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TEHRI DAM-BREACH VERSUS MONSOON FLOOD ROUTING IN THE GANGA RIVER SYSTEM

Ramesh Maddamsetty [a], T. V. Praveen MISH [b], S. Surya Rao FISH [a] & K. Manjulavani [c]

[a] Dept. of Civil Engineering, GITAM Institute of Technology, GITAM University, Visakhapatnam, 45 E-mail:

[b] Dept. of Civil Engineering, College of Engineering, Andhra University, Visakhapatnam, 530003 E-mail:

[c] Dept. of Civil Engineering, College of Engineering, JNTU, Hyderabad, 500072 E-mail:

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by

Ramesh Maddamsetty[1], **T. V. Praveen**[2], MISH **S. Surya Rao**[1], FISH and **K. Manjulavani**[3]

ABSTRACT

Dam breach or dam break causes release of large quantity of storage water from the reservoir creating major flood wave capable of causing disastrous damage to the downstream residents and property. The preparedness to withstand such an eventuality by predicting the possible extent of inundation of downstream zone and by formulating the emergency action plan can mitigate the disaster. The present study aims at predicting the characteristics of the flood wave such as peak flood stage, peak flood discharge and their times of occurrence and stage and discharge hydrographs at different locations downstream in the river due to Tehri dam-breach flood and also for monsoon flood. NWS-BREACH model is used for Tehri dam on the Ganga river, to predict the breach characteristics and the breach hydrograph. The predicted dam-breach flood hydrograph is routed through the Ganga river system using NWS-FLDWAV model, assuming that all the major tributaries joining the downstream Ganga river are already in flood state. The monsoon flood is also routed through the Ganga river system using NWS-FLDWAV. The dam-breach flood wave characteristics at different locations along the downstream of main river and its tributaries are predicted, and the results are discussed. The results of dam-breach flood routing are compared with those of estimated from the monsoon flood routing.

KEY WORDS : Dam-breach, Flood routing, Numerical model, Ganga river system.

INTRODUCTION

Earth dams are one of the most wide spread dams because of their suitability for any type of foundations, their low cost, and relatively simple construction. Earthen

1. Dept. of Civil Engineering, GITAM Institute of Technology, GITAM University, Visakhapatnam - 45, m_rameshgitam@rediffmail.com,s_suryaraogitam@rediffmail.com
2. Dept. of Civil Engineering, College of Engineering, Andhra University, Visakhapatnam-530003, tvpraveen@hotmail.com
3. Dept. of Civil Engineering, College of Engineering, JNTU, Hyderabad-500072, ronilekha@gmail.com

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dams are very much vulnerable to failure. The earthen dams may breach due to overtopping or due to piping. The failure of earthen dams are gradual in nature, unlike in rigid dams which collapse suddenly.

When a dam fails large quantity of storage water from the reservoir suddenly released, creating major flood wave capable of causing disastrous damage to downstream people and property. The dam-breach food wave, which when routed through the river causes rise in river stage and increase in river discharge. The rise in flood stage causes inundation of surrounding areas and consequent loss of life and property. Prediction of characteristics of flood wave propagation in advance greatly reduces the flood-damage caused to people and property.

The objectives of the present study is

i) to predict the characteristics of the flood wave, such as peak flood stage, peak flood discharge and their times of occurrence and stage and discharge hydrographs, at different locations downstream in the river due to formation of hypothetical breach for Tehri dam on the Ganga river.

ii) to compare the dam-breach flood routing results with those of monsoon flood routing through the Ganga river system, which highlights the magnitude of the possible catastrophe of the breach formation in the Tehri dam.

This is carried out in two stages; In the first stage the breach characteristics and the breach outflow hydrograph are determined for Tehri dam by using U.S. National Weather Services (NWS)-BREACH model, and in the second stage the NWS Flood Wave Routing Model (FLDWAV) is used to route the dam-breach outflow hydrograph through the tree type of Ganga river system with the Ganga river as a main river and all the major tributaries of the Ganga river as integral part of the river network. The consequent flood stage and flood discharge as a function of time at different locations downstream in the river network (on the main river and on the tributaries) are determined. The dam-breach flood routing results are compared with monsoon flood routing results.

GOVERNING EQUATIONS

The U.S National Weather Services (NWS) Flood Wave Routing Model (FLDWAV, Fread, 1998) is a reliable and well documented model. The governing equations of the model are the complete one-dimensional Saint-Venant equations of unsteady flow. The system of unsteady flow equations is solved by a non-linear weighted four-point implicit finite difference method. The 1-D Saint-Venant unsteady flow equations of conservation of mass and conservation of momentum are as follows:

$$\frac{\partial Q}{\partial x} + \frac{\partial (A + A_o)}{\partial t} - q = 0 \qquad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q^2 / A)}{\partial x} + gA\left(\frac{\partial h}{\partial x} + S_f + S_e\right) = 0 \quad (2)$$

in which, Q is the discharge; A is the active flow area; Ao is the inactive storage area; q is the lateral outflow; x is the distance along waterway; t is the time; g is the gravitational acceleration; h is the water surface elevation; S_f is the friction slope; S_e is the expansion-contraction slope.

NUMERICAL MODELS FOR FLOOD ROUTING (NWS-BREACH, FLDWAV)

Brief Description of NWS-BREACH Model

A mathematical model (BREACH) was developed by U.S. National Weather Service (D.L.Fread, 1988) for predicting the breach characteristics (size, shape, time of formation) and the breach outflow hydrograph. The model is based on the principles of hydraulics, sediment transport, soil mechanics, the geometric and material properties of the dam, and the reservoir properties (storage volume, spillway characteristics, and the time-dependent reservoir inflow rate). The model is developed by coupling the conservation of mass of the reservoir inflow, spillway outflow, and breach outflow with the sediment transport capacity of the unsteady uniform flow along an erosion-formed breached channel. The bottom slope of the breach is assumed to be essentially that of the downstream face of the dam. The growth of the breach channel is dependent on the dam's material properties (d50size, unit weight, friction angle, cohesive strength). Final breach size, time of formation and the breach outflow hydrograph are the standard model output.

Brief Description of NWS-FLDWAV Model

U.S. National Weather Service has developed Flood Wave routing model (FLDWAV, D.L.Fread, 1998). This model replaces the DAMBRK and DWOPER models. FLDWAV is a generalized flood routing (unsteady flow simulation) model. The governing equations of the model are the complete one-dimensional Saint-Venant equations of unsteady flow which are coupled with internal boundary equations representing the rapidly varied (broad-crested weir) flow through structures such as dams and bridge/embankments which can develop a user- specified time-dependent breach. Also, appropriate external boundary equations at the upstream and downstream ends of the routing reach are utilized. The system of equations is solved by an iterative, nonlinear, weighted four-point implicit finite-difference method. The hydrograph to be routed may be user-specified as an input time series, or it can be developed by the model via user-specified breach parameters (size, shape, time of development). The possible presence of downstream dams which control the flow and may be breached by the flood, bridge/embankment flow constrictions, tributary inflows, river sinuosity, levees located along the tributaries and/or downstream river, and tidal effects are each properly considered in the FLDWAV model during the downstream propagation. FLDWAV can handle sub-critical, supercritical or a combination of each, varying in space and time from one to other. FLDWAV can also model river systems that have a dentritic tree-type structure. The auto-choosing time step option in the model can overcome the non-convergence problem, which may arise while routing the rapidly rising flood wave through the river system. High water profiles along the valley, flood arrival times, and discharge and stage hydrographs at user-selected locations are standard model output in the FLDWAV model.

APPLICATION OF NWS-BREACH MODEL

Dam-breach Outflow for Tehri Dam on the Ganga River

The U.S. National Weather Service (NWS) BREACH (D. L. Fread, 1988), model is used to simulate the failure pattern and to compute the dam-breach outflow hydrograph for Tehri dam on the Ganga river. This model requires the input of inflow flood hydrograph, spillway rating curve, Elevation-Capacity curve of reservoir and the engineering properties of the dam material. BREACH model is able to predict the breach characteristics such as final breach width, breach depth, side slope coefficient of breach, duration of failure and the breach outflow hydrograph.

Details of Tehri Dam (Singh, A. K., 2002)

The Tehri dam section comprised of central clay core, shell zones of pervious fill material on both sides of the clay core, transition zones of fine and coarse filters in between clay core and shell zones, and riprap on the upstream and downstream slopes. The height of dam above deepest foundation level is 260.5 m. The length of dam at crest level is 575 m and the width of crest is 20 m. The upstream and downstream slopes are 1V: 2.5 H and 1V:2H, respectively. The elevation of top of dam is at 839.50 m. Engineering properties of central core material and the outer shell material of the Tehri dam are shown in Table 1.

