EFFECT OF DOWNSTREAM BOUNDARY CONDITIONS ON THE PROPAGATION CHARACTERISTICS OF THE DAM BREAK FLOOD

आपो हिष्टा मयोभुवः

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 U.P.
INDIA
1994-95

PREFACE

For last more than one hundred years, the researchers have utilised popular de St. Venant's equations for defining the shallow wave propagation characteristics in the open channel. These equations are derived for unsteady gradually varied flow in the open channel. The approximate wave models defined based on the analytical solution of these linearised equations could be advantageous in certain situations instead of dynamic model for the want of compute time and efforts involved in data collection. The theoretical inequalities derived for the identification of where a particular wave situation occurs restricts their usage for the wide rectangular channels. In natural rivers, the flow wave type to occur at a site is attempted to be defined using the hysteresis of the loop rating curve of that site. The physical interpretation of this term further enhances its importance in daily routine. The effect of use of inappropriate boundary condition used for the solution of St. Venant's equations is shown on the characteristics of the flood wave propagation in the natural channel.

Present attempt of identification of flood wave types in the natural channels and their effect on the solution of dynamic wave equation has been put by Sh. S.K. Mishra, Scientist C and Dr. S.M. Seth, Scientist F & the Director of the National Institute of Hydrology, Roorkee. The support of Sh. Rajesh Agrawal, Research Asst. of the institute has been of immense importance in the preparation of this report and bringing the report in the final form.

(S M Seth)

DIRECTOR

C O N T E N T

LIST OF FIGURES

LIST OF TABLE

ABSTRACT

The understanding of the flood wave propagation is primarily based on the popular St. Venant's equations. The non-linear nature of these equations resorts to using a numerical scheme for solving them. The Four Point Finite Difference Implicit Scheme (or Preissmann Scheme) requires a downstream boundary condition for solution. The normally used boundary condition is the unique-steady state rating curve supplied through channel control. The actual boundary condition may however, not correspond to the user supplied boundary condition. It, therefore, may lead to emoureous computations.

The present report endeavours to study the above aspect with the help of the quantified hysteresis (dimensionless) of the rating curve. The criteria developed for defining the wave types may further help apply approximate flood wave models in liue of St. Venant equations (or full dynamic wave model).

INTRODUCTION

Since the inception of the St. Venant's equations, these have been in continuous use for the study of the flow behaviour in the open channels. Continuous attempts have been made for the solution of these equations but yet remains to be solved completely due to the complexities posed by the intrinsic non-linearity of these equations. However, the approximate solutions, linearised as well as numerical, have provided a great insight to the flow phenomena occurring in the open channels.

Solution of St. Venant's equations by a numerical technique such as finite difference implicit scheme, six point Abbott scheme- the former applied in the NWS DAMBRK model and the latter in DHI's MIKE11- invariably requires the use of downstream boundary conditions. One of the downstream boundary conditions can be either (i) time varying water surface fluctuations; or (ii) discharge hydrograph; or (iii) a rating curve. The first two types of information can be available at a site provided there exists a control structure. Normally used downstream boundary information is of third type- a steady state stage-discharge relationship. If the flow conditions does not lie within the kinematic range the computations due to inappropriate condition may lead to erroneous results.

An endeavour is made to study the flow behaviour in the downstream valley of the dam in various stages: (a) to study the flow behaviour at different locations of interest in the downstream valley using the hysteresis of the rating curves of various sites and to identify the reaches where kinematic or diffusive or dynamic wave situations occur; and (b) if the downstream boundary does not fall with in the limits of kinematic wave range, to suggest the remedial measure to arrive at more reliable results. (c) to relate the hysteresis with the phase difference between the stage and discharge waves and the attenuating tendency of a flood wave passing through the site under study. The study is substantiated by the two failure studies of the dams; one the Teton dam that failed in USA and the other the Machhu dam II that failed in the Gujarat State of India.

THEORETICAL BACKGROUND:

The mathematical models presently available to treat gradually varied, unsteady flow problems are based on St. Venant equations. These equations consist of the equation of continuity

$$\frac{\partial y}{\partial t} + y\frac{\partial u}{\partial x} + u\frac{\partial y}{\partial x} = 0 \tag{1}$$

and the one-dimensional conservation of momentum equation

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial y}{\partial x} + g(S_f - S_o) = 0 \tag{2}$$

Alternate but equally valid forms of these equations are

$$T\frac{\partial y}{\partial t} + \frac{\partial (Au)}{\partial x} = 0 \tag{3}$$

and

$$\frac{1}{g}\frac{\partial u}{\partial t} + \frac{u}{g}\frac{\partial u}{\partial x} + \frac{\partial y}{\partial x} + S_f - S_o = 0 \tag{4}$$

where,

- u = velocity in longitudinal direction;
- x = longitudinal coordinate;
- T = top width;
- A = flow area;
- S_o = slope of channel bed in longitudinal direction;
- S_f = friction slope; and
- g = acceleration of gravity.

Equations (1) and (2) or (3) and (4) compose a group of gradually varied, unsteady flow models termed as complete dynamic models. Being complete, this group of models can provide accurate results regarding unsteady flow; but, at the same time, they can be very demanding of computer resources. The models in this group are also limited by the assumptions required in the development of the St.

