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Research Article

Development of Safety Management Plan for Identified Floods using HEC-RAS

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Abstract

Floods have been recurrent phenomenon in India and cause huge losses to properties, livelihood system, lives, infrastructure and public utilities. India's high risk and vulnerability is highlighted by the fact that 40 million ha out of a geographical area of 3290 lakhs ha is prone to floods. On an average every year, 75 lakh ha of land is affected, 1600 lives are lost. The damage to crops, houses and public utilities due to floods amounts to about Rs.1805 crore (1). The frequency of major floods is more than once in five years. Floods have also occurred in areas, which were earlier not considered flood prone. It has been recognised that, while floods cannot be prevented, they can certainly be managed to minimise loss. Immediate preventive actions should be taken to minimise the floods. Safety plan for river passing through populated city is proposed in three steps. Floods are identified in first stage and routed along river in second stage to delineate inundation area. Safety management plan is presented in third stage that would minimize the damages. Application of the method for a river in urban area is presented.

Keywords: *Flood Identifications, Routing of Flood, Inundation Area, and Safety Plan.*

1. Introduction

Floods of varying magnitudes result from different rainfall patterns affect properties, infrastructures, public utilities and planned development activities in the country. Encroachment on flood plains adds to serious flood damages and loss of lives. Yearly fluctuations arise regarding onset of the monsoon and area not traditionally prone to flood also experience severe inundation. Population living in vicinity of flood plains have feeling of insecurity and fear. Cause of flood may be natural or manmade. In India major causes of floods are intensive precipitation, inadequate capacity of river channel to contain high flows as well as silting of river beds. Other major factors for flood include landslides that lead to obstruction of flow and change in river course, poor natural drainage, snowmelt, glacial outbursts, dam break flow and retardation of flow due to tidal and backwater effect.

Dam failure creates Mega-Disaster as the flood is accompanied with huge loss of life and damages to property. Unlike natural floods, disastrous effect is due to unusual high peak flow attained in short duration and moving hydraulic shock. In order to minimize the damages, various protective measures are to be taken. The measure depends on type of flood, local site conditions, extent of affected area and availability of expert and financial resources.

Hence development of safety plan against identified floods is proposed in three phases viz. Flood Identification, Routing of Flood and development of Safety Plan. Case study of river in urban area is presented.

2. Literature review

The literature review is presented as per the stages of study described above.

2.1 Selection of Flood

A flood results in huge losses. Hydraulic structures are constructed to avoid damages due to flood. For designing any hydraulic structure, proper selection of design flood value is of great importance. Different structures are constructed across river mainly to regulate the flow of water, for carrying traffic, to depose off safely the flood water. These include culvert, causeway, bridges, weirs, barrages, culvert, and spillway.

Dam break studies are to be undertaken as an aid to determine the design flood. Where the professional judgement or studies indicate an imminent danger to present and future human settlements, dam break flood or the PMF could be used as a design flood. Table 2.1 presents the flood suggested by different guidelines for design of various structures.

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Table 2.1: Design Guidelines of Structures

Sr No	Structures	Design Discharge	Guidelines
1	Causeway	Which allows to flood pass over it	IRC:5-1998
2	Culvert	50 years frequency flood	IRC:5-1998
3	Bridges	50 years frequency flood	IRC:5-1998
4	Bridges	200 years frequency flood	AASHTO1993
5	Weir	50 years frequency flood	IS 6966 part-1:1989
6	Spillway	25 years frequency flood	IS 11223-1995
7	Spillway	50 to 100 years frequency flood	Guideline in Texas
8	Dam	100 years frequency flood	Swedish Guidlie,2007
9	Nuclear Power Plant	Dam Break Flood	U.S.NRC United States of America

These hydraulic structures are designed with appropriate floods keeping in view the susceptible damage and catastrophes created in the event of failure. Hence we have to think of a flood value for which structures should be safe. By reviewing the design flood guidelines / practices and Irrigation Department manual following floods are selected for the present studies,

1) 50 year return period flood
2) Spillway Design Flood
3) Dam Break Flood

2.2 Routing of Flood

Broad categories of flood routing include:

- Reservoir Routing [Hydrologic]
- Stream flow Routing [Hydraulic]

In hydrologic routing method continuity equation is used while in hydraulic routing method continuity equation with the equation of motion is used. Both of these equations are commonly referred as St. Venant's equations. Due to the complexities in equations, the numerical method is used for solution that utilises some approximations of flood wave propagations. Accordingly various models have been developed viz:

1) Empirical model
2) Linearized model
3) Simplified Hydraulic model
4) Dynamic wave Hydraulic model

Empirical models are based on Lag method and gauge relations. These have very limited applications and give best results when applied to slowly fluctuating rivers with negligible lateral inflows and back water effects.

