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Optimization of hydraulic design of approach channel of spillway by hydraulic model studies

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Abstract

The approach channel is intended to divert the flow safely from its original course and the diversion may be intended towards spillway, power intake or any other hydraulic structure. The hydraulic design of the approach channel involves determining cross-section dimensions of the channel for the design flood at a given flow velocity, slope and shape or alternatively determining the discharge capacity for the given layout and cross-section dimensions. Proper alignment of approach channel minimizes the head loss by reducing the oblique flows. Sometimes, the spillway approach channel is submerged with unconfined boundaries, asymmetrical in layout. However, these conditions are site-specific. Hydraulic model studies play a substantial role in testing these kinds of layouts to find out an optimum layout. Studies have been carried out on a 1:140 scale model of the spillway to optimize the layout of an unconfined, unlined, asymmetrical, and submerged approach channel by the assessment of velocity profiles and flow pattern in the approach channel for different shaped layouts. Studies indicated that the efficient layout of the approach channel is governed by its maximum available width and straightforward approach, prevention of lateral inflows by the provision of additional embankments and provision of suitable length of the guide bund.

Keywords: Approach channel, Asymmetry, Guide bund, Flood, Spillway

Introduction

The spillway is a structure required for maintaining the reservoir water levels by disposing of the excess flood. The approach channel is a discharge carrier that diverts the flow towards the spillway. The alignment of the channel shall be desirably straight with confined boundaries to have better approach flows, which would improve the discharge capacity of the spillway. The geographical location of the channel and the non-availability of the forest clearances may keep the channel as non-straight, curved/oblique or partially straight and partially curved/oblique. In case of oblique channels, when a steady current enters a channel obliquely, the flow will be refracted in the direction of the channel and a secondary flow will be introduced [2]. Flood disposing channels may be designed without one embankment due to the non-availability of a suitable foundation [8].

The general design of spillway approach channel comprises an entry zone, central zone and exit zone. The entrance of the channel allows the smooth entry of flow. The middle portion should be straight or curved or partially curved and partially straight. The width at the exit of the channel should coincide with the width of the spillway. The guide bunds are provided at the exit of the channel (in front of the spillway) to guide the flow towards the spillway and also minimize the oblique flows in front of the spillway and protect the spillway flanks from subjecting to swirling flows. The geometry of the guide wall causes instability in the flow pattern and creates secondary and vortex flows in the approach channel and the shape of the guide wall reduces the performance of spillway to pass the peak flood discharge [4].

Finding out an optimized design of such unconfined, asymmetrical and submerged approach channel of spillway is essential in disposing of enormous floods. In the past, studies were carried out to assess the flow pattern in the approach channel of the spillway of Kamal Saleh dam, Iran, using Computational Fluid Dynamics (CFD) modelling, considering 350-m long approach channel [4]. However, when the approach channel of the spillway is longer and subjected to heavy floods, the transverse waves, flow instability and rotating flows upstream of the spillway would be enormous. The optimization of design is to be done by observing the flow pattern and measurement of velocities all along the approach channel for various layouts. The velocity of a fluid will depend on a number of factors, including the flow geometry, the fluid properties (density, viscosity), and the pressure. The purpose of studying the flow pattern is to examine the effect of geometry on the formation of transverse waves, flow instability and rotating and reciprocating flows in front of the spillway [5]. Velocity profiles in natural channels during high floods may be assessed by carrying out the sampling only in the upper portion of the flow area. The possibility to assess the velocity distribution considering the maximum velocity is important for the discharge monitoring during high floods [3]. Physical models are indispensable to observe the flow conditions wherever required. Ultimately, the design of the channel shall be optimized to have satisfactory flow conditions to improve the discharge capacity of the spillway.

Methods for optimization of hydraulic design of approach channel layout

In order to optimize the layout of an unconfined, asymmetrical, submerged approach channel, a 3-D 1:140 scale comprehensive physical model was constructed in Central Water and Power Research Station (CWPRS), Pune. The Froudian scale relations in terms of 1:140 scale model are given in Table 1. Hydraulic model studies for evolving a suitable arrangement of the diversion through open channel are almost indispensable and the model studies help decide the most efficient alignment of the diversion channel [1]. Various layouts of approach channel viz., curved, partially straight and partially curved channel; channel with different forms of guide bunds; and channel with and without guide bund, were constructed and hydraulic model studies were carried out to optimize the layout by observing the velocity profiles along the whole length and width of approach channel. The velocities were observed by a propeller-type current metre at various locations in the direction of flow, at a depth 0.6 times the depth of flow in the