TABLE-1
ENGINEERING PROPERTIES OF THE CORE AND SHELL MATERIAL OF TEHRI DAM

Property of Soil	Values for clay cor	Values for shell material
d50 , mm	0.001 mm	100 mm
Porosity (n)	0.4	0.4
Unit weight, KN/m^3	18.821 KN/m^3	18.821 KN/m^3
Cohesive strength, KN/m^2	159.92 KN/m^2	0 KN/m^2
Internal Friction Angle	00	330

Details of Reservoir

The gross storage and live storage of reservoir are 3540 mm^3, 2616 mm^3, respectively. Maximum Flood Level (MWL) and Full Reservoir Level are 835 m and 830 m, respectively. The details of Elevation - Capacity values of the reservoir are shown in Table 2.

TABLE-2

ELEVATION VERSUS CAPACITY VALUES OF THE RESERVOIR

Elevation, m	620	690	715	745	768	777	786	802	816	829	835	840
Capacity, M mm^3	0	250	500	1000	1500	1750	2000	2500	3000	3500	3750	4000

Details of Maximum Inflow Flood

The ordinates of maximum inflow flood hydrograph for 1000 year frequency for the Tehri dam are as given below:

Time,hrs	0	12	24	36	38	48	60	84	120	186
Inflow,m^3/s	800	1113	2016	10015	12848	6458	3841	1758	1003	800

Details of Spillway

The chute spillway with crest level at 815 m has a carrying capacity of 15,540 mm^3. The spillway consists of three bays of 10.5 m width, separated by piers of 4 m thickness. The chute has the stilling basin at its downstream end at an elevation of 596 m. The width of stilling basin in 50 m and the length is 140 m with a downstream weir. The details of spillway discharge w.r.t. head over the spillway for the Tehri dam are shown in Table 3.

TABLE-3

DETAILS OF THE SPILLWAY RATING CURVE

Head over Spillway, m	0.0	5.0	15.0	18.0	20.0	23.0	25.0	26.5
Spillway Discharge, cumecs	0.0	1050.2	5903.2	9551.3	12993.9	17783.3	20976.5	22573.1

NWS – BREACH model has been used for the Tehri dam to predict the breach characteristics and the breach outflow. The predicted dam-breach outflow hydrograph is shown in Fig. 1, and the predicted breach characteristics are as follows:

Output Summary of NWS – BREACH Model for Tehri Dam

Elevation of Top of Dam = 839.5 m; Time of Failure	=	1.99 hrs
Top Width of Breach at Peak Breach Flow	=	404.5 m
Bottom Width of Breach at Peak Breach Flow	=	18.11 m
Final Elevation of Bottom of Breach	=	628.4 m
Final Depth of Breach	=	211.1 m
Side Slope of Breach (1V:ZH) at Peak Breach Flow (Z)	=	0.92
Maximum Total Breach Outflow Occurring at Peak Time	=	9,80,324 mm^3

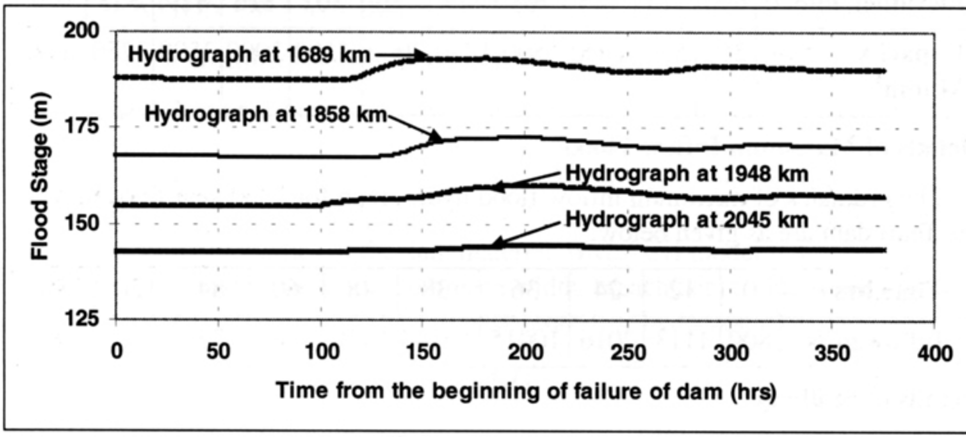

FIG. 1 PREDICTED BREACH OUTFLOW HYDROGRAPH FOR A HIGH ROCK-FILL DAM ON THE GANGA RIVER

APPLICATION OF NUMERICAL MODEL (NWS-FLDWAV) Validation Monsoon Flood Routing Through Dendritic Network of Ganga River System

The NWS-FLDWAV model is used for routing of monsoon flood through the Ganga river system from Haridwar to Farakka Barrage (Surya Rao et al., 2008, Ramesh et al., 2008). The study considers the main river and all its tributaries as an integrated single unit and predicts the combined effect on the flood characteristics. The flood hydrographs on the d/s of Son tributary in the channel-13 (Refer Fig. 3) obtained from the study are compared with that of Kamalam (2004) and found to be satisfactory as shown in Fig. 2.

APPLICATION OF NUMERICAL MODEL (NWS-FLDWAV Model) Dam-breach Flood Routing Through Tree Type of Ganga River System

The predicted dam-breach flood hydrograph from the NWS-BREACH model, is routed through the Ganga river system (Refer Fig. 3) using NWS-FLDWAV model. The dam-breach flood hydrograph is given as input flood hydrograph at the inlet of the main river Ganga. The log-pearson type-III distribution flood hydrograph is given

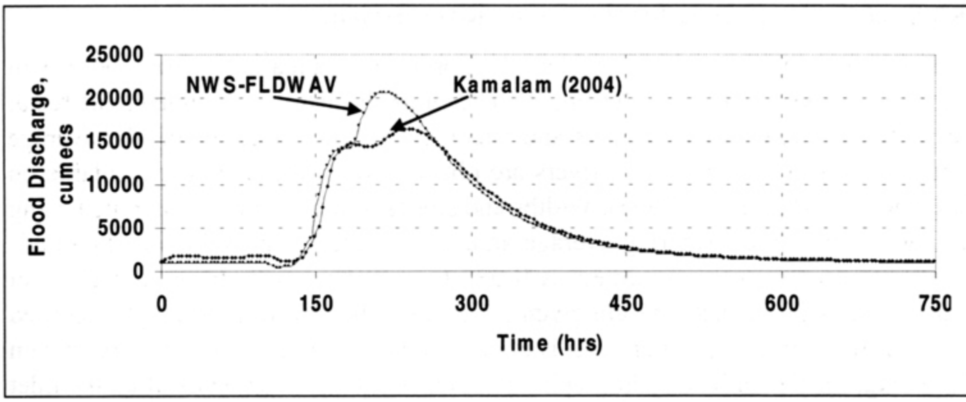

FIG. 2 VALIDATION OF NWS-FLDWAV MODEL FOR THE GANGA RIVER SYSTEM

as input flood hydrograph at the inlets of all the major tributaries. Stage-discharge relationship is given as downstream boundary condition at the tail end of the main river i.e., at the Farakka barrage. The results obtained are presented in graphical form.

Description of the Ganga River System

The Ganga river system considered in this study is the portion of Ganga basin from Tehri dam site to Farakka barrage, the total length of the Ganga river reach is of 2065 km as shown in Fig. 3. The Ganga river system consists of the Ganga river as the main river and 9 major tributaries, of which 6 tributaries (Ramganga, Gomti, Ghaghra, Gandak, Buri Gandak and Kosi) from the North and 3 tributaries (Yamuna, Ton and Son) from the South joining the main river are considered, with total 19 channels having combined length of 8,161 km (Fig. 3). The source of the river Ganga (Rao, K.L., 1995) is at Gangotri in Uttar Kashi and is located at an elevation of 7,010 m. The total length of the Ganga from its source to its outfall into the sea is 2,525 km.