Linearized Models use simplified form of the equation to obtain analytical solutions for velocity and water surface elevation. Here various sub-models are developed like classical wave model, simple impulse response model, complete and multiple linearized model. These models are not appropriate when back water effect exist due to the presence of tides, significant inflows, dams, bridges or cross section irregularities.

Simplified Hydraulic models are based on Kinematic models and Diffusion models. But in dynamic wave model complete St. Venant equation is used. Dynamic models can be classified as explicit or implicit depending up on method of solution. Explicit method transforms the differential equation into set of easily solvable algebraic equations. Implicit method transforms the differential equations into a set of simultaneous equations which may be either linear or nonlinear and require iterative method for solution.

2.2.1 Selection of Routing Models

Among the many models reviewed above, hydraulic model, based on solution of complete St. Venant equation is selected. The method has capability to simulate the widest spectrum of flow types and waterway characteristics over a variety of inline structures like levees, weir, low and high level bridges.

2.2.2 Applications of Routing Models

Doiphode Sanjay L, Oak Ravindra A : Sangli City, Maharashtra located in Upper Krishna basin that faces problems of floods and damages during monsoon, in every year. Many bridges over Krishna River get submerged, resulting cut off in communication, inundation of the city and surrounding area. [Doiphode Sanjay L,*et al*,2012]]

Mehdi Delphi: Two methods are applied for flood routing. First one is MIKE11 developed by Danish Hydraulic Institute (DHI) as a hydraulic numerical model. Second one is based on Method of characteristics that utilises simplified form of Kinematic wave solution for the length of 61 km of Karun River. [Mehdi Delphi , *et al* 2012]

P. Mirzazadeh, G. Akbari: In this study, two groups of finite difference numerical techniques i.e. Mc Cormack explicit scheme and Preissmann implicit scheme are utilised. MATLAB software is used with real river data. The results of these two schemes are compared with result of Mike 11 computer numerical model developed at (DHI). [P. Mirzazadeh,2012]

Mahessar, A. L. Qureshi, & A. Baloch: In this study, verification of results of the finite element model based two stepped semi implicit Taylor Galerkin technique has been carried out against available numerical predictions and field data. The proposed model has been applied to forecast daily discharges at Indus River for a reach between Guddu and Sukkur barrage of Sindh, Pakistan. [A. A. Mahessar *et al* 2013]

J. Szolgay, M. Danáčová, Z. Papánková: A nonlinear hydrologic routing model is proposed for the lower Morava River. It is based on a state-space formulation of a linear reservoir cascade model, which belongs to the class of lumped hydrological flow routing models.[

J. Szolgay,*et al* 2006]]: Fugang Xu,Hongwei Zhou, Jiawen Zhou, and Xingguo Yang : The proposed model can simulate the dam-break evolution process of all dike breach sizes for the Tangjiashan dammed lake which could possibly occur, the maximum discharge and the maximum water level on downstream are estimated. The model can provide support for decision-making by governments regarding lakes dammed due to landslide [Fugang Xu,*et al* 2012]].

2.3 Safety Plan

The safety plan is to provide information, policies, and procedures that will guide and assist in efficiently dealing with flood emergencies. When a flood watch is issued, all should be aware of potential flood hazards. Everyone in a Watch area should be ready to respond, act quickly and have an evacuation plan in place before flooding occurs.

Various measures, referred as flood control measures, are applied to minimise the losses due to inundation and these are employed either singly or in combination. The flood control measures are also termed as Flood Management Measures and can be planned either through structural measures or non-structural measures. Structural measures for Flood Management are physical in nature and aim to prevent flood water reaching the potential areas of damage, whereas non-structural measures strive to keep the people away from flood water.

Amongst the structural and non-structural measures available for flood management, the final or appropriate measure can only be decided after carrying out detailed hydrological and hydraulic studies duly considering favourable and adverse effect. The cost and topographical constraints are also to be considered in selection process.

3. Study area

The study area comprises of Khadakwasla Dam, Stretch of Mutha River up to Sangam Bridge. Khadakwasla dam, 1939 m long is constructed across Mutha River. The reservoir behind has total storage capacity of 374 Mm^3.