Table 1 Model scale relations

Physical parameter	Unit	Relation	Scale
Length scale ratio (L_r)	m	$L_p/L_m = L_r$	140
Area scale ratio (A_r)	m^2	$A_p/A_m = L_r^{(2)}$	19,600
Velocity scale ratio (V_r)	m/s	$V_p/V_m = L_r^{(1/2)}$	11.832
Discharge scale ratio (Q_r)	m^3/s	$Q_p/Q_m = L_r^{(5/2)}$	231,910.32
Time scale ratio (T_r)	sec	$T_p/T_m = L_r^{(1/2)}$	11.832
Manning's roughness coefficient ratio (n_r)	$s/m^{1/3}$	$n_p/n_m = L_r^{(1/6)}$	2.2787

model study, as it gives the average velocity. The studies are carried out on the following layouts as shown in Fig. 1.

1. 200-m-wide (at narrow section) straight approach channel without any guide bund
2. 200-m-wide straight approach channel with 145-m long curved left guide bund at the exit
3. 660-m-wide curved approach channel with 760-m long curved left guide bund at the exit
4. 450-m-wide (at narrow section) asymmetrical approach channel with 500-m long straight left guide bund at the exit
5. 550-m-wide (at narrow section) asymmetrical approach channel with 500-m long straight left guide bund at the exit

Straight approach channel 200 m wide at narrow section without guide bund

An approach channel of length about 2000 m and 200 m wide was considered for the study. The approach channel area was finished with a floating coat of cement plaster and painted. The Manning's coefficient is in agreement with the scale of the model considering the sandy bed channel with boulders is having a Manning's coefficient 0.027. The approach channel was having a mild slope of 1 in 10,000. The channel had side banks at slopes of 1 in 4. The bed elevation at the entrance was below average river bed and the width of the channel at the exit coincided with the spillway width and the bed elevation was at elevation, El. 17 m. The channel was constricted by hills both on the left and right at the entrance. When the water level increases above El. 25 m (average river bed level), the channel becomes submerged and unconfined. Figure 2a shows the top view of the approach channel 200 m wide without guide bund.

The approach channel is to pass floods up to a maximum of 141,583 m^3/s (0.61 m^3/s in the model) towards the spillway comprising of 48 spans of 16 m (W) × 20 m (H) in size, with the Full Reservoir Level (FRL) at El. 45.72 m and crest at El. 25.72 m, with all the spillway gates in fully open condition. The maximum tailwater level would be at El. 32.96 m while passing the maximum discharge.

Flow conditions and velocity profiles along the channel

The model was run for discharges up to Probable Maximum Flood (PMF) with all spillway gates in the fully open condition. Flow conditions for these operating