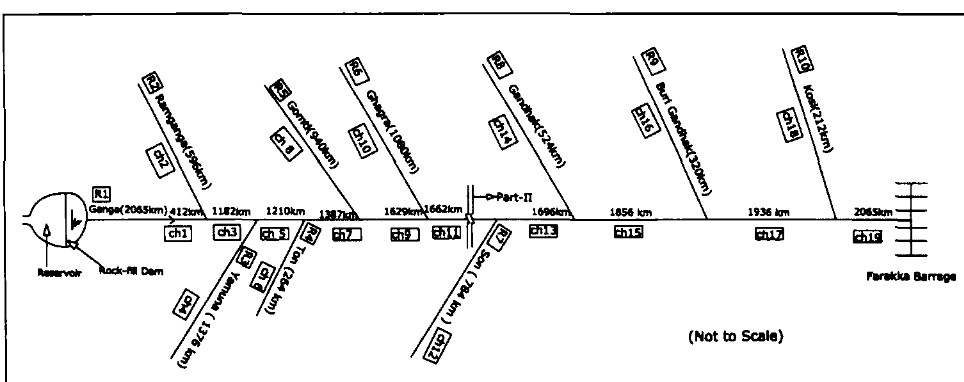

FIG. 3 DETAIL OF THE GANGA RIVER SYSTEM FROM ROCK-FILL DAM TO FARAKKA BARRAGE (RAO, K.L, 1995)

Details of the Input Data for the Ganga River System

The hypothetical network considers the portion of Ganga basin from Tehri dam site to the Farakka barrage (Refer Fig. 3). The entire discharge is assumed to be fed at the upstream end of inlet channels and lateral flow is not considered. The average annual flow data and lengths of rivers are obtained from the literature available on Indian Rivers (Rao, K. L., 1995). Widths and slopes of the rivers are computed using the Lacey's theory considering average annual discharges. The value of Manning's roughness coefficient is assumed as 0.025 for all the rivers. Flow and channel characteristics for the network are given in Table 4. The inflow hydrograph specified at the upstream end of the main river is of dam-breach flood hydrograph of Tehri dam (Refer Fig. 1). The inflow hydrographs specified at the upstream ends of all the inlet channels of tributaries are assumed to be of Log Pearson Type-III. The specified boundary condition at the tail end is derived from the discharge equation for the Farakka barrage.

Upstream Boundary Condition for the Main River Ganga and its Tributaries

Upstream boundary condition for the main river is the predicted dam-breach outflow hydrograph of Tehri dam using NWS-BREACH model (Refer Fig. 1). Log-Pearson Type III distribution is used for specifying the inflow hydrograph at the inlets of all the tributaries.

$$Q(t) = Q_b + (Q_p - Q_b)\,[\,e^a\,](t/t_p)^b \tag{3}$$

In which, $a = (t - t_p)/(t_g - t_p)$, $b = (t_p)/(t_g - t_p)$, $Q(t)$ = Discharge at any time t, Q_b = Base flow, Q_p = Peak discharge, t_p = Time of occurrence of peak and t_g = Time to centre of gravity of hydrograph. In the present study, Q_p/Q_{av} as 4, Q_{av}/Q_b as 8 and t_p/t_g as 0.9 is considered (CBIP, 1992, Surya Rao et al., 2000) for predicting the inflow flood hydrographs.

Downstream Boundary Condition for the Main River Ganga

Stage-discharge relationship is given as downstream boundary condition at the tail end of the main river i.e., at the Farakka barrage. This stage-discharge relationship is derived from the discharge equation for the Farakka barrage (B. S. Murty, 1998). The discharge through the barrage is composed of three components. These are as follows:

Discharge through under sluices : $Q_1 = 1.7\,(L_o - 0.1 N_o H_o)\,Ho^{3/2}$ (4)

Discharge through spillway : $Q_2 = 1.84\,(L_s - 0.1 N_s H_s)\,Hs^{3/2}$ (5)

Discharge through fish lock : $Q_3 = 1.84\,(L_f - 0.1 N_f H_f)\,Hf^{3/2}$ (6)

In which, L_o, L_s and L_f = total width of under sluice, spillway and fish lock, respectively. N_o, N_s and N_f = total number of bays in under sluice, spillway and fish lock, respectively. H_o, H_s and H_f = head of water over under sluice, spillway and fish lock crests, respectively. Total discharge through the Farakka barrage (Q) is the sum of all the three above mentioned components. In terms of the head of water behind the barrage, the combined equation can be written as:

$$Q = 1.7(439.2-4.6h)h^{1.5} +1.84(1537.2-16.6(h-1.53))(h-1.53)^{1.5}+1.84(16.48-0.2h)h^{1.5} \quad (7)$$

TABLE-4
FLOW AND CHANNEL CHARACTERISTICS OF GANGA RIVER BASIN (FOR DAM-BR mEACH FLOOD)

Sl. No	River Name	Ch. No.	Length of Channel, L, km	Width, B, m	Max. Discharge, Q, cumecs	Bed Slope, S_o	n
1	Ganga	1	292	2803	980324	0.00003	0.025
2	Ganga	3	770	1220	66004	0.00005	0.025
3	Ganga	5	28	827	30346	0.00005	0.025
4	Ganga	7	177	813	29314	0.00005	0.025
5	Ganga	9	242	794	27946	0.00005	0.025
6	Ganga	11	33	786	27392	0.00005	0.025
7	Ganga	13	34	785	27330	0.00005	0.025
8	Ganga	15	160	776	26657	0.00005	0.025
9	Ganga	17	80	772	26399	0.00005	0.025
10	Ganga	19	90	770	26299	0.00005	0.025
11	Ramganga	2	596	1237	67869	0.00005	0.025
12	Yamuna	4	1376	536	12742	0.00006	0.025
13	Ton	6	264	314	4372	0.00007	0.025
14	Gomti	8	940	372	6120	0.00007	0.025
15	Ghagra	10	1080	435	8394	0.00006	0.025
16	Son	12	784	261	3012	0.00008	0.025
17	Gandak	14	524	388	6686	0.00007	0.025
18	Burigandak	16	320	275	3342	0.00008	0.025
19	Kosi	18	212	403	7198	0.00007	0.025

TABLE-5
CHARACTERISTICS OF DAM-BREACH FLOOD STAGE HYDROGRAPHS

Distance Along The Ganga River, km	Peak Stage, m	Time of commencement of Rising limb, Hours	Time of Peak Stage, Hours	Time ending of Recession limb, Hours
0	669.4	0	1.4	6
119	491.6	1.5	3.8	19
241	447.3	4	7.2	36
420	399.1	9	18.5	85
644	354.5	21	35.5	118
966	319.4	39	60.5	144
1392	252.5	82	113	188
1649	201.2	109	141.1	228
2065	144.1	108	181.4	288

Discussion of Results

The U.S. National Weather Service (NWS) BREACH model (Fread, D. L., 1988), and NWS-FLDWAV (Flood Wave Routing) model (Fread, D. L., 1998) are applied to simulate the failure of dam and to predict the dam-breach flood wave propagation, respectively. NWS-BREACH model is applied to Tehri dam on the Ganga river and the breach characteristics such as duration of failure, final breach width, final breach depth, side slope of breach and the breach outflow hydrograph are computed. NWS-FLDWAV model is applied to compute the dam-breach flood wave propagation through the tree type of the Ganga river system, and the flood wave characteristics such as peak flood discharge, peak flood stage and their time of occurrence, discharge hydrographs and stage hydrographs at various locations on the downstream reaches of the river system are also computed and compared with that of monsoon flood routing results.

The predicted breach characteristics and the breach outflow hydrograph using the NWS-BREACH model are presented in the output summary of the previous section and in Fig. 1., respectively. The duration of development of the breach from initiation to its final dimension due to overtopping flood is 1.99 hrs and the consequent outflow through the breach and over the spillway is at its maximum value of 9,80,324 mm^3. The dam-breach outflow flood is routed through the Ganga river system over a length of 2,065 km i.e., from Tehri dam location to the tail end of river i.e., up to Farakka barrage. The details of the tree type of the Ganga river system are as shown in Fig. 3.

The computed peak flood discharge and peak flood stage along the downstream river reach for dam-breach flood and monsoon flood are presented in Figs. 4 and 5, respectively. The time of occurrence of peak discharge and peak stage along the downstream river reach for dam-breach flood and monsoon flood are presented in Figs. 6 and 7, respectively. The computed flood discharge hydrographs and flood stage hydrographs for selected locations along the Ganga river for dam-breach flood and monsoon flood are presented in Figs. 8 to 15. The second peak in the hydrographs at the d/s of Ramganga tributary as observed in Figs. 14 and 15 is attributed to the flood flow of Ramganga which is one of the major tributaries of the Ganga river. The quantitative values of the predicted characteristics of dam-breach flood wave and monsoon flood wave along the Ganga river are presented in Table 6.