Mutha river is a right bank tributary of the Bhima River in main Krishna basin. The Mutha river originates in the main Sahyadri ranges in taluka Mulasi, District Pune. A stretch of Mutha river, 15 km downstream of Khadakwasla dam up to the Sangam Bridge is considered in the present study. Different structures like 12 bridges and two causeways are present in study area. Index map of study area is shown in Figure 3.1.

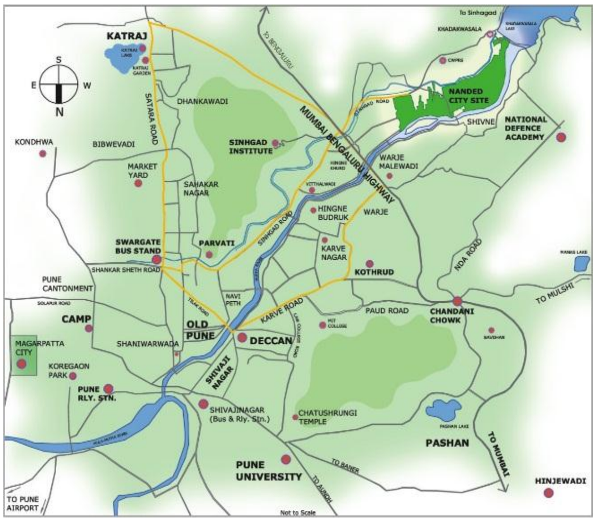

Figure 3.1: Index Map of Study Area

4. Data used and analysis

The data required for carrying out the studies were reviewed and request was sent to Department of Water Resources. The data used in the present study are given below:

a) Salient features of Khadakwasla Irrigation Project
b) Elevation area capacity table for Khadakwasla reservoir
c) Details of spillway like crest elevation, length and number of spans, shape of crest
d) Daily observed discharge (inflow and releases from) at dam and at Dattawadi site
e) Cross sections of river Mutha from dam site extending up site to Sangam bridge
f) Details of bridges like chainage, deck level, size and number of spans, piers, abutment spacing

Daily discharge data at Khadakwasla was reviewed and a series of annual maximum daily flow from 1976 to 2011 was extracted.

This data series was checked for continuity and consistency. Thereafter, the series was subjected to frequency analysis and floods with return period of 25, 50 and 100 year return period were derived using Gumbel and log Pearson distributions.

Cross section data were processed to make it compatible to HEC Format. Daily discharges at Dam site and Dattawadi were reviewed and three hydrographs as given below were selected as input for steady and unsteady simulation scenario. Peak discharge was selected for steady simulation.

Year	Hydrograph Selected		Peak Flow (m^3/s)	Water Level (m)
	From	To		
2005	7/27/05	8/7/05	1176.05	547.45
2006	8/5/06	8/12/06	1344.02	546.17
1997	8/20/97	8/28/97	2047.76	547.24
2004	8/9/04	8/20/04	1831.61	546.10

Details of bridges were available at three locations. These were used at other sites in absence of data by selecting nearest type of bridge from the available details for simulation.

5. Methodology

In order to minimise the damages due to floods, it is necessary to develop safety plan for identified river reach. Development of plan is carried out in three different steps viz

1) Selection of flood,
2) Routing of flood and
3) Development of safety plan

5.1 Selection of Flood

A review of structures within the study reach indicated that there is a variety of structures like bridge, weir and dam. Guidelines for arriving at design discharge of the structures were taken into consideration and floods referred in section 2 above were selected.

5.2 Routing of Flood

Routing of flood hydrograph is carried out to study change in shape of wave during the propagation along stream. Numerous models are reported in literature and the most appropriate model that has the capability to simulate the flow over the structures in the study area is to be selected for present study.

Thus, HEC-RAS model is selected as per the suitability to simulate the scenario under the prevailing conditions in the river reach.

Calibration of the model would be carried out using observed data and selected floods, mentioned in 4 above would be routed along the river reach. Results in the form of water level hydrographs at different locations would be used to identify the extent and duration of the submergence of the area of interest as well as time available at hand.

5.3 Development of Safety Plan

The extent of area that would need protection would be reviewed and suitable safety management plan would be derived.

6. Results and discussions

6.1 Derivation of Floods

By reviewing the floods as per the prevailing guidelines for design referred in 2.1 above and considering the situation experienced by the citizens in July 1961, 50 year flood, spillway design discharge and dam break flood were selected for the present study.