Venant equations and the assumptions required to apply them to a specific problem; e.g., assumptions regarding channel irregularities are usually required. From dynamic models, two groups of simplified models can be derived by making assumptions regarding the relative importance of various terms in the conservation of momentum equation (3).

The development and understanding of approximate models can, to some degree, be facilitated by rearranging Eq. (3) into the form of a rating equation which relates the discharge directly to the depth of flow (French, 1985). In general, the flow rate is given by

$$Q = \Gamma A R^m \sqrt{S_f} \tag{5}$$

where, Γ = empirical resistance coefficient;

R = hydraulic radius; and

m = empirical exponent.

In unsteady flow, S_f varies with both the slope of the wave and the depth of flow. In the case of a steady, uniform flow, the normal discharge is given by

$$Q = Q_N = \Gamma A R^m \sqrt{S_o}$$

$$\Gamma A R^m = \frac{Q_N}{\sqrt{S_o}} \tag{6}$$

Substituting Eq. (6) in Eq. (5) yields

$$Q = Q_N \sqrt{\frac{S_f}{S_o}} \tag{7}$$

Solving Eq. (4) for S_f

$$S_f = S_o - \left[\frac{1}{g}\frac{\partial u}{\partial t} + \frac{u}{g}\frac{\partial u}{\partial x} + \frac{\partial y}{\partial x} \right]$$

and substituting this expression in Eq. (7) yields

$$Q = Q_N \left[1 - \frac{1}{S_o}\frac{\partial y}{\partial x} - \frac{u}{S_o g}\frac{\partial u}{\partial x} - \frac{1}{S_o g}\frac{\partial u}{\partial t} \right]^{1/2} \qquad (8)$$

Kinematic wave (term 1)
Diffusion wave (terms up to $\frac{1}{S_o}\frac{\partial y}{\partial x}$)
Dynamic wave (all terms)

Equations (8) is termed as a looped rating curve (Fig. 1). In this figure, the points A and B indicate the points of maximum flow and maximum depth, respectively. The width of this loop and, therefore, the order of accuracy achieved by the approximate methods depend on the magnitude of the secondary terms in Eq.(8).

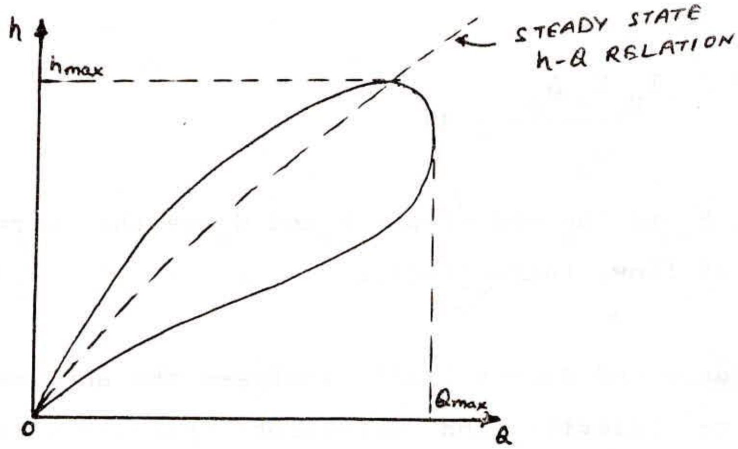


FIG. 1: LOOP RAING CURVE

In essence, the diffusion model assumes that in the momentum equation the inertia terms are negligible relative to the pressure, friction, and gravity terms. Ponce et al. (1978), in evaluating the range of applicability of the diffusion type of model, claimed that the diffusion model yields reasonable results in comparison with the complete dynamic model when

$$T_p S_o \left(\frac{g}{y_N} \right)^{1/2} \geq 15 \qquad (13)$$

where T_p = time of rise of a flood wave and y_N = steady, uniform flow depth. If Eq.(13) is satisfied, a diffusion model will accurately approximate the unsteady flow, and such a model can be used in place of the complete dynamic model.

The kinematic wave model assumes that the discharge is always equal to the normal discharge; therefore, the discharge is always a single-valued function of the depth of flow (Fig. 1). The St. Venant equation are thus reduced to Eq.(9) and the indicated terms in Eq.(8). The applicability criterion (Ponce et al., 1978) for the kinematic wave is given below:

$$\frac{T_p S_o V_o}{d_o} \geq 85 \qquad (14)$$

where, S_o is the bed slope; V_o and d_o are the normal velocity and depth of flow, respectively.

Ponce and Simons (1978) anslysed the shallow wave spectrum for the celerity and diffusion charcteristics using linear perturbation theory which were used for the solution of linearised St. Venant's equations valid for wide rectangular channel. The work was followed by Menendez and Norshini(1982) who explained the long wave spectrum based on amplitude and dispersion characteristics of the waves. The latter utilised the amplitude ratio (the ratio of depth and velocity wave amplitudes) and phase difference between these two waves instead of those used by the former, the discrete depth and velocity waves' amplitudes and phase difference zero.

A numerical scheme used for the solution of St. venant's equations is characterised by its amplitude and phase error portraits (Leendertse, 1967). Examples of amplitude and phase portraits for convection problems are given by Cunge (1969) and Ponce et al (1979).