The maximum flood stages corresponding to monsoon flood at the locations near the dam, 119 km, 241 km and 420 km along the main river Ganga are 616.1 m, 449.3 m, 418.9 m and 386.7 m, respectively. The maximum flood stages corresponding to dam-breach flood at the above said locations are 669.4 m, 491.6 m, 447.3 m and 399.1 m, respectively (Refer Figs. 9, 11, 13 and 15). The peak stage, time of commencement of rise of flood stage, time of peak flood stage and time of ending of flood stage of dam-breach flood along the Ganga river are presented in Table 5. The dam-breach flood peak flows are arriving the locations of main river at 46 km, 119 km, 241 km, and 412 km from Tehri dam location, in 2.4 hrs, 3.4 hrs, 5.8 hrs and 12.6 hrs, respectively from the beginning of failure of the Tehri dam. The monsoon peak flows are arriving at the said locations in 41.8 hrs, 45.6 hrs, 56.2 hrs and 75.8 hrs, respectively.

The computed flood discharge hydrographs on the Ramganga tributary at a section 5 km from the confluence due to the propagation of dam-breach flood wave and the monsoon flood wave in the Ganga river, are presented in Fig. 16. The negative values of discharge at the section on the Ramganga tributary near the confluence are attributed to the reversal of flow of flood wave passage through the main river Ganga. The flood discharge hydrographs due to dam-breach flood at the cross-sections 5 km upstream from the confluence of Ramganga on the main river (Ganga), 5 km downstream from the confluence of Ramganga on the main river (Ganga) and 5 km upstream from the confluence on the Ramganga tributary are presented in Fig. 17.

The computed flood discharge hydrographs and flood stage hydrographs for selected locations along the Ganga river due to dam-breach flood are presented in Figs. 18 to 20 and 21 to 23, respectively. The hydrographs farther away from the Tehri dam are observed to have multiple peaks (Refer Fig. 20) as the upstream tributaries contribute the monsoon flood and join the main river at different times.

The maximum discharge of reversal flow from the main river Ganga into the Ramganga and Yamuna tributaries due to passage of Tehri dam-breach flood wave through the main river Ganga is 67,640 mm^3 and 12,694 mm^3, respectively. The maximum discharge of reversal flow from the main river Ganga into the Ramganga and Yamuna tributaries due to passage of monsoon flood wave through the main river Ganga is 3,887 mm^3 and 1,504 mm^3, respectively.

CONCLUSIONS

1. The Ganga river system consists of main river (Ganga) and 9 major tributaries, total combined length of about 8,161 km. The FLDWAV model, while applying to the said Ganga river system as a whole, exceeded the maximum limit of total number of nodes. Hence the total network of Ganga river system is divided into two parts. In the first stage the FLDWAV model is executed for the first part consisting of the full length of the Ganga River and the tributaries upto Son, excluding the Gandhak, Burigandak and Kosi tributaries. In the second stage the FLDWAV model is executed for the Part-II with the part of the Ganga River from upstream of Son tributary to tail end (Farakka barrage) of main river considering the Gandhak, Burigandak and Kosi tributaries. Both Part-I and Part-II results at the common cross-section downstream of Son River are compared and found that discharge hydrographs of both Part-I and Part-II are same.

2. The combination of NWS – BREACH model (Erosion model for earth dam failures) and NWS – FLDWAV model (Flood Wave Routing) can be used for the studies related to dam-breach flood routing through the large network of dendritic type river system.

3. The maximum dam-breach flood discharge near the Tehri dam is 9,80,324 mm^3 and the peak flood depth of water is 59 m and it is occurring in 1.44 hrs. The dam-breach flood peak is attenuated along the downstream Ganga river. The Tehri dam-breach peak flood discharge at locations 46 km, 119 km, 241 km and 420 km along the Ganga river from Tehri dam are 8,01,047 mm^3, 5,95,603 mm^3, 2,58,832 mm^3, and 66,005 mm^3, respectively. The times of occurrence of the above Tehri dam-breach peak flood discharges from the beginning of failure of Tehri dam are 2.4 hrs, 3.5 hrs, 5.8 hrs and 16.3 hrs, respectively. The warning time available for peak discharge and peak stage at any location along the main river, for dam-breach flood is as expected much less compared to that of monsoon peak flood discharge and peak flood stage.

4. The dam-breach flood wave severity is very high in the main river Ganga up to the Ramganga confluence, i.e., about 966 km river reach of the Ganga from the Tehri dam location. The ratio of peak flood discharge due to dam-breach flood and due to monsoon flood at the locations near the dam, 46 km, 119 km, 241 km

and 412 km along the main river Ganga are 76.8, 63.7, 48.5 and 13.8, respectively. Beyond 420 km from the Tehri dam the said ratio of peak discharges is ranging from 8.3 to 1.8.

5. The time to the peak of the stage hydrograph from the beginning of the failure of the dam, the maximum depth of water, and the time of ending of recession limb of the stage hydrograph at selected locations of 46 km, 119 km, 241 km, and 420 km along the main river are 1 hrs, 57.3 m, 7 hrs; 2 hrs, 49.3 m, 19 hrs; 5 hrs, 35.4 m, 36 hrs; and 9 hrs, 17.8 m, 85 hrs, respectively.

6. About 80 km long river reach of the Ramganga tributary from the confluence with the Ganga river, is severely effected due to reversal of flow of dam-breach flood of main river into the Ramganga tributary. However, the flow continues in a downstream direction at all times for the remaining reach of Ramganga tributary. The reversal of flow indicates that the tributary stores considerable volume of the dam-breach flood flow of the main river leading to significant reduction in peak flood of main river on the downstream of the confluence in the main river.

7. The reversal of flow from the main river to the tributary is observed in all the tributaries, in both the cases of dam-breach flood and monsoon flood. The reversal of flow is large at the confluence locations of Ramganga and Yamuna. The ratio of maximum reversal of flow due to dam-breach flood and due to monsoon flood at the confluence locations of Ramganga and Yamuna is 17.4 and 8.4, respectively. The magnitude of reversal of flow in the other tributaries is insignificant.

