Sedimentation behind barrages and oblique river flow

KAPILESWAR MISHRA[1] & DHRUBAJYOTI SEN[2]

1 *Prajna Institute of Technology and Management, (PITAM) Palasa, Srikakulam, Andhra Pradesh, India*
kmishraiitkgp@gmail.com
2 *Department of Civil Engineering, Indian Institute of Technology, Kharagpur, West Bengal, India*

Abstract The waterways of many barrages are larger than required, due to overestimation of the design flood. The barrage gates are not completely opened except during the passage of the design flood, causing deposition of sediments and formation of shoals in the barrage pond. This results in the development of an oblique approaching flow towards the barrage and an increase in scouring due to a constricted waterway on both the upstream and downstream sides of the barrage. This paper presents examples of the present situation of sedimentation behind barrages and the incidence of oblique river flow, based on images obtained from the "Google Earth" virtual world model.

Key words barrage; oblique flow; sedimentation; waterway; shoal development

INTRODUCTION

A barrage can be defined as a barrier with a series of gates constructed across a river to regulate the water level and pattern of flow upstream in order to facilitate water offtake. The barrages across some of the Indian rivers discussed in this paper have been used for creating a pond on the upstream for meeting municipal water requirements by pumping or for diverting a part of the river water into irrigation channels. The gates of a barrage are not all fully opened simultaneously, except during the passage of the design flood, which may have a return period of the order of 1 in 50 years. Thus, theoretically, the possibility of all the gates being fully opened is likely to occur only once every 50 years. Furthermore, even during the design flood, the flood peak may last, at the most, only for a few hours. Therefore, to maintain a constant pool level, some of the gates have to be kept closed as the flood rises or recedes. During low flows, most of the gates are likely to remain closed, except for those of the undersluice bays, provided at the extreme ends of a barrage towards the off-take canal. The waterway of a barrage is generally designed to pass the design flood discharge, using Lacey's formula (CBIP, 1985) and, in general, is higher than that required due to overestimation of the waterway causing deposition of sediment in the upstream pond. For example, in the case of the Mahanadi barrage the waterway has the same width as the river and this is nearly three times that indicated by Lacey's formula. A river transports sediment throughout the year, particularly during floods. As the gates are not all fully opened at all times, the flow remains controlled through most of the gates, causing some of the sediment to deposit in the upstream pool due to the reduced velocity and turbulence of the flow. The present situation of sedimentation behind some of the river barrages in India resulting in the occurrence of flow inclined obliquely to the barrage gates (the axis) are discussed here, with the help of images from the "Google Earth" virtual world model. The flow directions in the images are from the top to the bottom. The right and left banks represent the side of the river when moving from upstream to downstream. The right bank is therefore located on the left hand side of each image.

EXAMPLES

The Wazirabad barrage on River Yamuna, Delhi

The river flow near this barrage supplying water to Delhi is inclined obliquely to the barrage axis on its upstream pool (Fig. 1). The original water off-take is located on the right bank (the divide wall and the undersluice bays may be seen towards this bank), a deep water channel has formed on that side. The left bank bays are obstructed by a protruding bank caused by deposition.

Fig. 1 The Wazirabad barrage on the River Yamuna, Delhi.

The barrage near ITO on River Yamuna, Delhi

For this barrage (Fig. 2), used as a pond for drawing cooling water to a thermal power plant nearby on the right bank, a large shoal on the upstream pool may be observed, causing oblique flow. The shoal has, over the years, become very stable, with signs of vegetation appearing in places. Even during high floods, the shoal does not apparently erode. Probably, the use of artificial means such as dredging or blasting, etc. may have to be resorted to for its clearing. Here too, the water withdrawal from the right bank has led to the gates closer to this bank being kept open for longer durations. This is apparent from the formation of the large expanse of stabilized shoal near the left bank of the barrage on the downstream side.

Fig. 2 The barrage near ITO on the River Yamuna, Delhi.

The Okhla barrage on the River Yamuna, Delhi

The Okhla barrage is used to divert water to the Agra Irrigation Canal (the offtake can be seen on the right bank, Fig. 3). This barrage was constructed to replace the century-old weir some distance upstream. However, the shoal formed in the pool of the barrage is much larger in size than that associated with the previous weir. It may be observed from the image (taken during the non-monsoon period and low flows, as the images are clear) that the shoal level rises much above the pool level. Therefore, most of the sediment must have been deposited during high floods of monsoons, and the oblique flow of the river is expected to occur even during such flows.

Fig. 3 The Okhla barrage on the Yamuna River, Delhi.