The NWS DAMBRK (National Weather Service's Dam Break Flood Forecasting Model) uses weighted four-point scheme (Priessmann scheme) for the solution of the St. Venant's equations due to stability and convergence reasons. The stage-discharge relation, a frequently used downstream boundary condition is expressed in terms of the Manning's equation so as to reproduce the hysteresis effect (Kabir and Orsborn, 1984) in the stage-discharge relation. The nuemrical experiments by Fahmy and Moral-Seytoux (1994) on the Malakal-Melnut reach use the dynamic loop rating curves at the downstream boundary and at some fictitious location, which is downstream of the downtstream boundary, for the calibration of Manning's n of the last cross-section.

RESULTS AND DISCUSSION:

The dynamic wave expressed mathematically by St. Venant's equations are used for the routing of the flood wave,engendered by the breaching of a dam, propagating in the downstream valley of the dam site. The National Weather Service's Dam Break Flood Forecasting Model (DAMBRK) uses four point finite difference implicit scheme (Preissmann Scheme) for the solution of St. Venant's equations utilising the downstream boundary conditions which can be either a stage hydrograph or a discharge hydrograph or a rating curve. Normally used boundary condition is the unique steady-state rating curve. The conditions which could occur at the downstream boundary may fall in a category other than the specified through a rating curve. A rating curve, unique and steady in itself represents a kinematic situation whereas a loop rating curve, on the other hand, may represent a diffusive wave or dynamic wave situation depending on how strong the loop of the rating curve is. Stronger loop in the rating curve shows a dynamic wave while a mild one shows a diffusive wave.

The essence of the works involved in this study is summarized in the following steps:

1. to carry out dam break analysis of the two earth dams already failed by breaching for the computation of flood wave characteristics at different locations at the downstream locations of interest in the river valley.

2. to identify a way by which a type of wave could be represented. The strength of the loop rating curves is represented by the term hysteresis.

3. to explain the physical significance of hysteresis with reference to the topography and physical characteristics of the river valley.

4. to identify the type of situation or wave occurring at the most downstream boundary of the river valley and present the flood wave behaviour graphically all along the downstream river valley.

5. to estimate the errors in the computation of wave characteristics due to specifying a inappropriate boundary condition used for the solution of the St. Venant's equations.

6. to portray the zones of the occurrence of different flood waves along the downstream river valley utilising the inequalities (Eqs. 13 and 14) and the strength (described in terms of hysteresis) of the loop rating curves.

7. to draw a graphical relation between hysteresis of the loop rating curve of the site and the phase difference of the discharge and stage or depth wave occurring at that particular site.

8. to show how the hysteresis is related with the diffusive characteristics of a flood wave passing through the site under consideration.

A discussion on the above aspects is dealt in detail the following paragraphs:

1. The selected two dams, already failed by breaching, for the study are the Teton dam in USA and Machhu dam II in Gujarat

(India). The data of the Teton reservoir and its downstream valley are taken from the National Weather Service's DAMBRK Manual (1981) and the data of Machhu are taken from the report (TN-22) of National Institute of Hydrology (NIH), Roorkee (India). For the computations of the flood wave characteristics at the locations other than the specified in the Manual and in the Report, the river valley cross-sections are linearly interpolated. The NWS DAMBRK program is made use of for the wave study in the rivers' reaches. The flood wave characteristics of the Machhu dam II failure are depicted in the Fig. 2. Similarly, the wave propagation characteristics of Teton dam failure. could be summarized.

2. In literature, the loop of the rating curve is defined by hysteresis. In this study, the computation of hysteresis is carried out as below:

- with the help of the computed characteristics- the depth or stage, and the discharge- of the flood wave at different locations in the downstream river valley the rating curves are developed for different sites.

- the rating curves so available are non-dimensionalized as below:

$$h = \frac{H - H_{min}}{H_{max} - H_{min}} \text{ ; and} \qquad (15)$$

$$q = \frac{Q - Q_{min}}{Q_{max} - Q_{min}} \qquad (16)$$

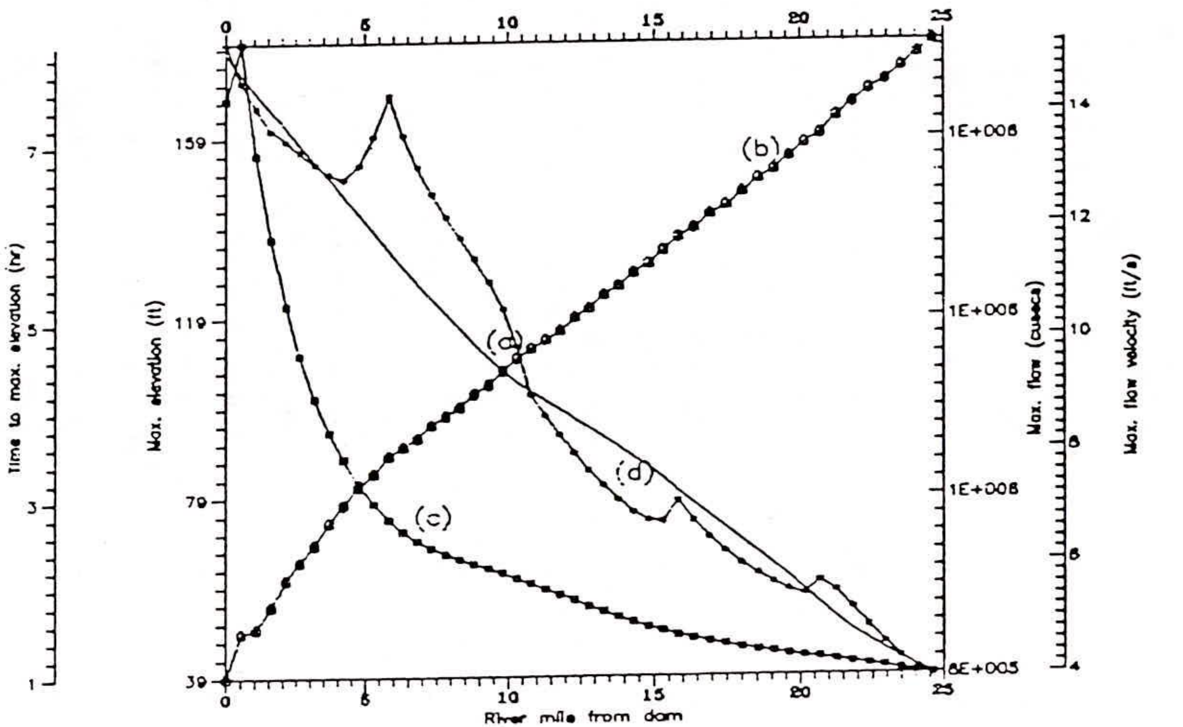


Fig. 2. Profiles of (a) Max. w.s. elevation (ft); (b) time to max. elevation (ft); (c) max. flow (cusecs); (d) max. flow velocity (ft/s) with river mile from Machhu Dam II (for final breach width=690.7 ft)

where,

h = dimensionless stage;

H_{max} = maximum computed depth at a site of interest;

H_{min} = minimum computed depth at a site of interest; and

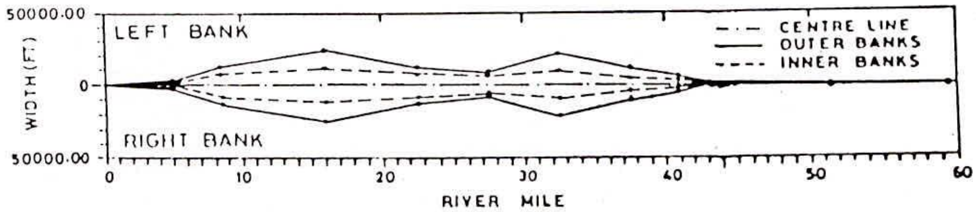
H = computed depth at a site of interest.

Similarly, Q stands for discharge.

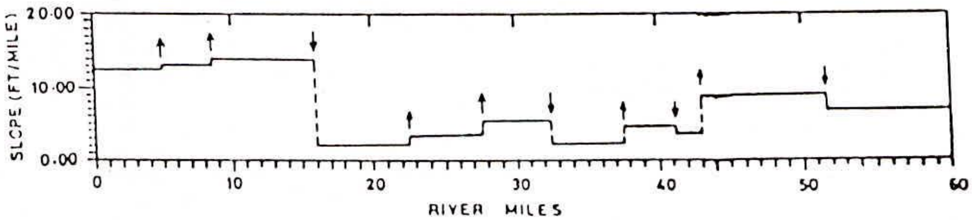
- the area lying within the loop of the rating curve is measured and termed as hysteresis.

More is the hysteresis, stronger is the loop of the rating curve and more dynamic is the flood wave. Conversely, less is the hysteresis, weaker is the loop of the rating curve and less dynamic or more diffusive is the flood wave. Zero hysteresis represents the kinematic wave situation i.e. the rating curve is unique steady-state stage-discharge relation. Mild loop in the rating curve shows a wave which is diffusive and strong loop shows the presence of a dynamic wave.

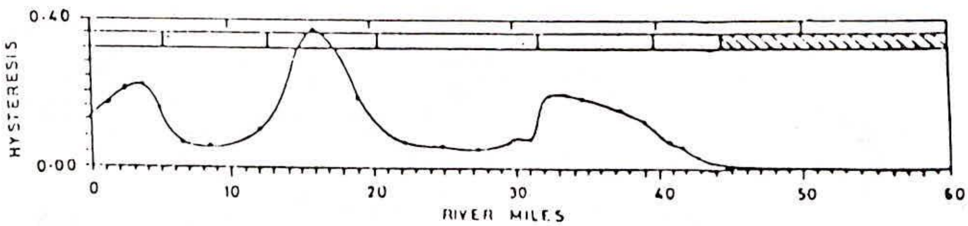
3. The results of the two case studies taken up for substantiating this study are presented in Figs. 3 & 4. Fig. 3 pertains to the study of Teton dam and the Fig. 4 to the Machhu study. The first of these, figures presents the plan view of the river valley and the middle one shows the slope variation along the channel and the third shows the variation of hysteresis as the flood wave propagates downstream. These are the idealized sketches of the river valley taken up for the computation of propagation characteristics of the flood wave. It is worth mentioning that the interpolated cross-sections are used for the estimation of hysteresis at desired locations in the river valley. Ostensibly,



(a) PLAN VIEW OF THE RIVER VALLEY. THE AVAILABLE CROSS-SECTIONS ARE REPRESENTED BY DOTS.



