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INTEGRATED DAM BREAK ANALYSIS – CASE STUDY OF INDIRA SAGAR AND OMKARESHWAR PROJECTS

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ABSTRACT

The study of catastrophic flooding that may occur in the event of a dam failure is of great importance because of the risks to life and property in the potentially inundated reaches below the dam structure. In many a cases, such risks are compounded owing to the possibilities of cascading dam failures. Occurrence of cascading disasters, though very rare, have drawn attention to the requirement of conducting integrated dam break analysis of such closely placed projects that are liable for cascading effects. The integrated dam break analysis for the hypothetical cascading failure scenario, however remote they may be, are required in order to assess probable damages and also to plan necessary measures for mitigating the losses.

The integrated dam break study – even when carried out with the latest mathematical models and improved data – falls largely in the realm of predictions based on the set of assumptions made for the study. The predicted outcome are the flood hydrograph of discharge from the dam breaks and the propagation parameters of the flood waves, which can be suitably utilized for identification of the inundated area, flood depth, flow velocity and travel time of the flood waves.

This paper presents a case study of the dam break analysis for the Indira Sagar project and the Omkareshwar project on river Narmada for the hypothetical scenarios of their failures in isolation, and in cascading mode. The study, involving mathematical dam break simulation for the varied modes of failure of two dams, was carried out by Central Water Commission for the Narmada Hydroelectric Development Corporation. Besides detailing the model setup and procedure of the study, the paper also dwells into limitations of data, assumptions entailed, and the outcome of the study.

1.0 INTRODUCTION

Dam break may be summarised as the partial or total failure of a dam leading to the uncontrolled release of water. Such an event can have a major impact on the land and communities downstream of the failed structure. A dam break may result in a flood wave up to tens of metres deep travelling along a valley at quite high speeds. The impact of such a wave on developed areas can be sufficient to completely destroy infrastructure such as roads, railways and bridges and to demolish buildings. With such destructive force comes an inevitable loss of life, if advance warning and evacuation is not affected. Additional features of such extreme flooding include movement of large amounts of sediment (mud) and debris along with the risk of distributing pollutants from any sources such as chemical works or mine workings in the flood risk area.

Though there have been great advancements in design methodologies, failures of dams and water retaining structures continue to occur. These, not so infrequent instances of dam breaks, establish that hazard posed by dams, large and small alike, is very real. As public awareness of these potential hazards grows, and tolerance of catastrophic environmental impact and loss of life reduces, managing and minimising the risk from individual structures is becoming an essential requirement rather than a management option.

The first European Law on dam break was introduced in France in 1968 following the earlier Malpasset Dam failure (1959) that was responsible for more than 400 casualties. Since then many countries have also established dam break study requirements and in others, dam owners have established guidelines for such assessments. In India also the areas of risk assessment studies and Emergency Action Plan (EAP) are increasingly being considered as vital, and these may get further emphasized with the formulation of Central Dam Safety Act in near future.

The objective of dam break modelling is to simulate the movement of a dam break flood wave along a valley or any area ‘downstream’ that would flood as a result of dam failure. The key information required at any point of interest within this flood zone is generally: time of first arrival of flood water; peak water level – allowing an idea of extent of inundation; time of peak water level; depth and velocity of flood water - allowing estimation of damage potential; and duration of flooding. Evidently, the nature, accuracy and format of information desired from a dam break analysis will be influenced by the end application of the data.

2.0 DAM BREAK MODELLING CASE STUDY

Dam break modelling can be carried out in most cost effective manner through mathematical simulation. The one dimensional modelling was adopted in the present study involves dam break scenario of ISP and OSP in isolation and also in cascading mode. The essence of dam break modelling is hydrodynamic modelling, which involves finding solution of two partial differential equations originally derived by Barre De Saint Venant in 1871. In the instant case, MIKE 11 model developed by Danish Hydraulic Institute has been selected because of its wide acceptability in India and abroad.

2.1 Indira Sagar Project (ISP)

Indira Sagar Project is a multipurpose project on Narmada River, located at East Nimar, Khandwa district of Madhya Pradesh. The project consists of 92 m high, 653 m long concrete gravity dam. The surface power house has installed capacity of 1000 MW. The FRL, MWL and MDDL of the reservoir are at El. 262.13 m, El. 263.35 m and 243.23 m respectively. The spillway with its crest at El. 245.13 m consists of 20 radial gates of size 20 m (W) x 17 m (H) each. The Probable Maximum Flood (PMF) is 83,534 cumec.