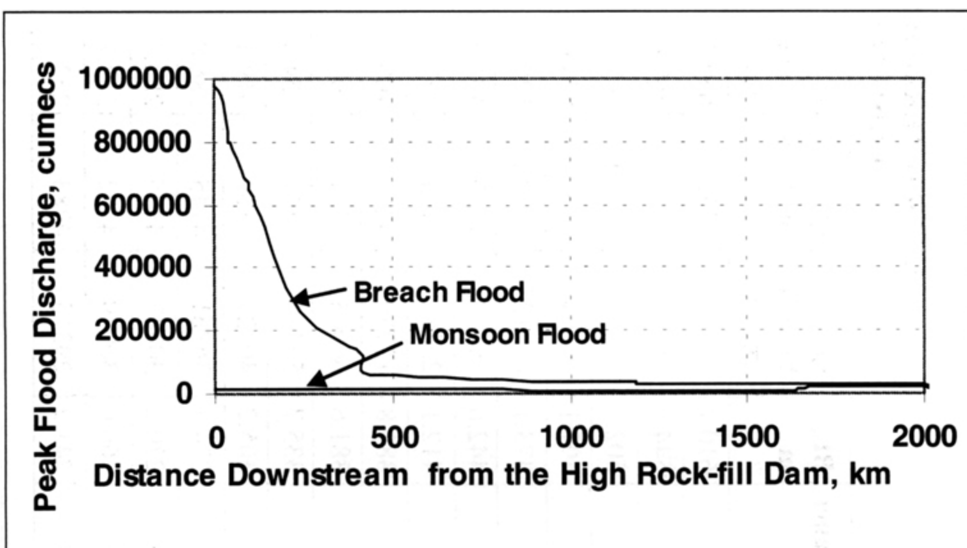

FIG. 4 PEAK FLOOD DISCHARGE FROM MONSOON AND DAM BREACH FLOOD

TABLE-6
CHARACTERISTICS OF TEHRI DAM-BREACH FLOOD, MONSOON FLOOD FOR GANGA RIVER

Distance, km	BL, m	Q_p breach (mm^3)	Q_P monsoon (mm^3)	H_p breach (m)	H_p monsoon (m)	T_Q breach (hrs)	T_Q monsoon (hrs)	T_H breach (hrs)	T_H monsoon (hrs)	D_p breach (m)	D_p monsoon (m)
0	610.7	980324	12759	669.4	616.1	1.4	39.8	1.4	39.8	59.0	5.3
15	544.2	959915	12735	599.8	548.6	1.9	40.3	1.9	40.3	56.0	4.4
33	502.9	878727	12680	562.7	508.7	1.9	41.3	2.4	41.3	60.1	5.7
46	497.1	801047	12577	554.0	502.9	2.4	41.8	2.4	41.8	57.3	5.8
83	473.1	688125	12422	520.5	477.9	2.9	43.7	2.9	43.7	47.7	4.8
119	442.6	595603	12293	491.6	449.3	3.4	45.6	3.8	46.1	49.3	6.7
242	412.1	258832	11155	447.3	418.9	5.8	56.2	7.2	57.6	35.4	6.8
412	381.8	127391	9267	400.5	387.9	12.6	75.8	18.5	84.1	19.0	6.3
420	381.6	66005	7951	399.1	386.7	16.3	85.1	18.5	85.9	17.8	5.2
644	335.7	55415	7141	354.5	341.5	31.7	112.8	35.5	116.6	19.0	5.8
966	305.2	40329	5169	319.4	309.4	58.1	173.8	60.5	175.2	14.4	4.3
1181	274.7	36861	4745	286.8	279.1	73.4	209.3	88.8	222.7	12.3	4.5
1218	270.2	30347	4435	280.5	273.6	91.2	229.4	95.5	230.4	10.5	3.5
1233	266.6	30049	4472	277.7	271.1	96.0	231.8	97.4	232.8	11.4	3.6
1384	241.2	29315	4783	252.5	245.6	106.6	255.4	115.2	262.1	11.5	4.5

Distance, km	BL, m	Q_p breach (mm^3)	Q_P monsoon (mm^3)	H_p breach (m)	H_p monsoon (m)	T_Q breach (hrs)	T_Q monsoon (hrs)	T_H breach (hrs)	T_H monsoon (hrs)	D_p breach (m)	D_p monsoon (m)
1458	229.0	28260	4696	238.6	232.3	119.5	273.1	121.0	274.1	9.8	3.3
1610	198.4	27947	4631	208.6	202.5	130.6	296.2	132.5	297.1	10.3	4.1
1625	196.8	27877	4627	204.9	199.6	132.0	298.6	136.8	299.1	8.2	3.2
1635	192.3	27749	4642	203.3	199.1	133.0	300.5	140.6	301.7	11.1	6.7
1650	192.3	27419	11284	201.2	198.1	142.6	302.1	141.1	302.4	9.0	5.6
1660	191.3	27393	11358	198.7	195.6	142.1	302.9	144.5	303.2	7.5	4.5
1682	183.1	27365	13795	193.9	190.9	149.8	303.2	147.4	304.1	10.9	7.8
1690	183.1	27330	15095	193.0	190.1	148.3	304.3	150.7	306.3	10.0	7.1
1860	162.1	26658	14721	172.2	169.5	164.2	325.1	165.6	330.2	10.2	7.4
1870	161.9	26637	14814	170.7	168.1	165.1	330.7	166.6	31.8	8.9	6.3
1932	151.1	26399	14657	160.9	158.2	170.9	337.4	173.8	347.1	10.0	7.1
1940	150.2	26353	14674	160.3	157.6	171.8	345.6	174.7	348.2	10.1	7.3
1950	150.1	26299	14656	159.3	156.7	172.8	346.6	175.7	349.1	9.3	6.6
2065	140.1	26053	14556	144.1	143.3	181.4	357.6	181.4	357.6	4.1	3.2