(b) BED SLOP VARIATION ALONG THE RIVER VALLEY. UP AND DOWN ARROW MARKS INDICATE STEEPENING AND FLATTENING, RESPECTIVELY, OF ADJOINING DOWNSTREAM REACHES.



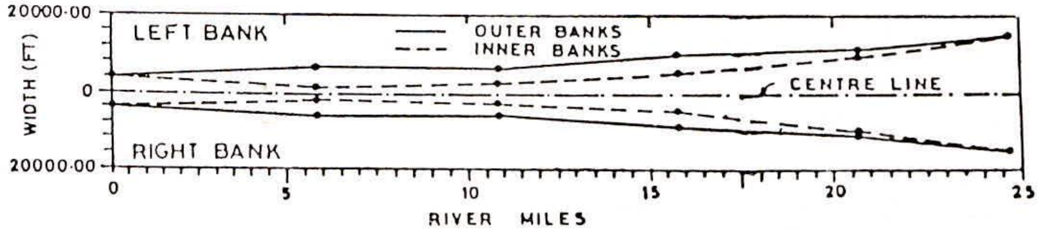
(c) HYSTERESIS VARIATION ALONG THE RIVER VALLEY.

[ ] DYNAMIC WAVE ZONE

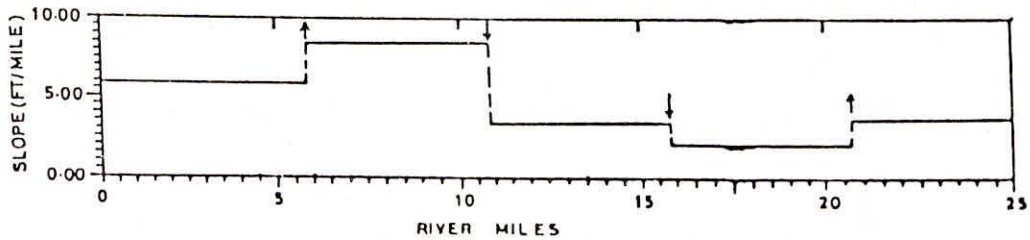
[ ] DIFFUSIVE WAVE (DW) ZONE

[ ] KINEMATIC WAVE (KW) ZONE

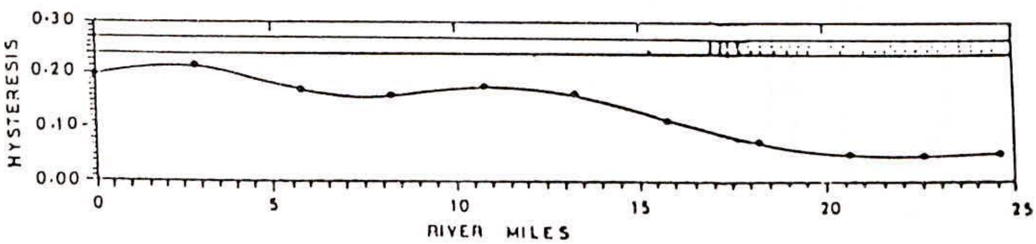
FIG.3 TETON DAM FAILURE STUDY. ZERO MILE CORRESPONDS TO DAM SITE.



(a) PLAN VIEW OF THE RIVER VALLEY. THE AVAILABLE CROSS-SECTIONS ARE REPRESENTED BY DOTS.



(b) BED SLOPE VARIATION ALONG THE RIVER VALLEY. UP AND DOWN ARROW MARKS INDICATE STEEPENING AND FLATTENING, RESPECTIVELY, OF ADJOINING DOWN STREAM REACHES.



(c) HYSTERESIS VARIATION ALONG THE RIVER VALLEY.

[ ] DYNAMIC WAVE ZONE

[⋯] DIFFUSIVE WAVE (DW) ZONE

FIG. 4 MACHHU DAM FAILURE STUDY. ZERO MILE CORRESPONDS TO DAM SITE.

the variation of the hysteresis is a combined effect of the contraction or expansion and the channel slope. Contraction or expansion in a river reach results in the loss of energy during the propagation of the flood wave and so happens if the channel slope changes from steeper to milder. The expansion losses are normally more than the losses due to contraction given the extent of contraction or expansion is same. The up arrow marks in the figure showing slope variation indicate the steepening of the adjacent down-stream reach slope and conversely, the down arrow marks indicate reduction in channel slope. Clearly visible from the Figs. 3 and 4 is that where these two physical characteristics of the river valley plays unidirectionally towards the loss of energy, the hysteresis is more pronounced and vice versa. Therefore, it can be inferred that the more is the loss of energy, more is the hysteresis or weaker is the flood wave or more dynamic is the flood wave. The steepening tendency of the bed slope takes the flood wave towards the kinematic situation. Conversely, the reduction in the bed slope tends to bring the wave to become dynamic or diffusive depending up on the extent of reduction. More prismatic the channel is lesser loss of energy is to occur and lesser be the hysteresis or more tendency of the flood wave to be towards kinematic situation. Conversely, more is the expansion or contraction, more loss of energy of the wave is to occur tending to bring the wave towards dynamic situation. Succinctly, the hysteresis of a loop rating curve of a site represents the type of a flood wave at that site and is apparently related with the loss of energy occurred during the propagation of the flood wave downstream.