The Dakpathar barrage on River Yamuna

This barrage (Fig. 4), also on the River Yamuna, located in its mountainous reaches near the scenic town of Dakpathar in the Shivalik Hills, is used for diverting water into a power channel. The deeper section of the river is apparent towards the left bank, the side on which the off-take lies. The tail race of the Khodri power generation scheme joins the river slightly upstream of the barrage from the right. The water discharging from this tail race channel appears to have cleared some of the shoals towards the right bank. Also, since the waterway for the barrage has been kept smaller than that obtained by Lacey's method, the amount of shoal does not appear to be too threatening. Given that most of the water is diverted into the hydropower channel, the river appears rather dried up downstream, especially during the non-monsoon periods.

Fig. 4 The Dakpathar barrage on the River Yamuna.

The barrage on the River Ganga near Kanpur

This barrage on the River Ganga (Fig. 5) was constructed relatively recently, for the supply of drinking water to the city of Kanpur (located near the right bank of the river). Although there are no visible shoal formations in the pool just upstream of the barrage, the river itself is seen to be strongly inclined to the barrage axis, a reason to produce oblique flow. This is also clear from the heavy sedimentation downstream of the barrage towards the left bank. A strong turn, by nearly a right angle to the axis of the barrage, may be observed for the flow emanating from the last few bays of the barrage to the left. Such a flow situation, which is nearly parallel to the barrage axis, is normally responsible for producing deep scour just downstream of the barrage gates.

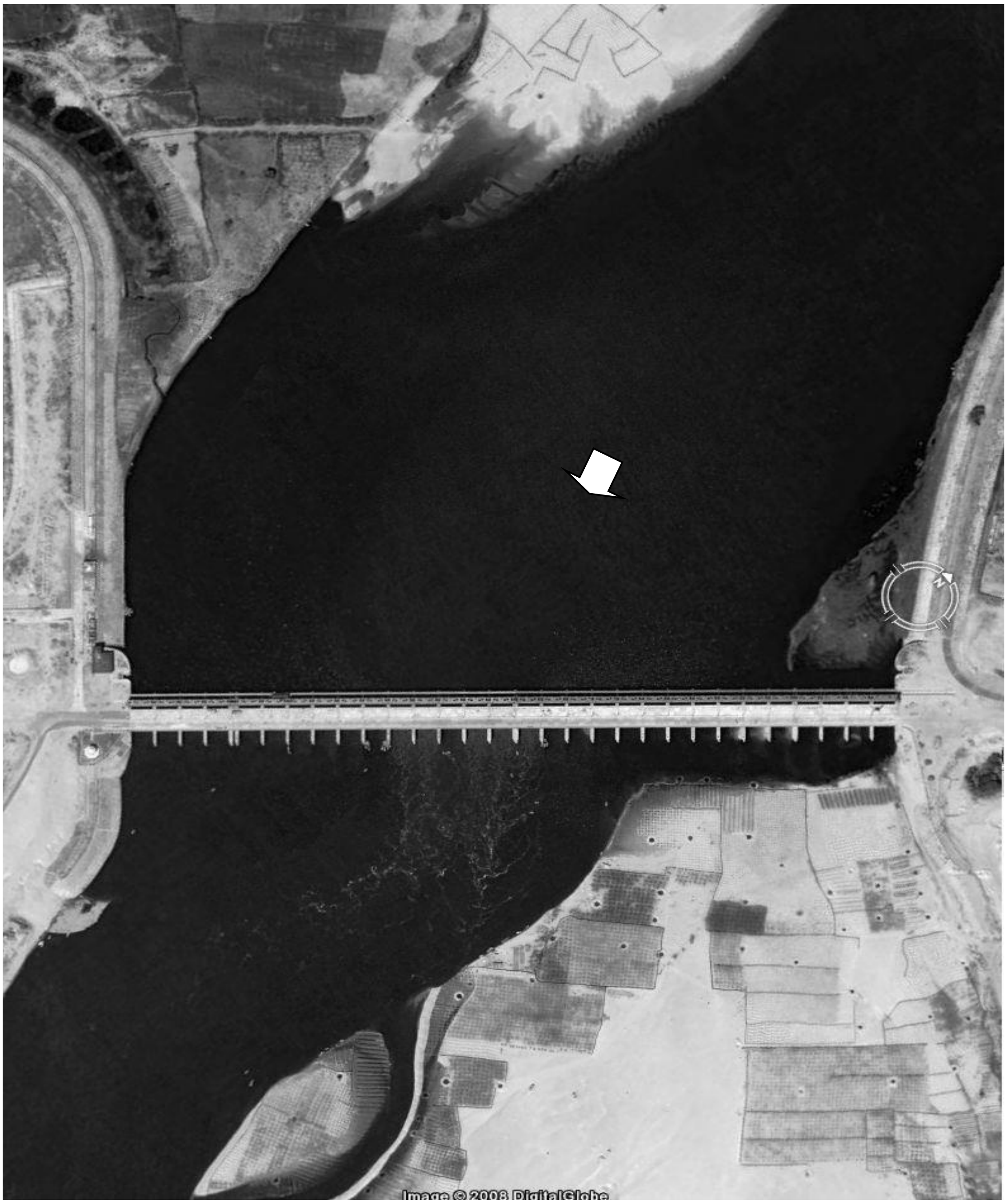

Fig. 5 The barrage on the River Ganga near Kanpur.