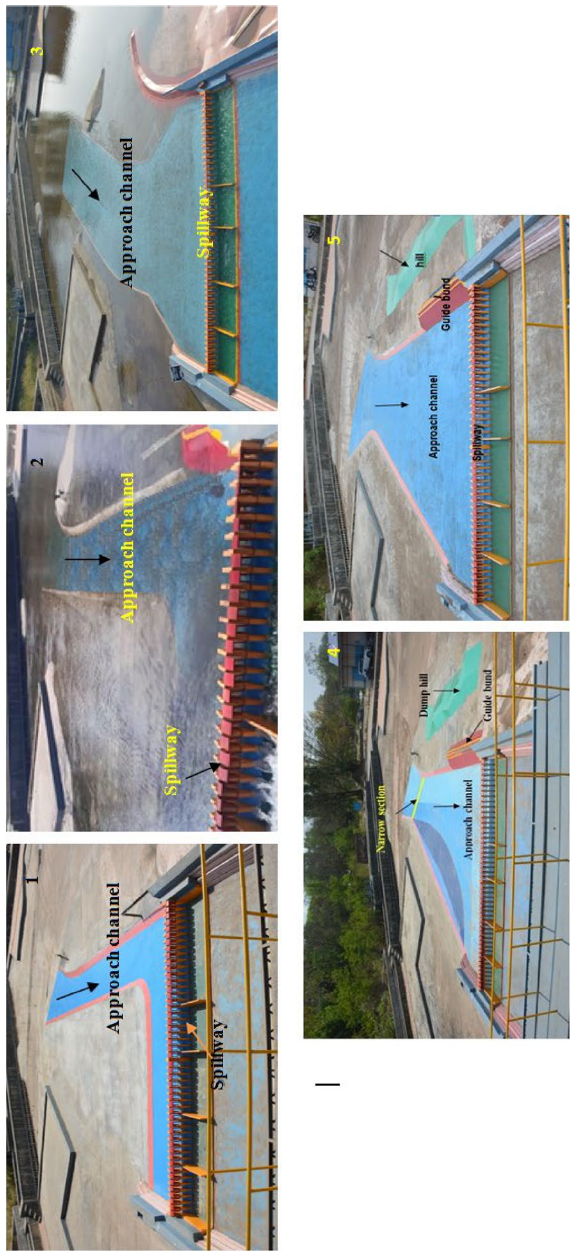

Fig. 1 Various layouts of the approach channel

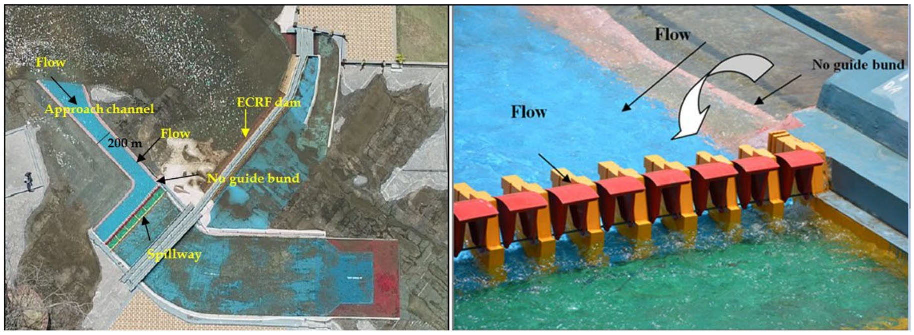

Fig. 2 Approach channel (**a**). Layout (**b**). Flow conditions in the region of no guide bund

Table 2 The velocities (m/s) along the approach channel for different layouts

Ch	Approach channel (200 m wide at narrow section with 145-m-long guide bund)			Approach channel (660 m wide at narrow section with 760-m-long guide bund)			Approach channel (450 m wide at narrow section with 500-m-long guide bund)			Approach channel (550 m wide at narrow section with 500-m-long guide bund)		
	Left	Centre	Right	Lft	Centre	Rgt	Lft	Centre	Rgt	Lft	Centre	Rgt
0	3.9	4.4	4.9	3.4	4.8	4.0	4.0	5.5	4.0	3.8	5.5	3.9
100	2.3	5.5	3.5	2.4	5.8	3.0	1.3	7.7	1.6	0.3	7.4	0.9
200	12.6	6.6	1.8	4.0	7.8	2.0	1.7	8.6	1.1	0.5	8.0	0.6
500	5.2	4.8	5.3	8.8	7.8	2.3	1.9	10.1	1.8	1.3	9.0	1.2
800	5.9	6.7	6.6	7.8	6.4	2.0	6.9	9.8	1.9	8.1	9.5	1.4
1100	7.0	7.1	7.1	8.1	8.2	2.3	7.2	9.0	2.4	6.7	9.0	3.4
1400	6.3	5.9	5.4	7.4	7.5	1.0	7.3	8.6	2.8	7.0	7.9	8.6
1700	5.1	3.9	4.7	11.5	13.4	3.0	3.4	5.4	5.0	2.9	5.9	6.8
2000	5.1	6.7	5.2	5.1	4.4	9.3	2.9	7.8	7.6	2.7	4.8	5.5

conditions showed that the flow enters the approach channel and the spillway in multiple directions viz., from right side of approach channel, through the entrance of the approach channel and through the passage between a left-side hill and dam. The channel was straight but aligned oblique to the main river course. This caused oblique flow conditions in the approach channel as the flow is predominantly moving towards the left and centre of the spillway. The lateral flows from the Earth Cum Rockfill (ECRF) dam were seen pushing the entire flow towards the right creating oblique flow conditions in the entire approach channel. The upstream velocities were more due to the narrow section of the approach channel that disposes huge flood. For ungated operation of the spillway, velocities of the order of 9.2 m/s were observed at chainage 100 m (Ch. 100 m) upstream of the spillway along the centre line. Table 2 shows the velocities observed along the approach channel along the left, centre and right banks. Violent flow conditions were observed along left abutment for non provision of guide bund since the flow is impinging into the channel. Figure 2b shows flow conditions in the approach channel while passing discharge 141,583 m^3/s of Probable Maximum Flood (PMF) for ungated operation of spillway. The maximum water level observed along the channel for PMF was at about El. 46.5 m at the entry of the channel and El. 45.35 m at the exit.