4. Fig. 3 shows that as the flood wave travels downstream of the dam- zero mile corresponds to the dam site- the hysteresis

increases up to 4.00 miles and then decreases and during its further travel downstream it reaches the highest value at about 16.00 mile. Again, the increase or decrease in the hysteresis is due to the combined effect of channel characteristics apparent from the figure. After traveling for about 45.00 miles from the dam site, the flood wave characteristics nears to the kinematic wave situation- the hysteresis assume a value approaching to zero- and remain kinematic till the flood wave reaches the most downstream point of interest where the appropriate downstream boundary condition is to be supplied externally to the DAMBRK program to compute the flood wave characteristics. The single-valued stage-discharge relationship, fed through a downstream channel control, supplied for the computations much reasonably closely conforms with the wave characteristics at this location. But a close investigation of the Machhu study results (Fig. 4)- the hysteresis variation can be explained in a similar fashion as done for Teton study- reveals that the hysteresis at the most downstream location i.e. at 24.63 mile does not reach a value where the flood could be inferred to be kinematic therefore the use of a single-valued stage-discharge relation as a downstream boundary condition may lead to erroneous computations of the flood wave characteristics and it is shown in the forthcoming text.

5. The flood wave characteristics occurred in the Machhu river valley (Fig. 2), were computed using a downstream channel control and in the above para, it is shown that the applied boundary condition does not conform with the computed as the hysteresis at the most downstream location is neither zero nor it approaches to zero. To meet the requirement of zero or near zero hysteresis at the downstream boundary, the reach length is increased

hypothetically up to 100 miles keeping the slope of the extended reach equal to the slope of the last reach- that just upstream of 24.63 miles- and the cross-section the same as of the last cross-section- section at 24.63 miles- assuming that during the travel, the flood wave would reach to kinematic situation which is equivalent to zero or nearing zero hysteresis. Again the computations are made and the results are presented in Figs.5 & 6. It is evident from the figure that the computations due to the extended reach tends to increase the magnitude of the depth or stage and the discharge at 24.63 miles. The difference between the two is of the order of 10 ft (about 3 meters). The effect is apparent up to about 4 miles from the downstream location. The inaccurate estimates of the stage due to inappropriate application of downstream boundary may lead to significant underestimation of the inundated area. The effect is more pronounced at the downstream boundary but gradually dampens as the computations proceed upstream from the downstream boundary.

6. Utilising the inequalites (Eqs. 13 & 14), the zones of different kinds of waves occurring along the river valley during the propagation of dam break flood wave are portrayed. The information available on maximum depth, maximum discharge, time of rise of the flood wave at different locations are made use of in the decision making. However, the kinds of waves so described and portrayed are subject to variation. Based on the trade-off between the hysteresis values and the inequalities' values, the wave types could be defined using the hysteresis as given in Table-1. The sketched zones in the Fig. 3(c) & 4(c) indicate that in the Teton reach, the dynamic wave occurs in the reaches described by 0-5.5, 12.75-20.80, and 32.00-40.00 miles whereas kinematic wave occurs in the reach described by 44.5-59.5 miles. In the other reaches,

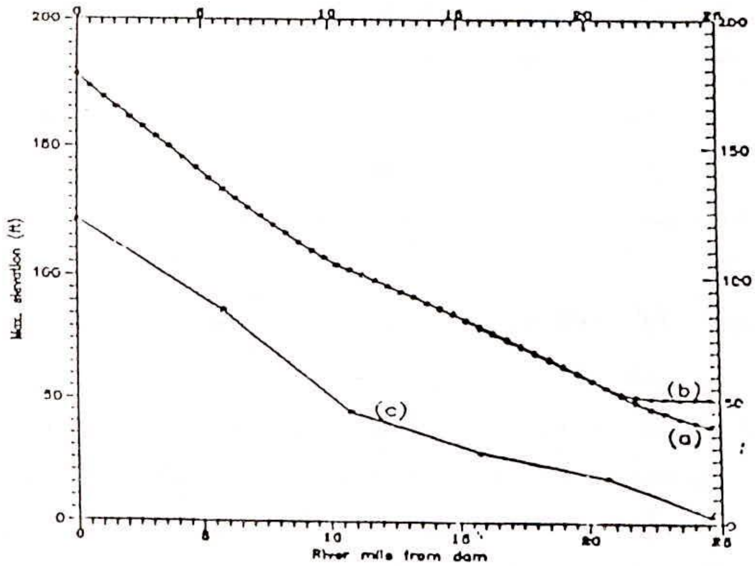


Fig. 5 Profiles of (1) max. w.s. elevation (ft):(a) without; (b) with hypothetical reach of 100 miles; (2) river bottom (ft) (c) with river mile from Machhu Dam II