2.2 Omkareshwar Project (OSP)

Omkareshwar Project is an important multipurpose project on Narmada river, located at East Nimar, Khandwa district of Madhya Pradesh. OSP is located in between Indira Sagar Project and MaheShwar Project. Index map showing location of Indira Sagar, Omkareshwar and Maheshwar Project is given below (Fig.1). The project consists of 53 m high, 949 m long concrete gravity dam. The surface power house has installed capacity of 520 MW. The FRL, MWL and MDDL of the reservoir are at El. 196.60 m, El. 199.62 m and El. 193.54 m respectively. The spillway with its crest at El. 179.60 m consists of 23 radial gates of size 20 m (W) x 18.04 m (H) each. The Probable Maximum Flood (PMF) is 88,315 cumec.

Fig.1: Index map showing location of Indira Sagar, Omkareshwar and Maheshwar Project

2.3 Data for Case Study

Dam break flood analysis requires a range of data to depict accurately to the extent possible the topography and hydraulic conditions of the river course and dam break phenomenon. The important data that has been used in the study are: cross sections of the river from ISP dam site to Maheshwar dam site at interval varying from 0.75 km to 2.5 km; elevation-surface area relationship of the ISP and OSP reservoirs; rating curve of ISP and OSP spillways; salient features & rating curve of spillway of Maheshwar Project; and design flood, i.e., Probable Maximum Flood hydrograph (PMF) for ISP and OSP. The MIKE 11 model was set up using input data as supplied by the Narmada Hydroelectric Development Corporation Ltd. (NHDC).

2.4 Dam Breach Parameters & Sensitivity Analysis

Assuming that a dam fails, the important aspects to deal with its effect are: time of failure; extent of overtopping before failure; and size, shape and time of the breach formation. Estimation of the dam break flood will be governed by these parameters. Prediction of the dam breach parameters and timing of the breach are very important for any dam break study, though they are extremely difficult to predict. The predominant mechanism of breach formation is, to a large extent, dependent on the type of dam and the cause due to which the dam gets failed. Hence the breach parameters are required to be judiciously assumed on the basis of information available for the concerned dam and some of the guidelines that are available internationally.

As per the UK Dam Break Guidelines, in the case of concrete gravity dams, the breach width should be taken less than 0.5 times the crest length of the dam. The breach development time for gravity dam should be about 0.2 hour. The breach depth for such dam can be taken corresponding to the relatively weaker locations in the dam such as galleries etc. In view of the above and other similar case studies, different scenarios of dam breach parameters - four for ISP dam break and four for OSP dam break - have been identified for sensitivity analysis. The worst-case scenario of ISP and OSP are then taken up for the integrated study. In all cases, breach section is assumed to be rectangular with side slope being zero. In all these cases, the initial breach level has been considered corresponding to the top of dam (i.e. at EL 267.0 m for ISP and at EL 203.0 m for OSP). The final breach level has been taken corresponding to the level of the galleries.

As an academic exercise, a separate simulation of the model has also been carried out for an assumed virgin river scenario due to occurrence of PMF. For this purpose a different model set up has been created without considering the ISP, OSP and Maheshwar dam; and the results of simulation have been compared with the isolated and integrated dam break scenarios.

3.0 DAM BREAK ANALYSIS OF ISP

For dam break study of ISP, the Narmada river has been represented in two parts: (i) Narmada_ISP-OSP branch, which covers a length of 42.478 Km of Narmada river downstream of ISP up to OSP dams and (ii) Narmada_OSP-MSP branch, which covers a length of 53.267 km of Narmada river downstream of the Omkareshwar Project (OSP) dam site up to the Maheshwar Project (MSP) dam. The reservoir and the spillway have been represented by separate branches in the model. The reservoir has been represented by area corresponding to different elevations and the dam has been placed in the reservoir branch incorporating requisite details of dam (i.e. length, top level etc) in the dam break structure. The spillway is specified as a special weir in the spillway branch with discharges at different water levels. The upstream boundary for dam break model is the design flood hydrograph –with PMF to be impinged at the reservoir. Since OSP is merely a control structure, the discharges through the OSP spillway at different levels are assumed for fully open condition of all gates. The end control structure has also been specified as special weir placed at Maheshwar dam site. The downstream boundary is applied as Q-h relationship at a location 10 km d/s of Maheshwar dam site. The complete MIKE11 model set up for the entire stretch is given schematically in Fig-2 below:

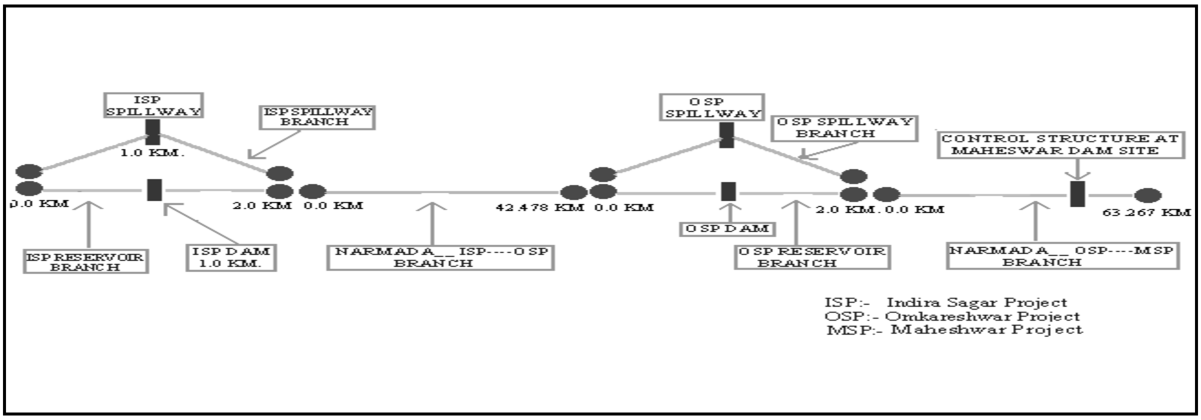

Fig-2: Model set up for Dam break study

The critical condition for ISP dam break study will be when the ISP reservoir is at FRL and design flood hydrograph (PMF) is impinged. Accordingly, in this study, first the reservoir routing has been carried out by impinging the PMF in to the ISP reservoir, assuming that the water level in ISP reservoir is at FRL of 262.13 m and all gates have been opened up for incoming flows above this level. The maximum water level reached in the reservoir due to application of flood hydrograph is 263.33 m, which occurs 88 hours and 20 minutes after the application of flood hydrograph. As the top of the ISP dam is at El 267m, no overtopping of the dam will occur. For the hypothetical case of ISP dam breach, it has been assumed that the dam will breach when the water level in the reservoir reaches 263.33 m level. The breach parameters considered for sensitivity analysis for the different case scenarios along with the results of simulation are summed up in Table-1 below:

Table-1

Simulation results for different breach scenarios of ISP dam

Scenario No.	Breach description	Breach parameters					Simulation results	
		Breach Level (m)		Breach Width (m)	Breach depth (m)	Breach Develop Time (Min)	Max. Disch. through breach (Cumec)	Max. Disch. just d/s of OSP dam (Cumec)
		Initial	Final					
1.	Two non-over flow blocks considered to breach till inspection gallery level at El 230 m at 88 hours and 20 minutes after the occurrence of PMF	267	230	44	37	10	11455	76293
2.	The 6 spillway blocks considered to breach till inspection gallery level at El 230 m at 88 hours and 20 minutes after the occurrence of PMF	267	230	150	37	10	39059	103236
3.	The 10 spillway blocks considered to breach till inspection gallery level at El 230 m at 88 hours and 20 minutes after the occurrence of PMF	267	230	250	37	10	65112	128122
4.	The 3 spillway blocks considered to breach till inspection gallery level at El 210 m at 88 hours and 20 minutes after the occurrence of PMF	267	210	75	57	10	39524	103898

It can be seen that scenario no. 3 of sensitivity analysis of ISP (i.e. breach width 250m, breach depth 37 m and breach development time of 10 minutes) gives maximum discharge, and hence, adopted for further analysis. The peak discharge through ISP dam breach for this condition is 65,112 cumec, which occurs 10 minutes after the start of the breach. The combined discharge of dam breach and spillway just downstream of ISP dam is 1, 28,122 cumec. Time series of discharge through breach and combined discharge through breach & spillway just d/s of ISP are given in Plate-1. The longitudinal profile showing maximum water level for PMF and dam breach condition is given in Plate -2.

4.0 DAM BREAK STUDY OF OSP WITHOUT CONSIDERING ISP:

In this case, only OSP dam and its downstream valley till the Maheshwar dam has been considered for the study. Impingement of PMF is simulated directly in the OSP reservoir and existence of ISP dam has been ignored.

The critical condition for OSP dam breach will be when the OSP reservoir is at FRL and design flood hydrograph (PMF) is impinged. Accordingly, in this study, first the reservoir routing has been carried out by impinging the PMF to the OSP reservoir, assuming that the water level in reservoir is at FRL of 196.60 m and all gates have been opened up for incoming flows above this level. The maximum water level reached in the OSP reservoir due to application of flood hydrograph is 200.86 m, which occurs 80 hours and 30 minutes after the application of flood hydrograph. As the top of the dam is at El 203 m, no overtopping of the dam will occur. For hypothetical case of dam breach, it has been assumed that the dam will breach when the water level in the reservoir reaches 200.86 m level. The breach parameters considered for sensitivity analysis for the different case scenarios along with the results of simulation are summed up in Table-2 below:

Table-2

Simulation results for different breach scenarios of OSP dam

Scenario No.	Breach description	Breach parameters					Simulation results	
		Breach Level (m)		Breach Width (m)	Breach depth (m)	Breach Develop Time (Min.)	Max. Disch. through breach (Cumec)	Max. Disch. just d/s of OSP dam (Cumec)
		Initial	Final					
1.	The 8 spillway blocks including five diversion sluices spillway blocks considered to breach till sluice level at El 161 m at 80 hours and 30 minutes after the occurrence of PMF	203	161	200	42	10	67870	119073
2.	The 10 spillway blocks including five diversion sluices spillway blocks considered to breach till level at El 161 m at 80 hours and 30 minutes after the occurrence of PMF	203	161	250	42	10	84791	128057
3.	8 blocks of Power Dam considered to breach till level at El 173 m at 80 hours and 30 minutes after the occurrence of PMF	203	173	212	30	10	42033	120859
4.	12 spillway blocks considered to breach till inspection gallery level at El 170 m at 80 hours and 30 minutes after the occurrence of PMF	203	170	300	33	10	69293	107174

It can be seen that scenario no. 2 of sensitivity analysis of OSP (i.e. breach width 250m, breach depth 42 m and breach development time 10 minutes) gives maximum discharge, and hence, adopted for further analysis. The peak discharge through the breach for this condition is 84,791 cumec, which occurs 10 minutes after the start of the breach. The combined discharge of dam breach and spillway just downstream of the dam is 1,28,057 cumec. Time series of discharge through breach and combined discharge through breach & spillway just d/s of OSP are given in Plate -3. The longitudinal profile showing maximum water level for PMF and dam breach condition is given in Plate -4.

5.0 INTEGRATED DAM BREAK STUDY OF ISP AND OSP:

This study follows the same model setup of ISP. Only difference in this case is that the occurrence of OSP dam breach is also considered. The OSP dam breach occurs due to the combined outflow of the ISP spillway, ISP breach (for a breach width of 250 m and breach depth of 37 m) and PMF for the intermediate catchment between ISP and OSP Dams.

The critical condition for this integrated dam break study will be when the ISP, OSP and Maheshwar reservoirs are at FRL and design flood hydrograph (PMF) is impinged on ISP and the contribution corresponding to PMF for intervening catchment above OSP. Accordingly, in this study, first the reservoir routing has been carried out by impinging the PMF into the reservoir, assuming that the water level in ISP, OSP and Maheshwar reservoirs are at FRL of 262.13 m, 196.60 m and 162.76 m respectively. The maximum water level reached in the ISP reservoir due to application of above flood hydrograph is 263.33 m, which occurs 88 hours and 20 minutes after the application of flood hydrograph and at this time ISP will breach carrying a maximum discharge of 1,28,122 cumec just d/s of ISP because of the combined effect of breach and spillway discharge. The maximum water level in the OSP reservoir due to ISP dam breach is 204.26 m which occurs at 91 hours and 20 minutes after the application of flood hydrograph in ISP reservoir. The top of the OSP dam is at El 203 m; hence the dam will fail due to overtopping. For hypothetical case of dam breach, it has been assumed that the OSP dam will breach only when the water level in the reservoir reaches 204.26m, which is 1.26 m above the top of OSP dam. The results of above simulation are summarized in Table-3 below:

Table-3

Simulation results of integrated breach of ISP and OSP dam

Breach description	Breach parameters					Simulation results	
	Breach Level (m)		Breach Width (m)	Breach depth (m)	Breach Develop Time (Min.)	Max. Disch. through breach (Cumec)	Max. disch. just d/s of OSP dam (Cumec)
	Initial	Final					
FOR ISP DAM BREACH							
The 10 spillway blocks considered to breach till inspection gallery level at El 230 m at 88 hours and 20 minutes after the occurrence of PMF	267	230	250	37	10	65112	128122
FOR OSP DAM BREACH							
The 10 spillway blocks including five diversion sluices spillway blocks considered to breach till level at El 161 m at 91 hours and 20 minutes after the occurrence of PMF	203	161	250	42	10	92126	137685

It can be seen that the combined discharge of ISP and OSP dam breach and spillway just downstream of the OSP dam is 1,37,685 cumec. Time series of discharge through breach, and breach & spillway just d/s of OSP are given in Plate -5. The longitudinal profile showing maximum water level for PMF and dam breach condition is given in Plate -6.

6.0 OUTCOME OF THE INTEGRATED STUDY

6.1 <u>Dam break of ISP in isolation</u>

- The peak discharge through ISP dam breach is 65,112 cumec and the combined discharge of ISP dam breach and spillway just downstream of the ISP dam is found to be 1, 28,122 cumec. The flood wave takes about 3 hours to travel a river reach of 42.478 km to OmkareShwar Project.

- The increase in maximum water level due to ISP dam breach in comparison to 'no ISP dam-breach condition' along the river reach from Indira Sagar Project site to OmkareShwar Project site varies from 6.05 m to 8.55 m. The corresponding variation from Omkareshwar Project site to Maheshwar Project site is 4.0 m to 6.0 m.

