Dam break at PMF during flood condition when Mekong is at high level – Arrival time in the river Case 3



Map 3. Flood mapping for upstream reservoir showing village and city located upstream- Case 4



Map 4. Flood mapping for village at confluence of rivers - Case 3

5. Discussion of results

Four different cases as mentioned earlier were considered for dam failure simulation. Case 2 is supposed to occur when a sudden flood condition occurs only in the tributary basin when the Mekong is flowing at its normal low discharge. Further the case 3 would occur when both Mekong and its tributary are having their PMF flood. In case 2 flow velocities in the tributary river would be higher and in case 3 the water levels would be very high in tributary as well as Mekong River. In all these cases the failure due to overtopping was considered. Further, the conditions for failure due to piping were also studied and not much difference was observed. Maximum breach flood during the fair-weather condition for case 1 was 6,259 m^3/s and while during the case 2 when PMF is impinging, it was considerably higher 10,109 m^3/s. Further in case 3 when PMF is impinging and Mekong is also flowing with high flood levels, it was again reduced 6,261 m^3/s owing to the very high-water levels in Mekong River. It was observed that breach flood reached from dam to confluence in about 40 to 45 mins in all the cases. Water levels near confluence were in the range of 247 to 250 m when Mekong was flowing at normal low flows, whereas when Mekong was also flowing at corresponding flood levels, the water levels near confluence reached the order of 268 m or so. There are habitations located on the right bank of Mekong River at average elevations of around 250 to 260 m, which are prone to submergence during such dam breach. Further studies showed that, it would take longer time more than 2 to 3 days; to deplete the entire reservoir and passage of entire flood downstream and moreover it depends on the water levels in Mekong River, which in turn depends upon the discharge released from the upstream dam.

As such there would be implications upstream of the dam where flood condition would persist for longer time. High velocities of the order of 10 to 12 m/s were observed in case 2, whereas it got reduced to less than 6 m/s or so for the case 3. For additional case 4 it was observed that maximum water level at reservoir tail on the upstream was 281.84 m and at downstream at confluence with Mekong the level was 263.45 m. At upstream village the water level observed was 281.84 m and around 8-9 houses got impacted by flood. And for downstream village maximum water level observed is 263.45 m and 9-10 houses get impacted by flood. Each of these villages which were prone to flooding were surveyed in detail for the collection of data such as population living in the houses, livestock, property details, agriculture and forestry details, and so on. The probable impacts of the dam breach were evaluated and the preparation of emergency action plan was carried out by government deputed agencies in Laos. The evacuation routes and safe zones as shown in Map 3 and 4 were also communicated to the various stakeholders. The mock drills were performed to intimate the appropriate agencies and start the evacuation process and a comprehensive rapid action plan was also prepared. The mock drills are supposed to be carried out every year as a part of emergency action plan.

6. Conclusion

The simulation of a dam breach revealed that flood discharge rates could range for different cases from 6,000 to 10,000 m^3/s, with breach velocities between 5 to 6 m/s, and the flood would reach the Mekong confluence in 40 to 45 minutes. Surface velocities in the tributary of Mekong River during such a breach could be between 6 to 12 m/s for various cases. Flood flow in the tributary is heavily influenced by downstream water levels in the Mekong River, making dam operations, particularly the outflow from the Dam situated to the upstream from confluence, crucial. If the spillway gates were to failure, simulation shows that with all five gates stuck during a 1 in 500-year flood (4,431 m^3/s), the reservoir water level would rise upto 281.84 m. The dam break analysis provided useful data and insights for preparing the emergency action plan for the project.

7. Acknowledgement

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