Straight approach channel 200 m wide at narrow section with 145-m long curved guide bund

For the same profile as mentioned above, a curved guide bund of 145 m long was provided at the exit, along the left flank of the spillway to assess the improvement in the flow conditions in the approach channel.

Flow conditions and velocity profiles along the channel

With the provision of guide bund, the flow conditions were improved and velocities were reduced along the left flank of the spillway up to the exit of the bund. The velocities of the order of 5.5 m/s were observed at Ch. 100 m upstream of the spillway along the centre line. The upstream velocities were more or less similar from chainage 500 m to the entrance. Return currents were prevailing due to the entry of lateral flows at the end of the guide bund. Figure 3 shows flow conditions in the approach channel while passing discharge 141,583 m^3/s for the ungated operation of the spillway. Table 2 shows the velocities observed along the approach channel along the left, centre and right sides. The maximum water level observed along the channel for PMF was at El. 46.5 m at the entry of the channel and El. 45.35 m at the exit.

Approach channel partially curved and partially straight with a curved guide bund

The approach channel that was considered subsequently for the study comprised 660 m wide and about 2000 m long with bed elevation at El. 17 m. The width of channel at the entry was 660 m and increases to 1000 m at chainage 200 m upstream. The channel has a curvature of radius 800 m at chainage 1000 m thus making the alignment curved. The channel was constricted by hills both on left and right. A guide bund of 760 m long was provided along the left flank of the channel.

Flow conditions and velocity profiles along the approach channel

Flow conditions in the model showed that the flow enters the approach channel and the spillway in multiple directions as for earlier layouts. This caused oblique flow conditions in approach channel as the flow is predominantly moving towards the left and centre

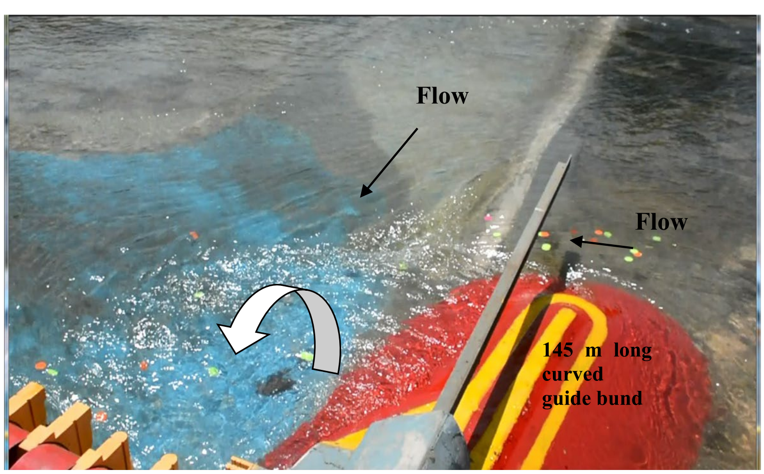

Fig. 3 Flow conditions in approach channel ($Q = 141{,}583$ m.^{3}/s, ungated operation)

of spillway. The lateral flows from the reservoir are pushing the entire flow towards the right. Hydraulic model studies indicated that the velocities of the order of 1–5.8 m/s were observed at Ch. 100 m upstream of the spillway along the centre line. For discharges higher than 25% of Probable Maximum Flood, flow was seen accelerating along the guide bund and rapids were seen forming. Velocities of the order of 4–12 m/s were observed along the guide bund for discharges from 25 to 100% of PMF. The water levels at 100 m upstream of the spillway are 34.36 m for 25% of PMF and 45.35 for PMF discharge [6]. The maximum water level observed along the channel for PMF was at El. 47 m at the entry of the channel and El. 45.35 at the exit. The velocities observed along the approach channel are shown in Table 2. Figure 4 shows the flow conditions in the approach channel while passing 141,583 m^3/s with the ungated operation of the spillway.