- The increase in maximum water level due to ISP dam breach in comparison to occurrence of PMF in the virgin condition of Narmada river (considering no ISP and OSP dam) along the river reach from Indira Sagar Project site to OmkareShwar Project site varies from 4.39 m to 17.16 m. The corresponding variation from Omkareshwar Project site to Maheshwar Project site is 2.19 m to 3.77 m.

6.2 Dam break of OSP in isolation

- The peak discharge through the OSP dam breach is 84,791 cumec and the combined discharge of dam breach and spillway just downstream of dam is found to be 1,28,057 cumec. The flood wave takes about 3 hours 30 minutes to travel a river reach of 53.267 km to MaheShwar Project.

- The increase in maximum water level due to OSP dam breach in comparison to 'no OSP dam-breach condition' along the river reach from Omkareshwar Project site to Maheshwar Project site varies from 3.48 m to 5.26 m.

- The increase in maximum water level due to OSP dam breach in comparison to occurrence of PMF in the virgin condition of Narmada river (considering no ISP and OSP dam) along the river reach from Omkareshwar Project site to Maheshwar Project site varies from 0.72 m to 4.32 m.

6.3 Integrated Dam Breaks of ISP and OSP

- The peak discharge through the OSP dam breach (considering ISP dam has breached) is 92,126 cumec and the combined discharge of OSP dam breach and spillway just downstream of OSP dam is found to be 1,37,685 cumec. The flood wave takes about 2 hours 40 minutes to travel a river reach of 53.267 km to MaheShwar Project.

- The increase in maximum water level due to integrated ISP and OSP dam breach in comparison to 'no dam-breach condition' (i.e. considering no dam-breach of ISP and OSP) along the river reach from OmkareShwar Project site to MaheShwar Project site varies from 4.78 m to 8.85 m.

- The increase in maximum water level due to integrated ISP and OSP dam breach in comparison to occurrence of PMF in the virgin condition of Narmada river (i.e. considering no ISP and OSP dam) along the river reach from OmkareShwar Project site to MaheShwar Project site varies from 2.97 m to 6.62 m.

- The increase in maximum water level due to integrated ISP and OSP dam breach in comparison to OSP dam breach in isolation along the river reach from OmkareShwar Project site to MaheShwar Project site varies from 0.34 m to 1.48 m.

7.0 DISCUSSION AND CONCLUSION

Modelling process is nothing but approximation of a physical phenomenon through which the physical phenomenon and its effects can be studied. Thus, as in the case of any other modelling process, dam break modelling has inherent approximations through assumptions. The foremost assumptions are in the hydrodynamic equations (Saint Venant's equations) like incompressibility and homogeneity of water, sub-critical flow, large wave lengths etc. The uncertainties associated with the breach parameters, especially breach width and breach development time also cause uncertainty in flood peak and arrival times. There is also uncertainty associated with volume losses incurred by the flood as it propagate downstream and inundates large flood planes where infiltration and detention storage losses may occur. Such losses are difficult to predict. Further the high velocity flows associated with dam break floods can cause significant scour of alluvial channels. This enlargement in channel cross section is neglected since the equations for sediment transport, sediment continuity, dynamic bed form friction etc. are not included among the governing equations. Further, the narrow channels with minimal flood planes are subject to over estimation of water elevation due to significant channel degradation.

Even with the inherent assumptions and limitations, the integrated dam break study of ISP and OSP upto the Maheshwar dam provides a sound indication of floods effects that are expected in the downstream reaches. However, these effects are required to be translated in terms of estimation of inundation areas, which in turn shall be used for the formulation of Emergency Action Plan (EAP). Since MaheShwar dam is placed immediately downstream of OSP, it may be natural progression to carry out the dam break analysis of Maheshwar, in integration with ISP and OSP dam breaks; and such a study is recommended.