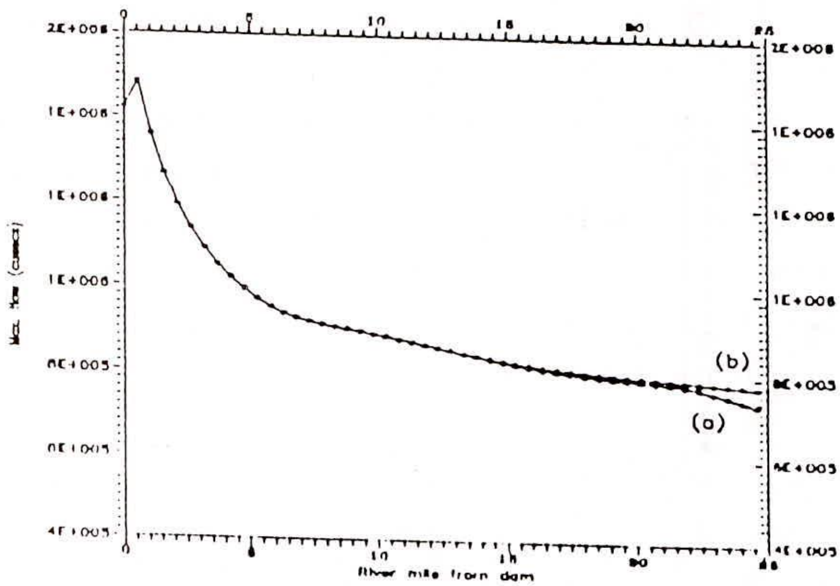


Fig. 6 Profiles of (1) max. w.s. elevation (ft):(a) without; (b) with hypothetical reach of 100 miles; (2) river-bottom (ft) (c) with river mile from Machhu Dam II

the diffusive wave occurs. In the Machhu reach, only two waves occur i.e. the dynamic and the diffusive; the former occur before 17.00 mile and the latter after this. The essence of preparing such sketches for the wave types lies in the fact that the application of approximate models to these individual reaches may provide the answers which are close to those obtained by applying the full dynamic wave model which, in turn, requires more computing time and more efforts in data preparation.

TABLE-1 : CRITERIA FOR WAVE TYPES

Wave Type	Hysteresis (dimensionless)	Phase Difference (radian)
Kinematic wave	$\eta < 0.025$	$\phi < 0.03$
Diffusive wave	$0.025 \leq \eta \leq 0.1$	$0.03 \leq \phi \leq 0.13$
Dynamic wave	$\eta > 0.1$	$\phi > 0.13$

7. A flood wave propagating in an open channel consists of two waves- depth or stage and velocity or discharge wave- travelling simultaneously. The phase difference is computed using the relation:

$$\phi = \frac{2\pi}{T} (t_{ph} - t_{pQ}) \qquad (17)$$

where,

ϕ = phase difference (radian);

T = the time period of the flood wave (the time of rise and the time of recession) (hr.)

t_{ph} = time to peak of stage wave (hr.); and

t_{pQ} = time of rise of discharge wave (hr.).

If the phase difference between the two waves, occurring at a site, is zero, there exists a unique stage- discharge relation- making the hysteresis equal to zero describing the kinematic wave situation. Grouping the Teton and Machhu hysteresis data together and plotting them against the corresponding phase difference between the stage and discharge waves, a linear relation is obtained (Fig. 7). The logarithmic scale of the hysteresis has been taken to show the extent to which it could take the value. Ostensibly, hysteresis equal to 1.0 is practically an impossibility for the occurrence of a wave in an open channel. From this figure, the derived approximate inequalities for defining wave types are summarized in Table-1.

8. In an endeavour to show how the hysteresis of a particular loop rating curve of a site is related with the attenuating tendency of the discharge wave passing through the site, a linear relation is developed (Fig. 8). The computations for obtaining percent attenuation per mile are made using

$$\% \text{ attenuation per mile} = \left(\frac{Q_j - Q_{j+1}}{Q_j} * 100 \right) / \Delta x \qquad (18)$$

where,

Q_j & Q_{j+1} = the peak discharges at successive locations j & J+1, respectively (m^3/sec.);

Δx = reach length in mile.

The results of the Fig. 8 are encouraging in a sense that the relation conforms with the established norms as the wave type changes from kinematic to dynamic (or allusively, the hysteresis

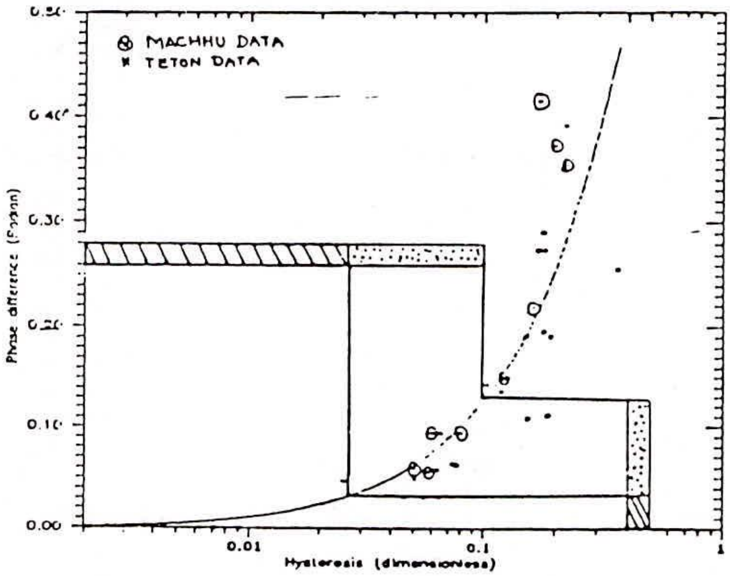


Fig. 7 : Dimensionless Hysteresis vs. Phase Difference (Radian) of Q & H -waves

[hatched box] - Kinematic wave zone
[dotted box] - Diffusion wave zone
(Right side of DW represents dynamic wave zone)