Approach channel 450 m wide at narrow section with a straight guide bund of 500 m long and with a left embankment

To optimize the layout of the approach channel to improve the flow conditions further, the study was conducted by widening the approach channel 450 m at the narrow section, also incorporating a 500-m long straight upstream guide bund along the left flank of the spillway and by the provision of an embankment of length of about 1500 m to the left of the approach channel. The provision of the embankment was to prevent the lateral entry of flow into the approach channel from the reservoir. The top elevation of the embankment was El. 50 m, above the Full Reservoir Level (FRL). The approach channel was by and large trapezoidal shape in plan. The width of the channel at the narrowest section is 450 m and this gradually becomes 1000 m at about 300 m upstream of the spillway. Studies were carried out to ascertain flow conditions along the approach channel, in front of the spillway, in the vicinity of the guide bund for discharges up to 141,583 m^3/s (PMF) for the ungated operation of the spillway.

Improvement in the discharge capacity of spillway

With the increase in the width of approach channel, the head over the spillway is likely to be decreased. But various factors that affect the approach flow conditions have influence on

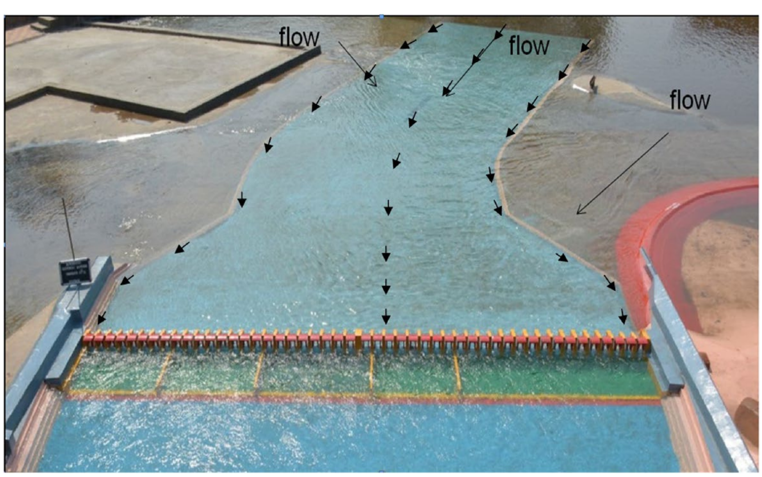

Fig. 4 Flow conditions in approach channel

the discharge capacity of the spillway. Hydraulic model studies indicated that the discharge capacity of the spillway improved as Probable Maximum flood (PMF); 141,583 m^3/s could be passed at Reservoir Water Level (RWL) El. 44.95 m when compared with El. 45.35 m, for the reduced width of the channel. This is a reduction of 2% of the head over the spillway. 75% of PMF (106,187 m^3/s) can be passed at RWL EL. 41.8 m, 60% of PMF (84,950 m^3/s) at El. 39.8 m, 50% of PMF (70,792 m^3/s) at El. 38.28 m and 25% of PMF (35,396 m^3/s) at El. 34.38 m. This layout was showing improvement in the discharge capacity of the spillway for a wider approach channel with distributed approach flow in front of the spillway.

Flow conditions and velocity profiles along the approach channel

Along the approach channel, the flow was seen distributed along the entire area and getting submerged and unconfined for reservoir levels beyond El. 25 m. The narrow section at the upstream entry of the approach channel created non-uniform flow fields. Further widening of the narrow section as per feasible site condition may further improve the flow conditions in the approach channel.

The incorporation of 500-m long straight guide bund reduced the velocities near the left abutment of the spillway. Frequent and periodic formation of swirling flows in front of the spillway was eliminated due to the blocking of lateral flows from the left side reservoir. Vortex shedding along the guide bund was also eliminated. The sharp rise of the water surface on the outer boundary of vortices was eliminated. Water surface profiles were contained in front of spillway piers and overtopping was not observed.

The left embankment was seen acting as a barrier preventing lateral entry of flow from the reservoir. An artificial pool is being created between the embankment and the straight guide bund, stabilizing flow and reducing the velocities along the left flank of the spillway. Along the spillway axis, the maximum velocities were 4 m/s, 5.5 m/s and 4 m/s along the left, centre and right sides of the spillway respectively for PMF condition. At Ch. 100 m upstream of the spillway, the maximum velocities were 1.3 m/s, 7.7 m/s and 1.6 m/s along the left, centre and right sides of the spillway respectively for the PMF condition. No return currents could be measured along the left flank of the spillway. At Ch. 200 m upstream of the spillway, the maximum velocities were 1.7 m/s, 8.6 m/s and 1.1 m/s along the left, centre and right sides of the spillway respectively for the PMF condition. Return currents of the order of 1.6 m/s were observed on the left flank. However, the approach velocities were observed maximum along the centerline of the approach channel. Maximum velocities of the order of 10 m/s were observed at the Ch. 500 m upstream of the spillway, along the centre of approach channel for PMF. Figure 5a shows flow conditions along the approach channel, in the vicinity of the guide bund and in front of the spillway for PMF condition. Along the nose of the guide bund maximum velocity observed was 6.5 m/s for PMF [7]. Table 2 shows the velocities observed along the approach channel. The maximum water level observed along the channel for PMF was at El. 46 m at the entry of the channel.