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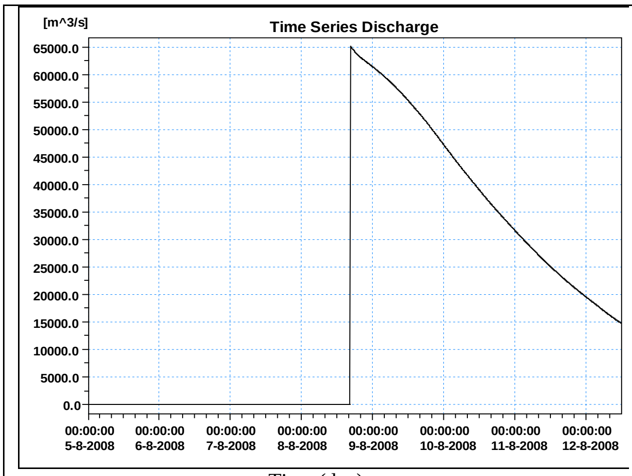
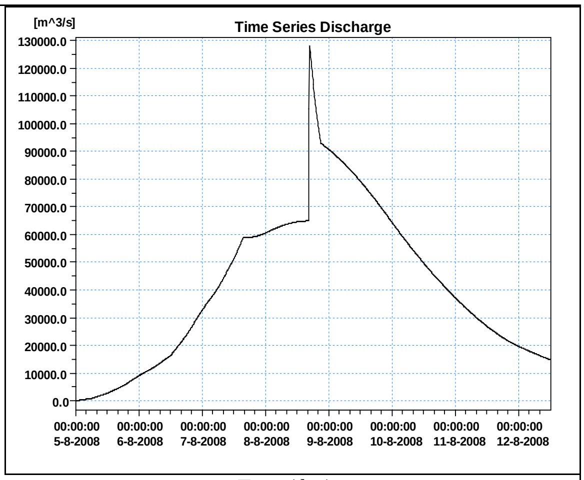
NOTE: The view expressed in the paper may not necessarily belong to the organization which the authors represent.