The Bhimgoda barrage on River Ganga at Haridwar

The Bhimgoda barrage on the River Ganga (Fig. 6) near the town of Haridwar, a Hindu pilgrimage, was constructed downstream of an older weir for diverting water into the eastern and western Ganga canals, off-taking from either bank. There is some visible sedimentation in the pool, but this is somewhat upstream of the barrage axis. However, closer inspection reveals that the flow of the river is somewhat inclined to the barrage axis. In the absence of the extended divide walls, the flow would be almost parallel to the barrage axis in the upstream pool nearer to the left bank of the barrage. As mentioned above, such a parallel flow may sometimes lead to a dangerous situation of causing deep scour on the downstream parallel to the gates.

Fig. 6 The Bhimgoda barrage on the River Ganga at Haridwar.

The barrage on the River Mahanadi at Cuttack

This, rather long (nearly 2 kilometres) barrage, on the River Mahanadi was also constructed to replace an older weir for diverting water to the irrigation canals on either bank (Fig. 7). The shoal formation in the pool on the upstream of the barrage, although not completely visible in the image, is extensive. The shoals have formed largely in the middle of the river and the deep channels are seen to exist on the left and right banks of the river apparently generated by the expected water passage through the undersluice bays of the barrage towards the banks. Close observation of the flows near the barrage provides evidence of very strong oblique flow.