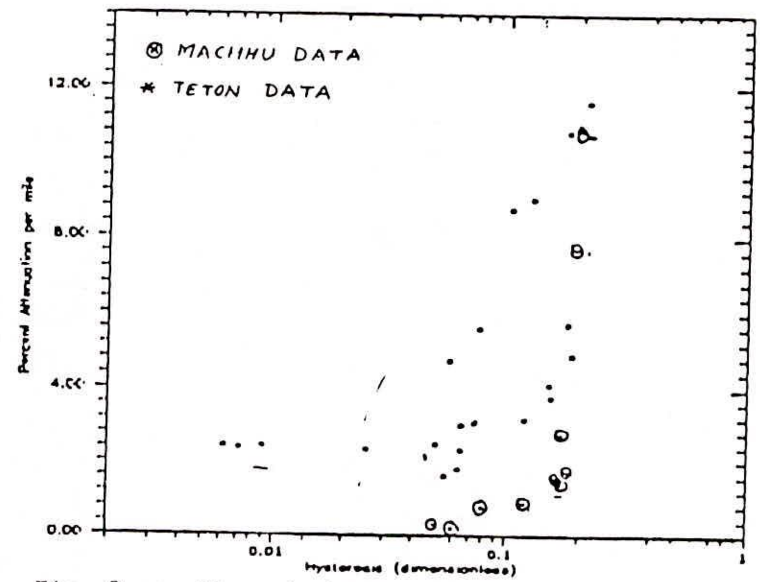


Fig. 8 : Dimensionless Hysteresis vs. Percent Attenuation per Mile of Reach Length

the increases) the diffusion or attenuation increases. But the relation seems more river specific. There are two similar, in trend, but distinct relations for the Teton and Machhu reaches; the former being milder than the latter. In the Teton reach, the kinematic wave shows approximately 2.5 percent attenuation per mile while 0.4 or less attenuation per mile shown for the diffusive wave in the Machhu reach. It is contrasting to that described above for the wave types and their attenuating characteristics. Apparently, it occurs due to the incorporation of the reach length in describing the attenuating characteristics. Therefore, it can be inferred that different rivers describe different relations for the description of the magnitude of the attenuation to occur under certain wave type and their results should not be intermingled with each other for deriving a general relationship.

CONCLUSION:

The use of NWS DAMBRK model is made for analyzing the wave types in the downstream reaches of the Teton dam of USA and the Machhu dam II of India. The study reveals that the hysteresis of the loops of the rating curves of the sites could be utilitied for defining the flood wave types- kinematic or diffusive or dynamic- occurring in the downstream valleys of the two dams. The inappropriate application of downstream boundary condition for the computations of flood wave characteristics in the downstream valley leads to erroneous results and this is shown through the Machhu study. The application of extended reach for more reliable computations is suggested. The wave type based zoning of the river valley reaches may be of use in reducing computing time and the efforts involved in data preparation for the application of the full dynamic wave model.

Further, the hysteresis is related with the phase difference between the stage and discharge waves occurring during their passages through a site under consideration and with the attenuating tendency of that discharge wave. In the light of the results of the present study, it needs relooking into and reevaluating of the earlier theoretically derived inequalities used for defining the type of wave formation in the open channels to enhance their pragmatic utility to the natural channels of complex geometry.

REFERENCES:

Cunge, J. A. (1969),'On the subject of a flood propagation computation method (Muskingum method),'J. Hydr. Res., 7(2), 205-230.

Fahmy, H.E.S. and H.J. Moral-Seytoux (1994),'Hybrid non-inertia and statistical model versus hydrdynamic routing,' J. Hydr. Engg., 120(6), 706-721.

French R.H.(1985),'Open channel hydraulics,' McGraw-Hill Book Co., Inc. New York, NY, 551.

Kabir, N. and Orsborn, J.F. (1984),'Numerical flood routing for natural channels', Schreiber, D.L.(ed), Proc. of the Conf. on Water for Resources and Development,' A.S.C.E., New York, Aug. 14-17, pp. 148-152.

Leendertse, J. J.(1967),'Aspects of a computational model for long period water wave propagation,' RM-5294-PR,The Rand Corporation , Santa Monica, Calif.

Menendez, A.N. and Norshini, R. (1982),'Spectrum of Shallow Wwater waves: An analysis,' J. Hydr. Div., ASCE, 108(HY1, 75-94.

National Weather Service(NWS) (1981),'The NWS dam-break flood forecasting model', Users Manual, Davis, Calif. 95616.

NIH (1985-86),'Data requirement and preparation for DAMBRK model', by M. Perumal and S. Chandra, TN-22, NIH, Roorkee, India.

Ponce, V.M., Li, R.M. and Simons, D.B. (1978),'Applicability of kinematic and diffusive models,' J. Hydr. Div., ASCE, 104(HY3), 353-360.

Ponce, V.M., Chen, Y.H. and Simons, D.B. (1979),'Unconditional Stability in Convection Computation,' j. Hydr. Div., ASCE, 105(9), 1079-1086.