PLATE-1

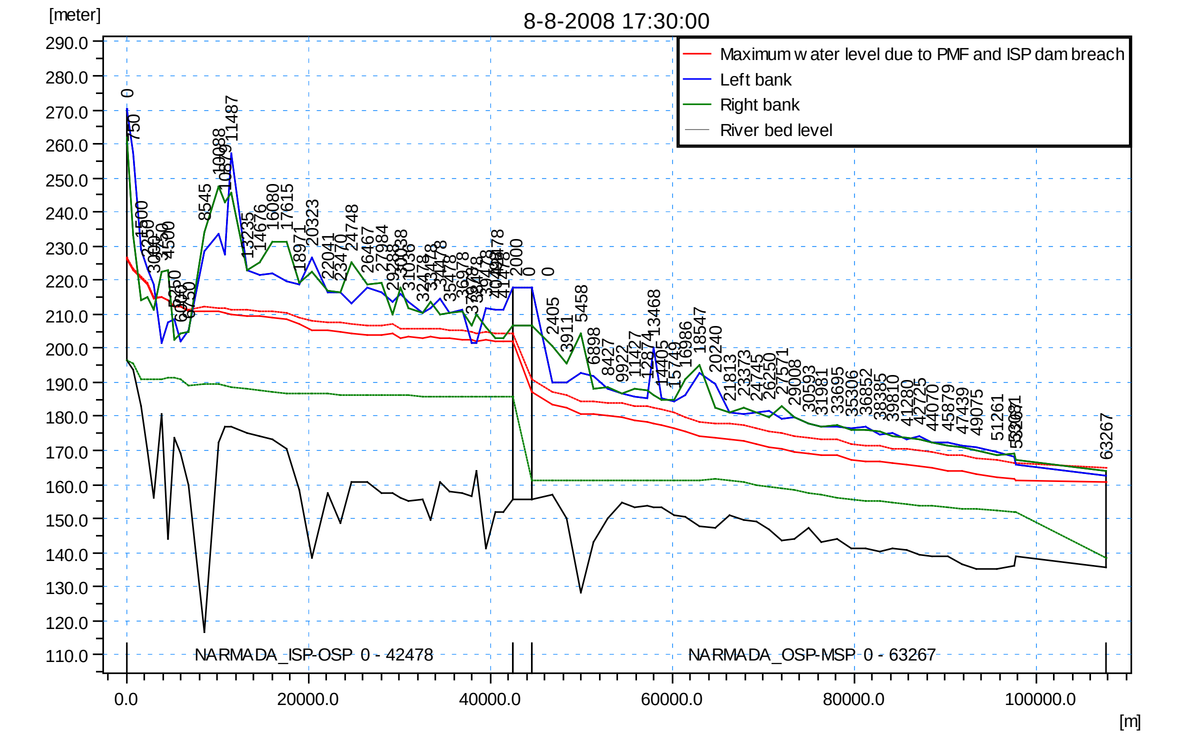


Discharge through breach section of ISP



Combined discharge through breach section and spillways just d/s of ISP dam

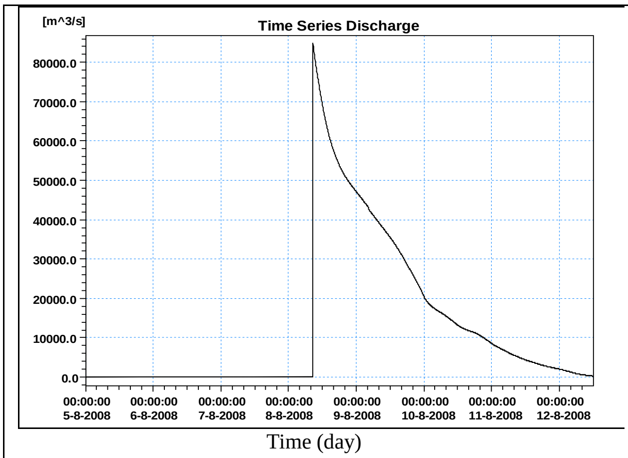
PLATE-2

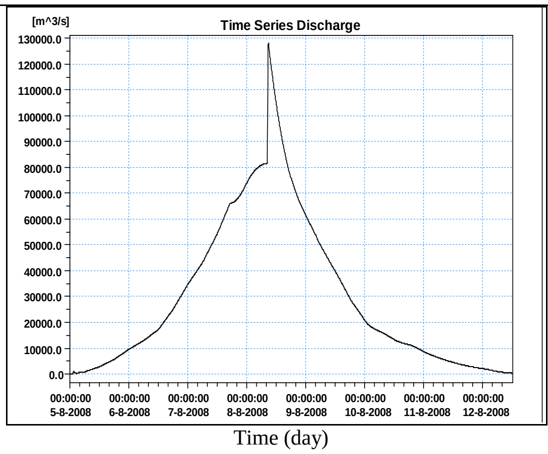


Longitudinal profile showing max. water level for PMF and ISP dam breach condition

Note: All dates are arbitrarily assumed for study purpose only

PLATE-3

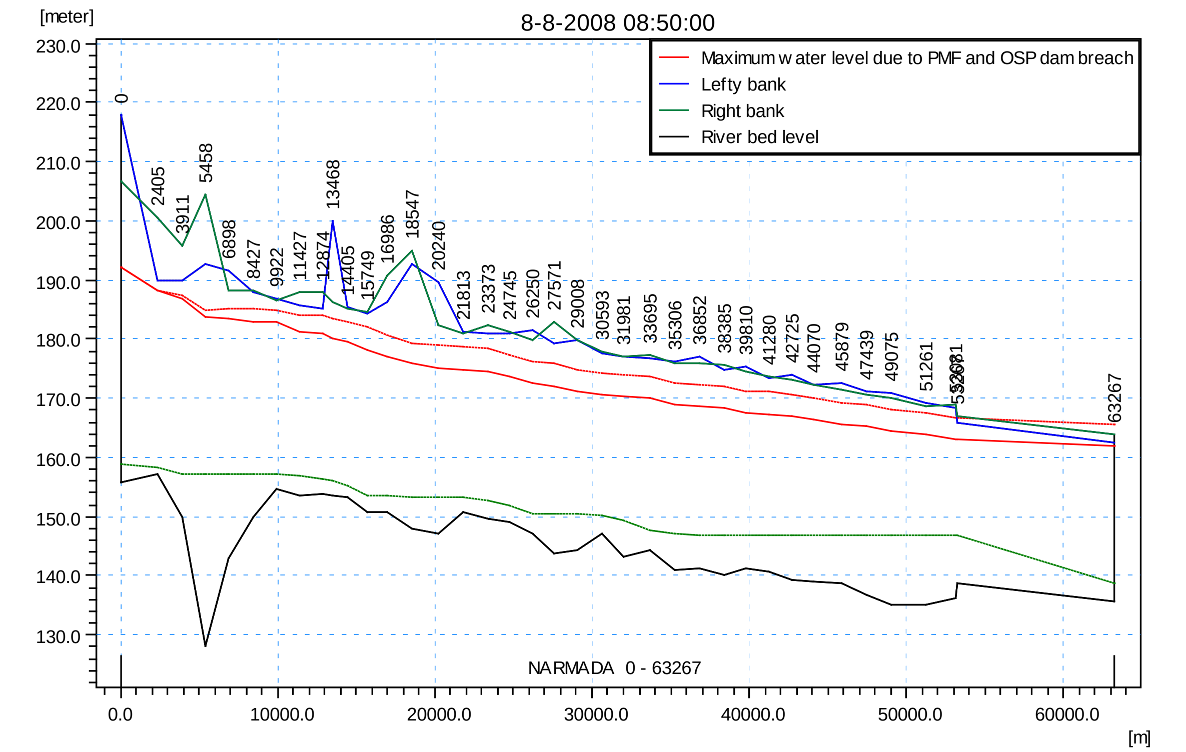




Discharge through breach section of OSP in isolation

Combined discharge through breach section and spillways just d/s of OSP dam in isolation