Approach channel 550 m wide at narrow section with a straight guide bund of 500 m long with left embankment

To optimize the layout of the approach channel further, the model study was conducted by widening the narrow section from 450 to 550 m. Due to this, the width of the channel at the entry increased to 1300 m from about 900 m.

Fig. 5 Flow conditions in the channel **a** for 450-m-wide layout and **b** for 550-m-wide layout

Flow conditions and velocity profiles along the approach channel

The flow conditions for this layout were nearly similar to that of the 450-m-wide channel layout, but the velocities were marginally reduced with the widening of the narrow section to 550 m. Increase in the width of the channel at the entry also reduced the velocities at the entry. The flow was entering in multiple directions and due to the hill protrusion along the right bank and confinement of two hills; the flow was diverted towards the right, thus entering the spillway in the oblique direction. The effect of guide bund was prevailing as it seems the velocities along the left bank are minimum. Along the centerline of the spillway, the velocities were predominantly high.

Due to the provision of the left embankment, a stagnant pool is being formed between the left embankment and the guide bund, which reduced the velocities along the left flank. Along the spillway axis, the maximum velocities were marginally reduced to 3.8 m/s, 5.5 m/s and 3.9 m/s along the left, centre and right sides of the spillway respectively for the PMF condition. At Ch. 100 m upstream of the spillway, the maximum velocities were 0.7 m/s, 7.4 m/s and 0.9 m/s along the left, centre and right sides of the spillway respectively for PMF condition. No return currents could be measured along the left flank of the spillway. At Ch. 200 m upstream of the spillway, the maximum velocities were 0.8 m/s, 8 m/s and 0.6 m/s along the left, centre and right sides of the spillway respectively for the PMF condition. Return currents were eliminated. However, the approach velocities were observed maximum along the centerline of the approach channel. Maximum velocities of the order of 9.5 m/s were observed at the Ch. 800 m upstream of the spillway, along the centre of approach channel for PMF. Figure 5b shows flow conditions along the approach channel, in the vicinity of the guide bund and in front of the spillway for PMF condition. Table 2 shows the comparison of velocities along the left, centre and right of the approach channel for different layouts. The maximum water level observed along the channel for PMF was at El. 46 m at the entry of the channel.

Results and discussion

The comparison of the observed velocities is done in different ways. The observed velocities are compared for the operating condition of PMF with all spillway gates fully open. Firstly, the comparison is made for the layouts with and without the provision of a guide bund. Then the comparison is made for various layouts with varying widths of the channel. Later, the comparison is made for the two layouts that have been provided with left embankment to prevent the lateral entry of the flow from the reservoir. The comparison of velocity profiles is done for the left, centre and right of the approach channel separately. Table 2 shows the velocities along the approach channel for different layouts with different lengths of guide bunds.

The comparison of velocities with and without the provision of a guide bund

The velocities were observed along the left, centre and right side of the 200-m-wide approach channel with and without the provision of a guide bund. Figure 6 shows the comparison of velocities along the approach channel and in front of the spillway while passing the discharge of PMF with the ungated operation of the spillway. In this graph, 200_ Left_ without Guide bund denotes the velocities along the left side for the layout of 200-m-wide approach channel without a guide bund.

From the results, it was observed that the velocities in the approach channel were decreased along the left, centre and right flanks of the spillway with the provision of guide bund than without its provision. At Ch. 100 m the velocities were drastically reduced from 13.6 m/s to 2.3 m/s along left flank. However, when the effect of bund ceases, the reduction in the velocity also ceases and the velocities were by and large the same. Hence, the comparison of velocities further upstream is not shown in Fig. 6. The lateral entry of high-velocity flows from the reservoir was creating oblique flows in the approach channel and also in the vicinity of the left flank of the spillway. The velocities were 5–7 m/s at the entry, centre of the channel due to its reduced cross-section.