Observed flows at Khadakwasla were analysed and 35 year series of annual maximum daily flow was derived. The series was subjected to frequency analysis and flood with return period of 50 year was derived using Gumbel and Log Pearson III distributions. These were reviewed and estimated value of 2300.99 m^3/s by Gumbel distribution was selected.

Spillway design discharge of 2564 m^3/s as given in Salient Features of Khadakwasla dam was used in the studies. The hydrograph for the year 1997 was used as base hydrograph and the ordinates were raised proportionately. The resulting hydrograph (Figure 6.1) is used in further studies.

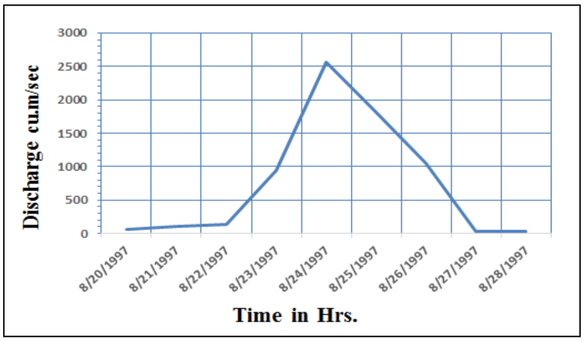

Figure 6.1: Spillway Design Flood Hydrograph

6.2 Flood Routing - River Mutha

6.2.1 Capabilities of Simulation Model

HEC-RAS model developed by US Army Corps of Engineers was selected in the present studies. The model has a variety of boundary conditions under steady and unsteady simulation scenarios. These include the following options:

- Time series of observed water level / flow
- Rating curve
- Groundwater Flow
- Normal depth
- Critical Depth

In addition, internal boundaries can be specified in one of the forms given below.

- Lateral inflow hydrograph
- Uniform lateral inflow hydrograph
- Groundwater Flow
- Stage / flow hydrograph

Model also has capability to simulate flow through gates.

- Elevation Controlled Gates
- Time Series Gate Openings

Model Output is either a plot or a statement of the variation of the selected parameters at desired locations and at preselected time interval.

6.2.2 Calibration of Simulation Model:

Calibration of the model was attempted under steady state conditions for the following floods. Water levels obtained in simulation were compared with observed values.

Table 6.1: Steady Flow Without & With Bridge Simulation

Year	Discharge (m^3/s)	Observed Water Level (m)	Computed Water Level (m)	
			Without bridges	With bridges
2005	1176.05	547.45	547.46	547.50
2006	1344.02	546.17	546.23	546.22
1997	2047.76	547.24	547.28	547.29
2004	1831.61	546.10	547.14	547.56

Calibration process was continued under unsteady scenario using the concurrent flood data as given in Table 6.2.

Table 6.2: Hydrographs used in Unsteady Flow Simulation

Year	Hydrograph Selected		Peak Flow (m^3/s)	Water Level (m)
	From	To		
2005	7/27/05	8/7/05	1176.05	547.45
2006	8/5/06	8/12/06	1344.02	546.17
1997	8/20/97	8/28/97	2047.76	547.24
2004	8/9/04	8/20/04	1831.61	546.10

The calibration results for the runs are presented in Figures below that show unsteady flow simulation results without bridges and with bridges.

It can be seen from the hydrographs that model peak water level occurs at the same time and the model value remains higher than the observed water level by about 2m. At this stage different attempts were made by varying n value. However, there was only marginal change in model water level and the difference remained almost unchanged.

This has happened as model has not exactly same condition as actual in the river at locations of bridge and corresponding road or deck level. The necessary measures for correcting the deviations would require keying in correct details of all bridges, which were not available.

Therefore, the results of calibration are considered to be indicative in nature and would require updating before applying to field in light of the above limitations.

Further runs for routing of dam break flood were continued with the model parameters derived under present scenario for n=0.03.