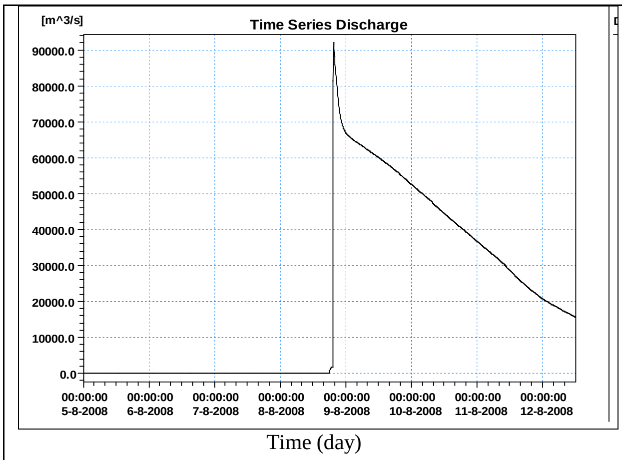
PLATE-4

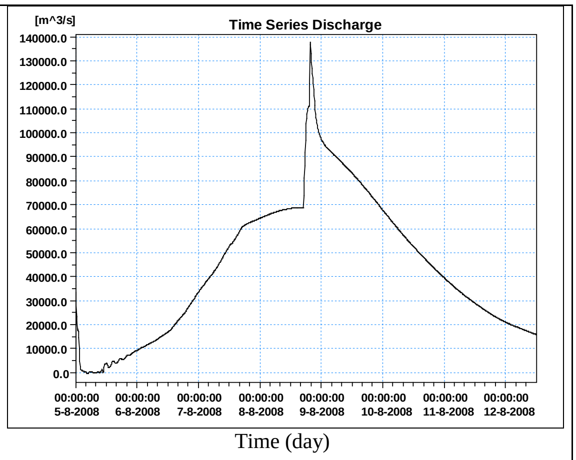


Longitudinal profile showing max. water level for PMF and OSP dam (in isolation) breach condition

Note: All dates are arbitrarily assumed for study purpose only

PLATE-5

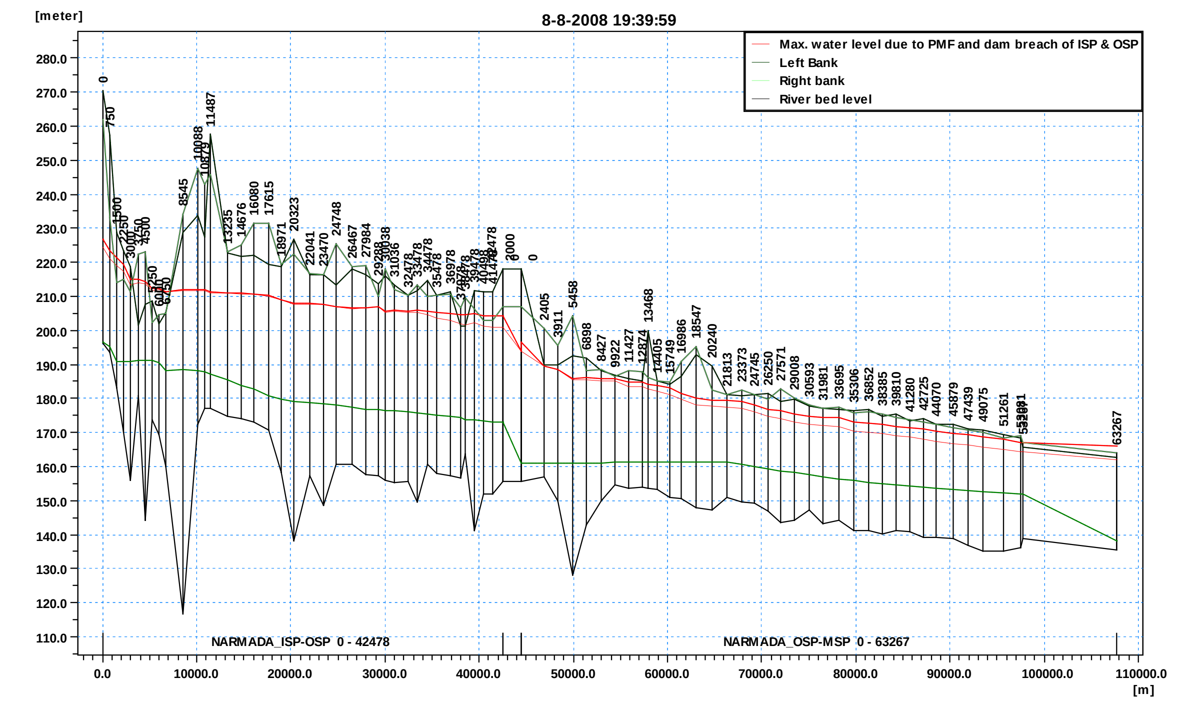




Discharge through breach section of OSP in integration with ISP breach

Combined discharge through breach section and spillways just d/s of OSP dam in integration with ISP breach

PLATE-6



Longitudinal profile showing max. water level for PMF and dam breach of ISP and OSP dams

Note: All dates are arbitrarily assumed for study purpose only