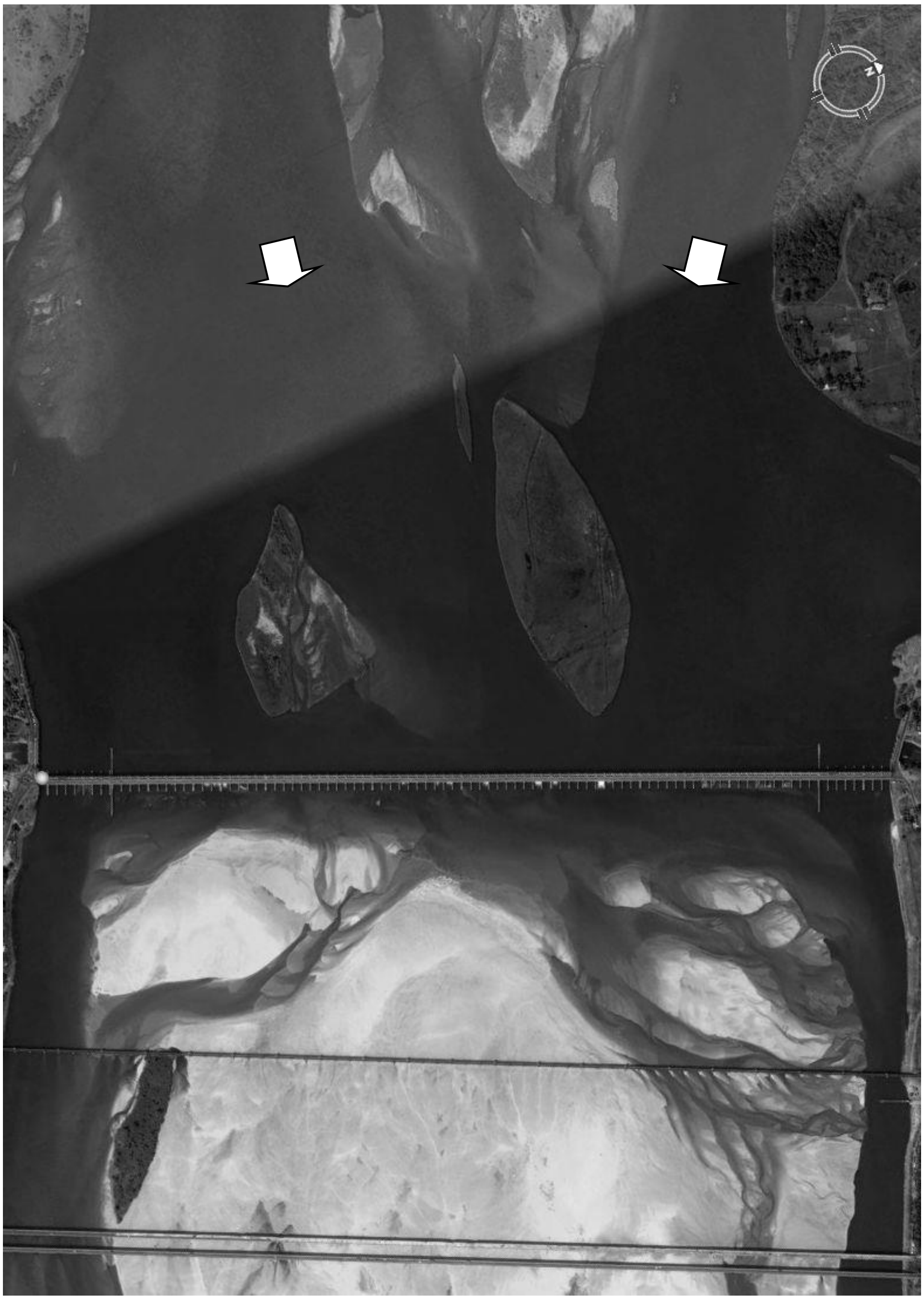

Fig. 7 The barrage on River Mahanadi at Cuttack.

The barrage on River Kosi, India–Nepal border

The Kosi barrage is located on the “alluvial fan” of the Kosi River as it descends onto the plains from the hills of the Himalayan nation Nepal (Fig. 8). This barrage probably faces the most critical situation regarding the effect of sediment deposition both upstream as well as downstream of the barrage. As is well known, the river has shifted westwards by about 150 km over the last 200 years and the trend seems to be still continuing, as can be seen from the flow of the river downstream of the barrage. In addition the main channel of the river upstream of the barrage is inclined substantially to the barrage. A very strong oblique flow is seen to exist across the barrage bays on the downstream. Interestingly, the canals can also be seen to be heavily silted, a problem which has been the subject of considerable research by water engineers over the past few decades. On 18

Fig. 8 The barrage on River Kosi, Himalaya foothills near India–Nepal border.

August 2008, a sudden breach of the left bank afflux embankment caused the river to flow unbridled and resulted in huge economic and material loss.

DISCUSSION

River barrages in India have to cater to varied flows in the river, ranging from a maximum during the monsoons to very low flows at other times. As a result, a very wide waterway for the barrage is normally considered, which is worked out on Lacey's formula based upon a high flood discharge of about 1 in 50 years. However, this leads to non-operation of most of the gates for a significant length of time each year, causing heavy sediment deposition on the upstream pool of the barrage. Diversion of most of the water through canals causes deposition of shoals, also downstream. A direct effect of this condition is the appearance of oblique flows near the barrage, a situation that is potentially dangerous for causing deep scour parallel to the gates. This situation has not yet been studied in detail, although BIS (1991) and Asawa (1996) mention it briefly. Sometimes, the barrages in plains are provided with a waterway even larger than Lacey's, although those in the hills are sometimes advised with a smaller waterway. Table 1, compiled from CBIP (1985) and Varshney *et al.* (1993), shows a list of some of the barrages with the waterways actually provided in relation to that suggested by Lacey's formula.

Table 1 Ratio of the waterway actually provided to that estimated by the Lacey's formula (sometimes called the Looseness factor) for some of the barrages shown in Figs 1–8.

Barrage	Wazirabad, Delhi	ITO, Delhi	Dakpathar	Mahanadi	Kosi
Ratio of waterway	1.12	1.19	0.89	3.00	1.45

It may be observed that for all the barrages mentioned here, with the exception of the Dakpathar barrage in the mountainous stretch of River Yamuna in the Shivalik Hills, the ratio of waterway (also called the Looseness factor) is more than one. This means that the length of the barrages is more than that required to successfully pass the design flood, indicating that the chances of sedimentation in the upstream pool is very high, as supported by the extent of shoaling shown in the examples of barrages mentioned this paper.

CONCLUSIONS

An unfavourable combination of unequal opening of barrage gates and the formation of shoals (deposited sand/sediment bars) both upstream and downstream of a barrage, may cause severe deviation from normal flow conditions, causing oblique flow instead of the desired normal flow with respect to the gates. One reason for this is the overestimation of the waterway of the barrage, leaving a large scope for deposition of sediment on the upstream pool. The waterway may also have to be judiciously designed, probably considering a dominant discharge of the river, rather than a high flood discharge that is likely to occur after an interval of many years. Although this has been suggested in CBIP (1985), it is not generally followed, especially for the barrages constructed in the plains, having wide valleys.

REFERENCES

Asawa, G. L. (1996) *Irrigation Engineering*, Second Edition. New Age Publishers, India.

CBIP (1985) *Manual on Barrages ad Weirs on Permeable Foundation*, *Volume 1*, Central Board of Irrigation and Power, India, Publication 179.

BIS (1991) *Criteria for Investigation, Planning and Layout of Barrages and Weirs*, *IS 7720*. Bureau of Indian Standards, India.

Varshney, R. S., Gupta, S. C. & Gupta, R. L. (1993) *Theory and Design of Irrigation Structures Volume II*, Nem Chand and Bros., India.