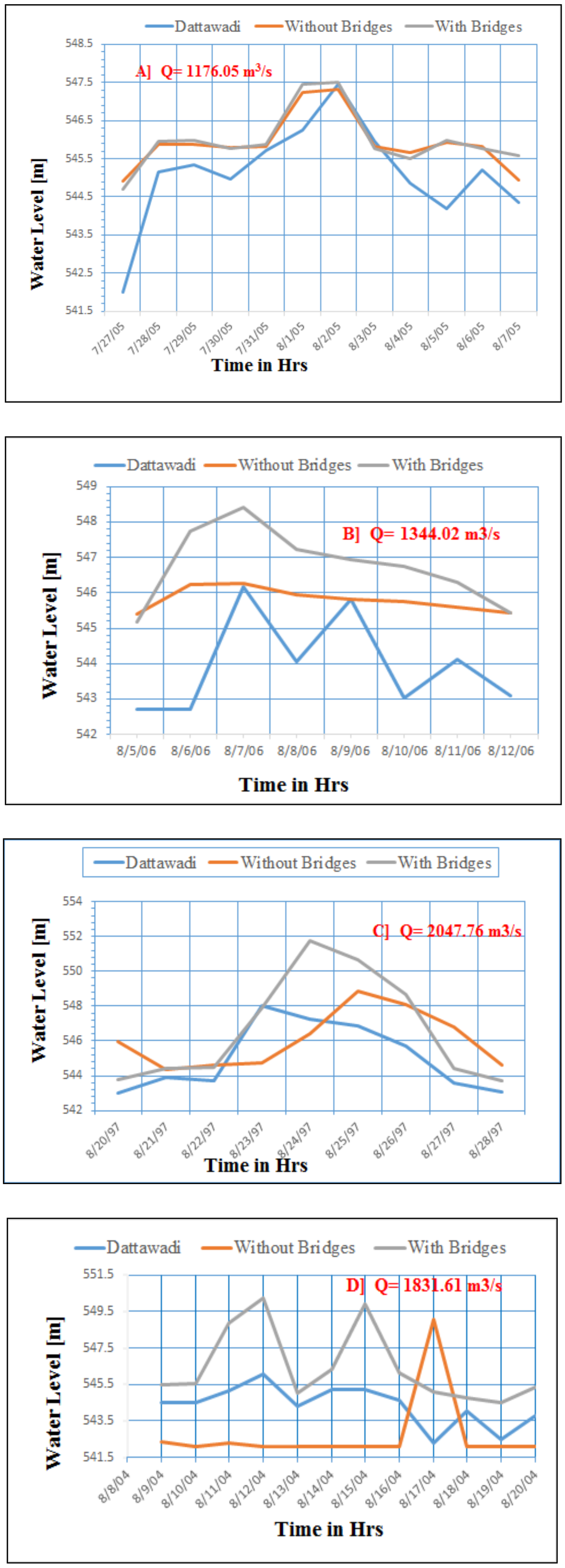

Figure 6.2: Water Surface Profiles

6.2.3 Routing of Dam Break Hydrograph

HEC RAS model has two options for simulating dam break scenario viz. in line structure and specifying the storage at location of a dam. In the present studies, later option was used and breach parameters were derived. It is further considered that dam, being earth and rock fill type, fails due to overtopping. The range of parameters derived is given in Table 6.3.

Table 6.3: Dam Breach Parameters

Breach Parameters	Values
Width of Breach	15 to 100 m
Side Slope (1: Z)	Z = 0.5 to 3.0
Time of Failure	0.5 to 3.0 hr

A range of breach parameters is considered to get a clear picture of the scenario under worst condition and also to carry out sensitivity study of the parameters. The water surface profiles under each scenario were reviewed with reference to road level at the bridges. e.g. It was noticed that Nanded Shivane Bridge would be submerged for 40 minutes duration from 3:10:00 to 3:50:00 hrs. Depth of the submergence from the road level is 1.47 m for dam break with lower value of dam breach parameter (Figure 6.3).

Sensitivity runs were taken using inflow hydrographs with peak flow equal to 25 year, 50 year return period and spillway design discharge.

In addition, area beyond current bank line would be submerged under dam break flood.

Further, times of travel of wave peak from dam site to different locations were extracted. A review of the time shows that period up to 01:00:00hrs would be available from Dam axis to the Shivaji Bridge.