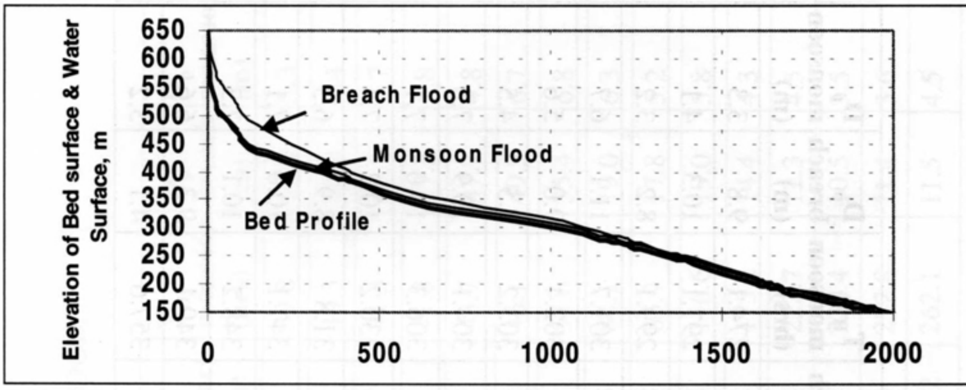

FIG. 5 PEAK FLOOD STAGE FROM MONSOON AND DAM BREACH FLOOD

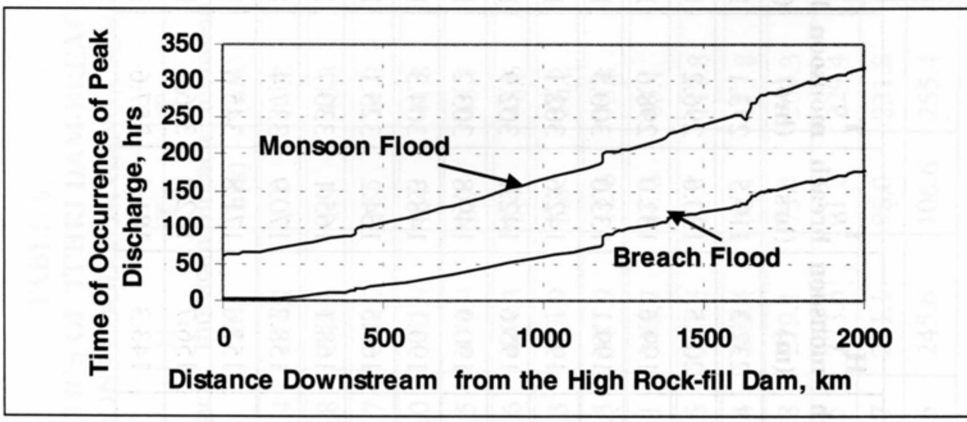

FIG. 6 TIME OF OCCURRENCE OF PEAK DISCHARGE OF MONSOON AND DAM-BREACH FLOOD

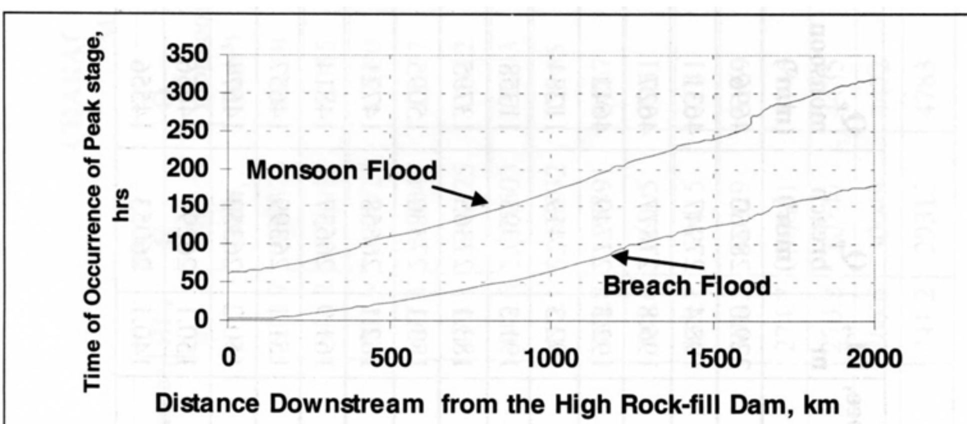

FIG. 7 TIME OF OCCURRENCE OF PEAK STAGE OF MONSOON AND DAM-BREACH FLOOD

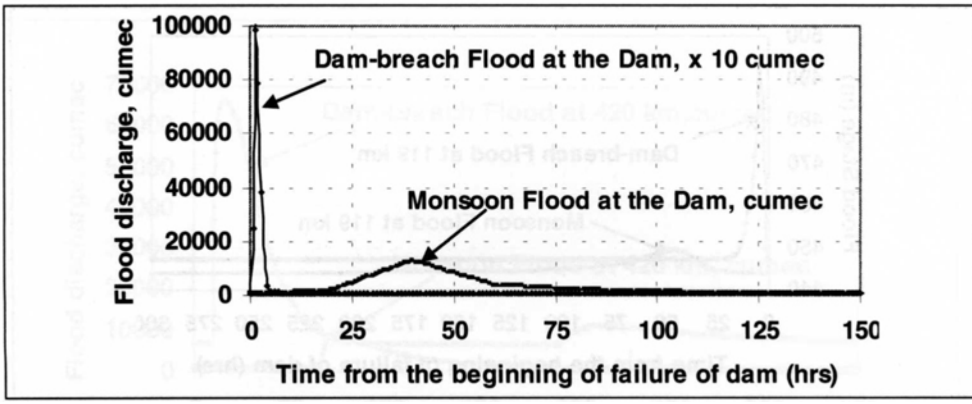

FIG. 8 DISCHARGE HYDROGRAPHS ON THE GANGA RIVER DUE TO DAM-BREACH FLOOD AND MONSOON FLOOD

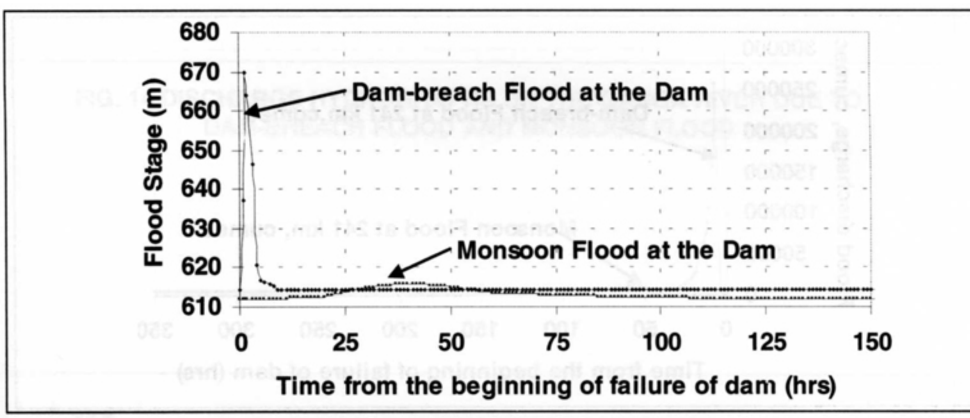

FIG. 9 STAGE HYDROGRAPHS ON THE GANGA RIVER DUE TO DAM-BREACH FLOOD AND MONSOON FLOOD

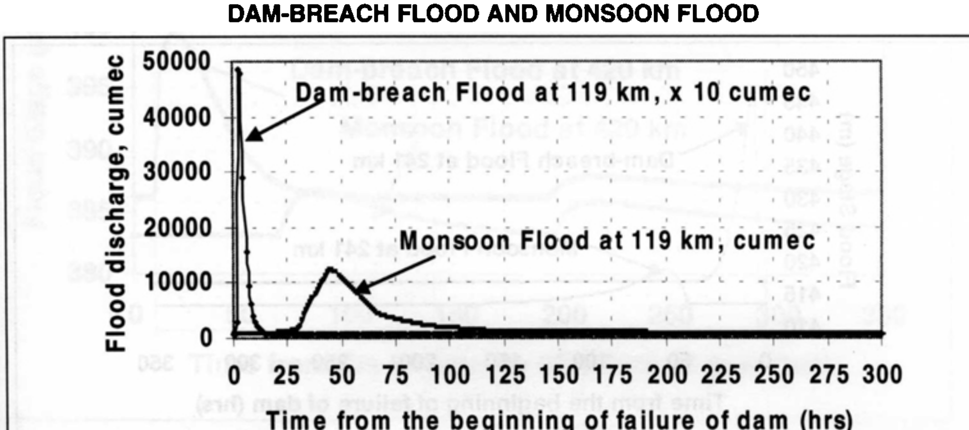

FIG. 10 DISCHARGE HYDROGRAPHS ON THE GANGA RIVER DUE TO DAM-BREACH FLOOD AND MONSOON FLOOD

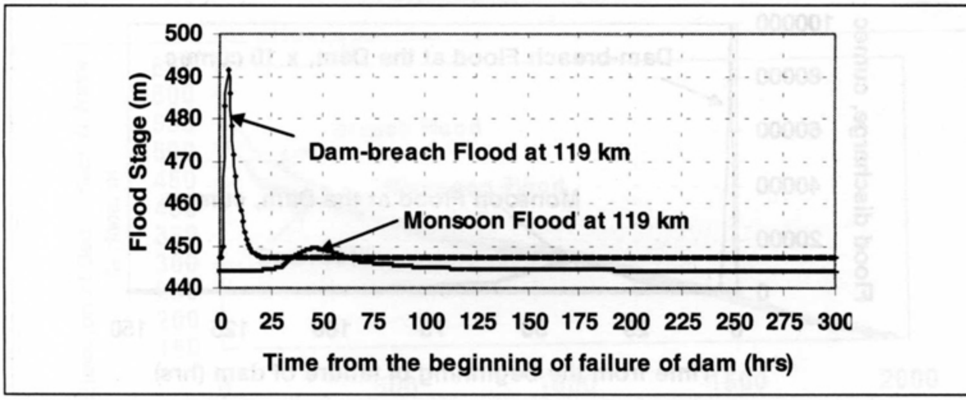