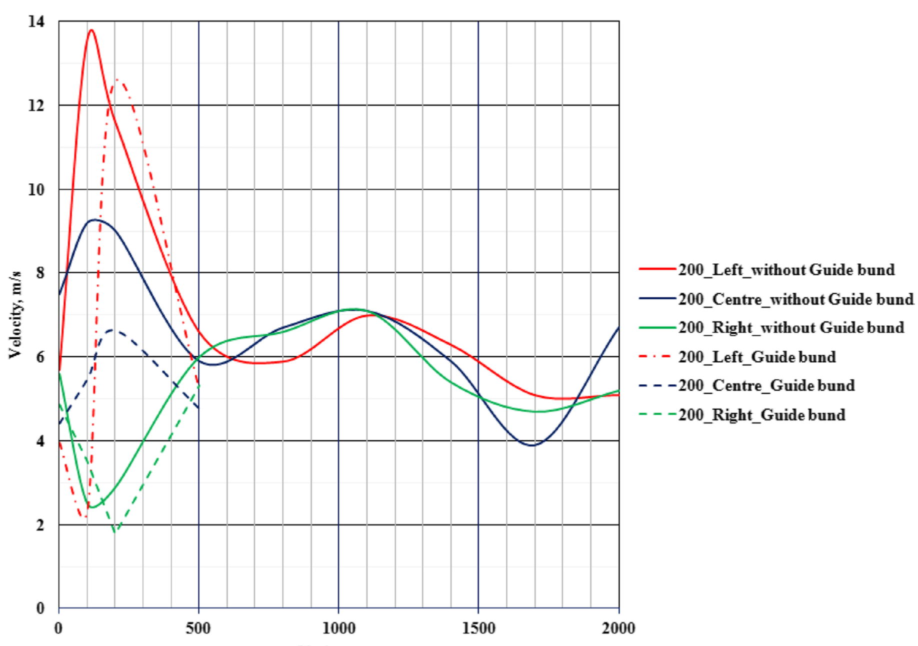

Fig. 6 Velocities along the left, centre and right of the 200-m-wide channel with and without the provision of Guide bund (GB)

The comparison of different layouts with varying widths of the approach channel

This comparison is done considering the observed velocity profiles along the approach channel, for all the different layouts under study, viz., 200-m-wide straight channel, 660-m-wide curved channel and 450-m and 550-m-wide straight channels. The velocity profiles along the left, centre and right of approach channel, for various layouts while passing PMF through the spillway, are shown in Fig. 7. In this graph, 600_ Left denotes the velocities along left side for the layout of 600 m wide approach channel. From the figures, it was observed that the velocities are more along the left bank since the lateral flows are impinging into the approach channel from the reservoir. But with the provision of guide bund, the velocities reduced drastically along the length of guide bund. For the chainages beyond 500 m, the velocities were in a range of 6–8 m. Along the right side of the channel, the velocities were more for 200-m-wide channel, due to its narrowest section along the middle zone, than for other layouts. But at the entry zone, the velocities were higher. Along the centerline of the approach channel, the velocities were in the range of 6–9 m up to chainage 1400 m. For chainage beyond 1400 m, the velocities were reduced further due to the widened area at the entrance, except for 660-m-wide channel.

Comparison of the layouts with provision of left embankment to prevent the entry of flow from the reservoir

To improve the flow conditions in the approach channel by reducing the lateral flow entry from the reservoir, an embankment is provided for the channel layouts 450 m wide and 550 m wide at the narrow section. Similar flow conditions prevail in these both cases. Further, the widening of approach channel to 550 m at the narrow section improved the flow conditions further. The velocity profiles along the left, centre and right of approach channel, for both layouts while passing PMF through the spillway, are shown in Fig. 8. In this graph, 450_ Left denotes the velocities along the left side for the layout of approach channel, 450-m-wide at the narrow section. From Fig. 8, it can be seen that the velocities remained nearly the same along the left of the channel

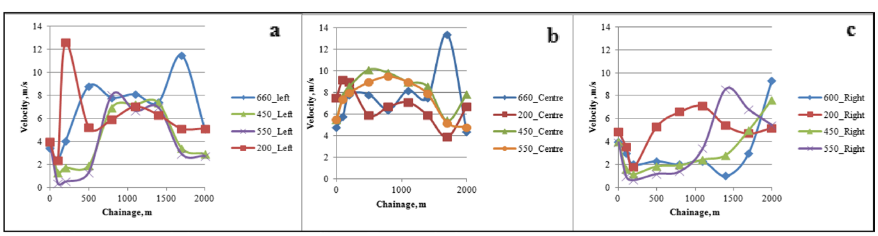

Fig. 7 Velocity profiles along various widths of approach channel **a** left, **b** centre and **c** right