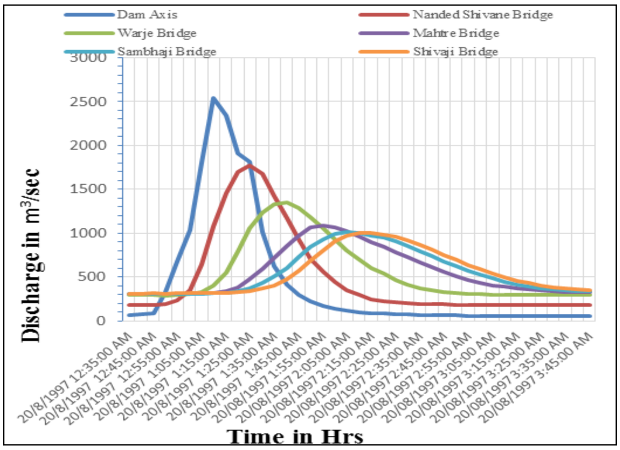

Figure 6.3: Dam Break Flood HydrograpH

Table 6.4: Peak Discharge Details at Bridges

Station	Date	Peak Flow (m^3/s)	Time of Peak (hr)
Dam Axis	20/08/97	2541.65	1:10
Nanded Shivane Bridge	20/08/97	1767.23	1:25
Warje Bridge	20/08/97	1346.48	1:40
Mahtre Bridge	20/08/97	1084.09	1:55
Sambhaji Bridge	20/08/97	1013.77	2:05
Shivaji Bridge	20/08/97	1003.10	2:10

6.3 Safety Management Plan

City of Pune has already experienced dam break flood in July 1961. Thereafter, high flows up to 2775.05 m^3/s (98000 cfs) have to be released due to high inflows resulting from intense rainfall in the upstream catchment; when Khadakwasla lake is filled almost up to Full Reservoir Level.

As a result, necessity of development of safety management plan is well known to citizens and also to the regulatory authorities. Some attempts have been made in this direction and possible areas that would get flooded have been identified. The safety management plan would thus include deciding types of measures to be taken either singly or in combination.

A) Commonly adapted measures include raising of banks by construction of embankments or flood walls, issue of warnings, compensating the affected people and units. If the event has very low probability of occurrence and economy permits, later alternative with activation of Emergency Action Plan (EAP) that includes shifting of persons and valuables to a higher safe elevations; duly considering damage and the available time, could be one of the best choices.

1) Most obvious and commonly used measure to minimise flooding is construction of embankments or raising of the banks.
2) This alternative requires availability of financial, human and material resources.
3) In the present scenario, assumption on availability of all these resources, could direct to take up this alternative.
4) However, taking in to account the growth of city up to say 2025 and the already attempted masonry wall for this purpose, would lead to necessity of second review due to availability of space.
5) Even if thinnest possible section of RCC wall is considered, the cost may become exorbitant.
6) Further, there would be additional rise in water level and increase in velocity due to constriction. Changes in bed level may occur in case bed of river is erodible in nature. However, this aspect is not carrying any importance in the present scenario.

B) Next possible alternative would be increasing the existing channel capacity by lowering the bed and increasing the width of river. Later option is not practicable in the present case as adequate space is not available. The alternative of deepening may be considered in the present case for reviewing along with economic and feasibility considerations. The site inspection revealed that bed consists of hard material. As such this alternative may not be cost effective. Further, space for storage and disposal of dredged material could be a key factor in cost economic angle. However, this can be considered as an alternative measure.

C) The next alternative in the available options is identifying the likely affected area and take up steps to rehabilitate the project affected persons either temporarily or on long term basis and develop a plan for rehabilitation and change in land use pattern, as required.

This involves identification of areas that would need such help, number of people likely to be affected and availability of safe place(s) at higher elevation.

D) In the present scenario, attempts made earlier have identified the area and likely number of people that would be affected and hence shifted to higher elevation.
E) This would require issue of warnings by competent authorities and making arrangements for shifting of people. The authorities have been identified.
F) The areas near downstream end and the warning issuing Authorities are identified. Arrangements for shifting of people that could be shifted in an hours' time are to be kept in readiness by a Cell that is in active and alert state throughout the monsoon.

Conclusions

Dam break is a complicated and compressive process and the actual failure mechanics are not well understood. The dam break simulation tool, HEC-RAS, was applied to Khadkwasla Dam near Pune city, Maharashtra. Dam break simulation and analysis was done using river geometry data and hydraulic data. The dam break due to overtopping is considered here. It was noticed that the event has greater impact at the locations nearer to the dam in comparison with the locations away from dam. Water level hydrographs at different locations were analysed to identify the flood affected area. Deck level of the bridge was used to decide extent and duration of submergence due to dam break flood. The commonly adapted structural measures like construction of embankments and non-structural are discussed. Safety management plan for the affected area is suggested in the form of activation of EAP, issue of flood warning and evacuation of the affected persons duly considering the prevailing site conditions.

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