FIG. 11 STAGE HYDROGRAPHS ON THE GANGA RIVER DUE TO DAM-BREACH FLOOD AND MONSOON FLOOS

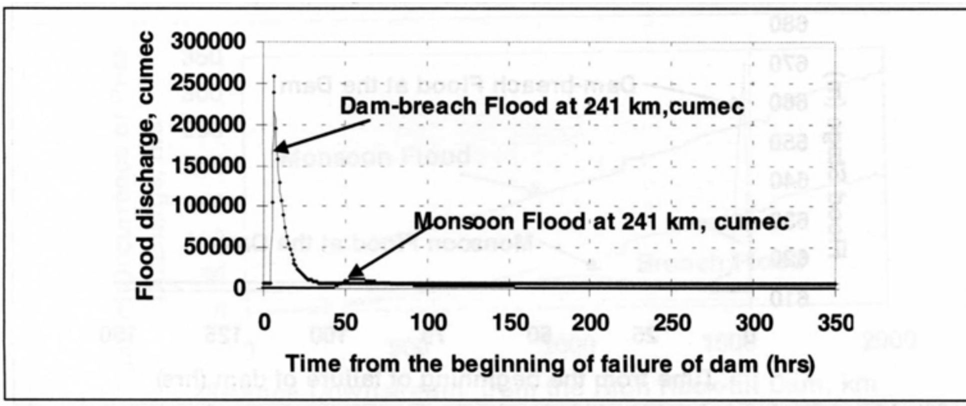

FIG. 12 DISCHARGE HYDROGRAPHS ON THE GANGA RIVER DUE TO DAM-BREACH FLOOD AND MONSOON FLOOD

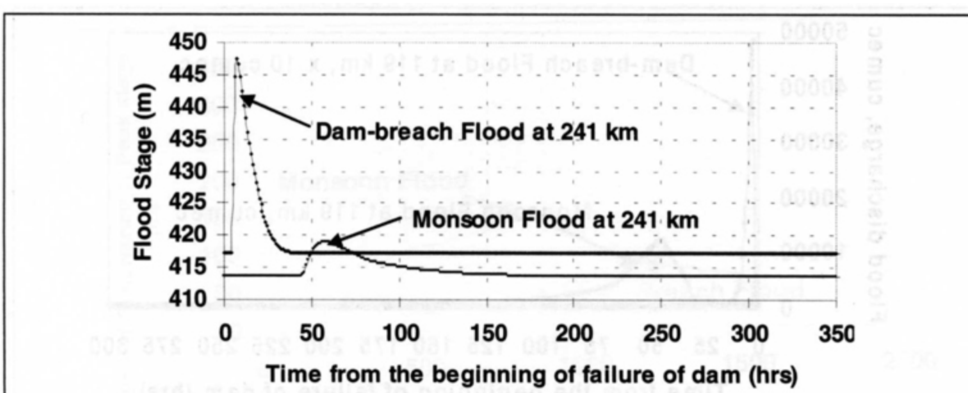

FIG. 13 STAGE HYDROGRAPHS ON THE GANGA RIVER DUE TO DAM-BREACH FLOOD AND MONSOON FLOOD

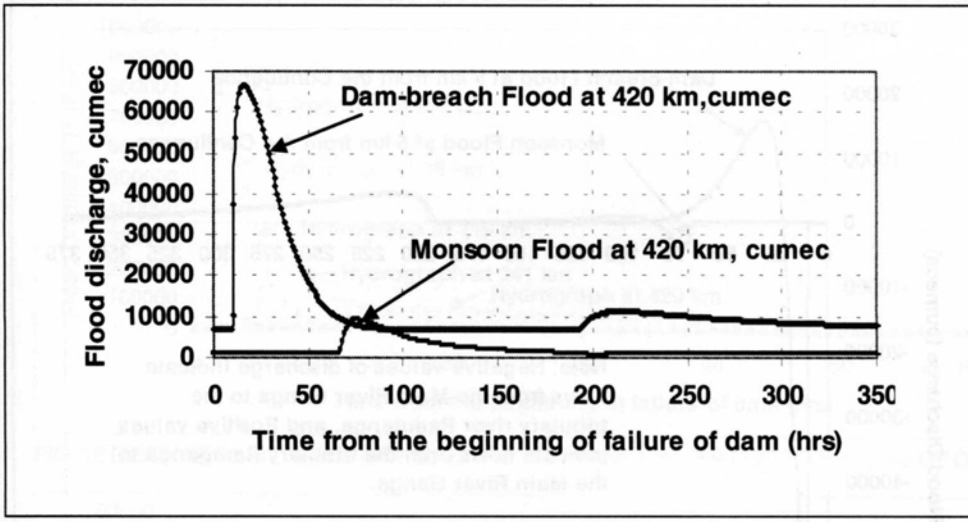

FIG. 14 DISCHARGE HYDROGRAPHS ON THE GANGA RIVER DUE TO DAM-BREACH FLOOD AND MONSOON FLOOD

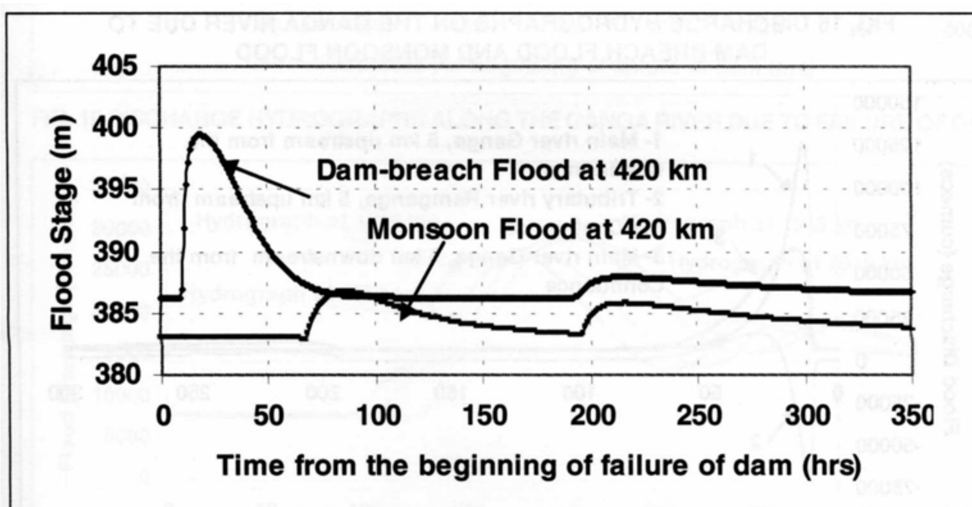

FIG. 15 STAGE HYDROGRAPHS ON THE GANGA RIVER DUE TO DAM-BREACH FLOOD AND MONSOON FLOOD

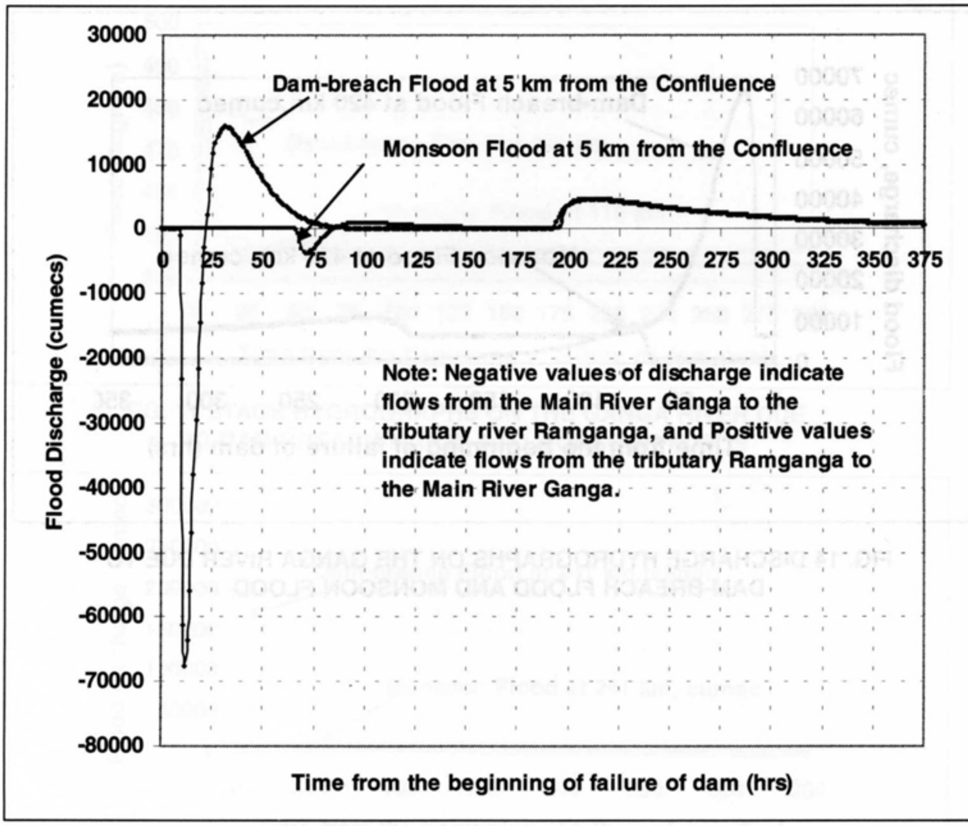

FIG. 16 DISCHARGE HYDROGRAPHS ON THE GANGA RIVER DUE TO DAM-BREACH FLOOD AND MONSOON FLOOD

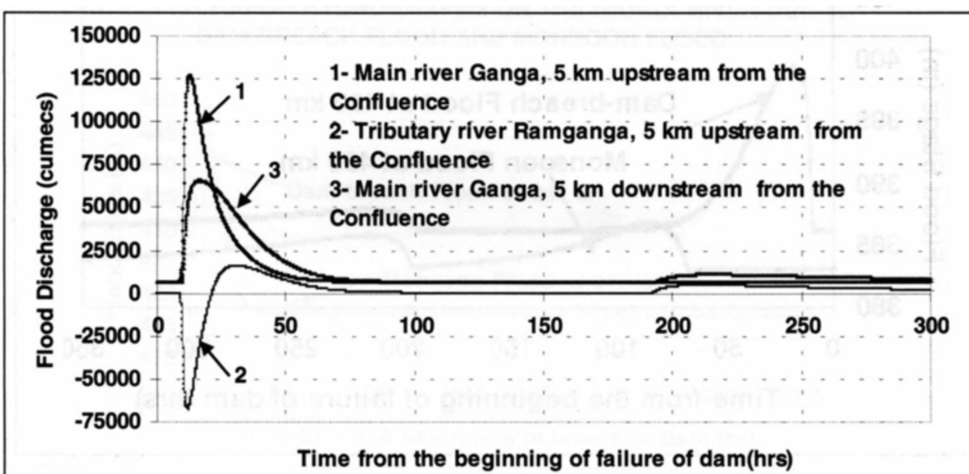