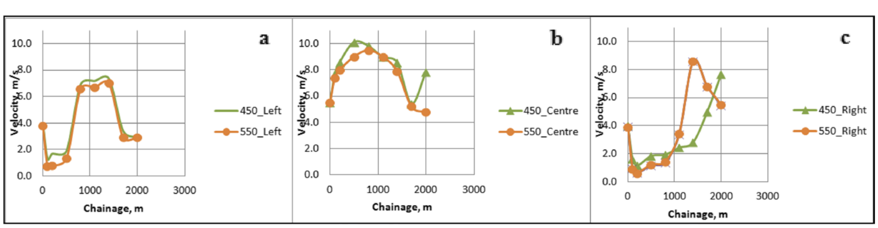

Fig. 8 Velocity profiles along **a** left, **b** centre and **c** right of approach channel for 450-m and 550-m width

for both layouts. This is because both the alignments on the left remained nearly the same. Along the right of the channel, the velocities were increased from chainage 1100 to 1700 m. But along the centre of the channel, the velocities were reduced at the entrance due to the widening of the channel.

Conclusions

Hydraulic model studies are indispensable in the design of asymmetric, unconfined and submerged approach channels of spillways that are governed by the site-specific conditions. For the problem under study, the design was optimized by testing various layouts in the physical model, viz., with curved alignment, with and without provision of guide bund, widening of narrow sections and provision of additional embankment. The layout with maximum widened cross-section improved the discharge capacity of the spillway, as the Probable Maximum flood (PMF); 141,583 m^3/s could be passed at Reservoir Water Level (RWL) El. 44.95 m when compared with El. 45.35 m, for reduced width of the channel. This is a reduction of 2% of the head over the spillway. 75% of PMF (106,187 m^3/s) can be passed at RWL EL. 41.8 m, 60% of PMF (84,950 m^3/s) at El. 39.8 m, 50% of PMF (70,792 m^3/s) at El. 38.28 m and 25% of PMF (35,396 m^3/s) at El. 34.38 m. The velocities along the left, centre and right of the approach channel vary for different layouts. Velocities on the left flank reduced from 12 m/s to about 1 m/s due to the provision of the left guide bund than without its provision. The guide bund is effective in stopping the lateral flows up to a certain chainage. The design of the upstream guide bund is vital in guiding the flows towards the spillway, minimizing the oblique flows and return flows, and thus provides stability to the spillway abutments. The provision of a left embankment prevents the lateral entry of flows from the reservoir into the approach channel and the velocities were 3.8 m/s, 5.5 m/s and 3.9 m/s along the spillway axis at left, centre and right respectively.

It can be inferred that the efficient layout of the approach channel is governed by its maximum available width and straightforward approach, prevention of lateral inflows by the provision of additional embankments and provision of a suitable length of the guide bund.

Abbreviations

A_m	Area of model
A_p	Area of prototype
A_r	Area scale ratio, L_r $^{(2)}$
CFD	Computational Fluid Dynamics
Ch.	Chainage
ECRF dam	Earth Cum Rock Fill dam
El.	Elevation
FRL	Full Reservoir Level
H	Height
L_m	Length in model
L_p	Length in prototype
L_r	Length scale ratio, L_p/L_m
n_m	Roughness coefficient of model
n_p	Roughness coefficient of prototype
n_r	Roughness coefficient scale ratio, L_r $^{(1/6)}$
PMF	Probable Maximum Flood
Q_m	Discharge in model
Q_p	Discharge in prototype
Q_r	Discharge scale ratio, L_r $^{(5/2)}$
RWL	Reservoir Water Level

T_m	Time period in model
L_p	Time period in prototype
T_r	Time scale ratio, $L_r^{(1/2)}$
V_m	Velocity in model
V_p	Velocity in prototype
V_r	Velocity scale ratio, $L_r^{(1/2)}$
W	Width

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Authors' contributions
All three authors collaborated in the research. VSR was responsible for the research itself including the literature review and empirical work. Authors MGMR and KCS were responsible for revising, guiding and advising throughout the research process. All authors read and approved the final manuscript.

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Availability of data and materials
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Declarations

Competing interests
The authors declare that they have no competing interests.

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