FIG. 17 DAM-BREACH DISCHARGE HYDROGRAPHS AT THE CONFLUENCE OF THE GANGA AND THA RAMGANGA TRIBUTARY

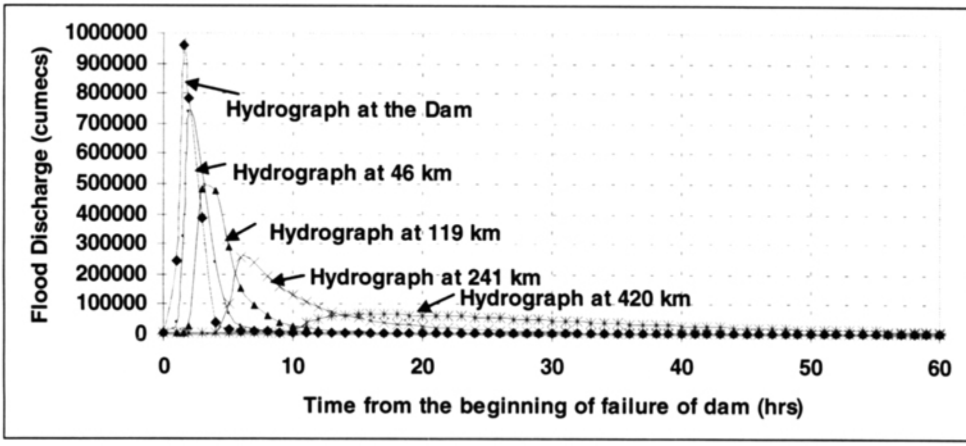

FIG. 18 DISCHARGE HYDROGRAPHS ALONG THE GANGA RIVER DUE TO FAILURE OF DAM

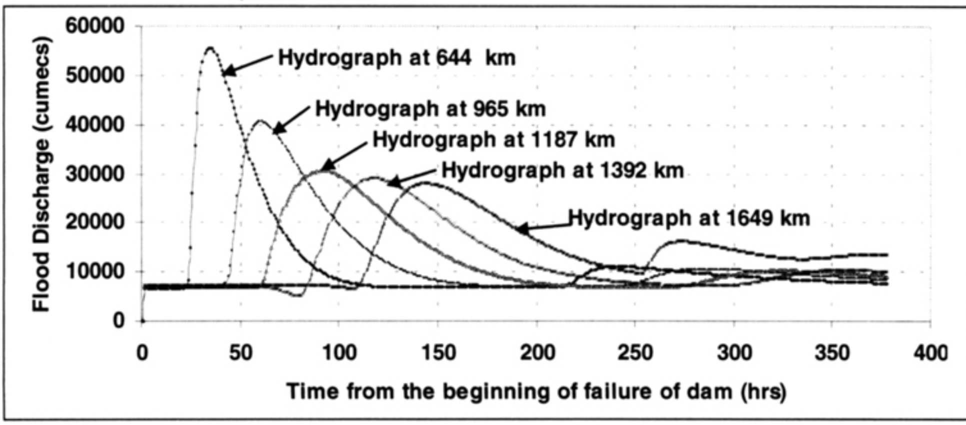

FIG. 19 DISCHARGE HYDROGRAPHS ALONG THE GANGA RIVER DUE TO FAILURE OF DAM

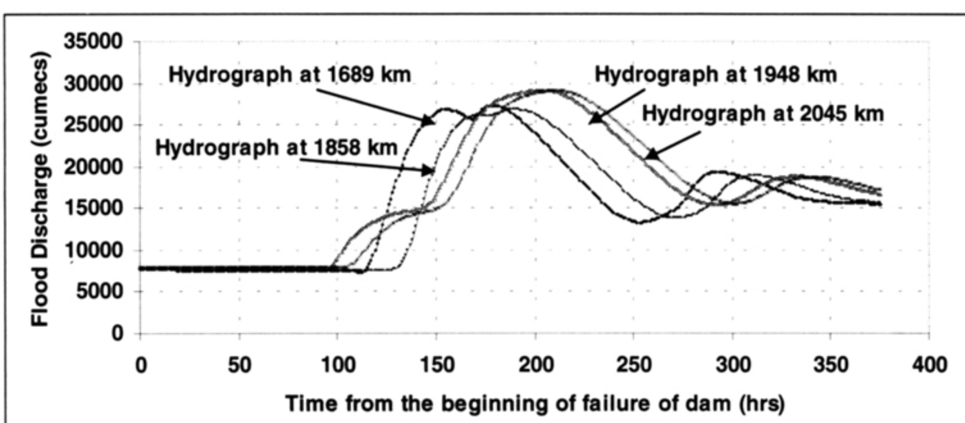

FIG. 20 DISCHARGE HYDROGRAPHS ALONG THE GANGA RIVER DUE TO FAILURE OF DAM

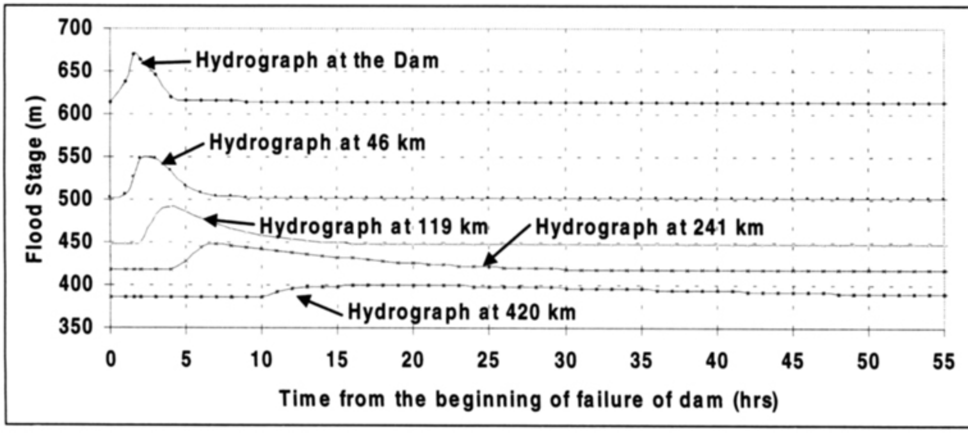

FIG. 21 STAGE HYDROGRAPHS ALONG THE GANGA RIVER DUE TO FAILURE OF DAM

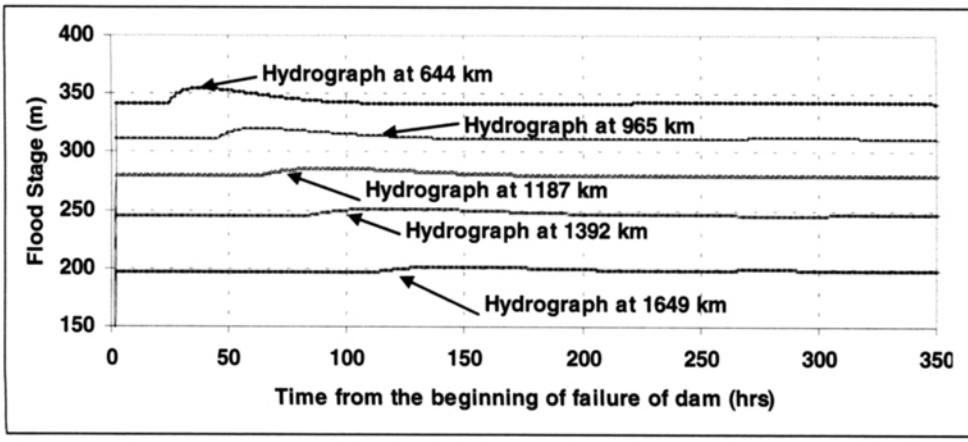

FIG. 22 STAGE HYDROGRAPHS ALONG THE GANGA RIVER DUE TO FAILURE OF DAM

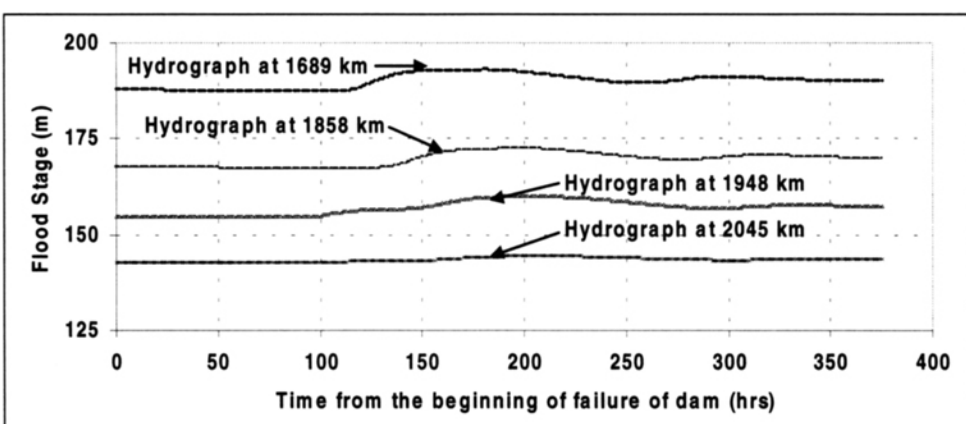

FIG. 23 STAGE HYDROGRAPHS ALONG THE GANGA RIVER DUE TO FAILURE OF DAM

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