Remedial methods for Geomechanical threats associated to River Hydraulics: Selected Case Studies in India

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***Abstract*—For each and every geologist, engineers, and hydrologist the study of river science and engineering has been and would be, one of the important study areas to be reckon with. The open channel flow such as river and associated hydraulics often initiate several geomechanical hazards including silting, scouring, meandering, migration, and floods. Such sort of hazard may lead to disastrous consequences if adequate remedial measures are not undertaken. In this paper the selected case study has been chosen for the northern and north-eastern parts of the India where such sort of phenomena has been witnessed such as Kosi and the Brahmaputra River. The relevant conclusions have been drawn in this paper. In this paper, two above selected cases in India have been described. Here are the important observations which are made have been briefly summarized: the first study is the alluvial basin of the Kosi river, with a maximum peak migration rate of 2.5744 km/year. Such migration could produce significant erosion and siltation, introducing severe civil and environmental hazards. By constructing appropriate barrage and associated hydraulic structures can reduced such risks. For the second case i.e., Dibrugarh town the foremost hazard observed was frequent flood which was associated with immense land erosion and migration of river channel. By the construction of spurs and the associated hydraulic structures, the solution has been demonstrated effectively. The research work is in progress and interesting results are presented in the full-length paper**

Keywords— Flood, Marginal embankment, River hydraulics, River migration, spur

I. INTRODUCTION

From ancient civilization to the modern today, river played a key role in changing the livelihood of the human-being as well as changing the land pattern of the Earth. A river is a stream of water that typically originates from the mountains, glaciers, springs and thereafter flows through the plain and finally destines them to the sea. Initially it passes through the rocky terrain of high altitudes with very high flow velocity and then gradually meanders towards the plain area where silting and scouring of the flow channel occurs. The flow velocity gradually decreases as it reaches the mouth of the sea. This final portion of the sea is called tidal river where river is affected by the tidal fluctuations of the sea [1]. Silting of the river is caused mainly due to the low velocity of the flowing water. When the bed slope of the river is below its critical value, the velocity of the river goes below the threshold value thus beginning the silting process. It occurs in aggrading river whereas the scouring takes place in degrading river. When the bed slope of the river is in its critical value, the river attains a stable condition with neither silting nor scouring situation. On reaching the mouth of the sea, the river divides itself into several branches forming deltas [2].

The meandering of the river is the deviation of its flow path from its axial direction. The river bends successively to form reverse curvature. Aggrading river carries significantly high number of silts resulting in siltation. Due to silting, the channel area of the river decreases and hence the flow velocity increases. This increased velocity of the river scours the opposite bank of the river thus introducing bends of reverse curvature and meandering takes place [3]. This process is the root cause of the geomechanical hazards of the river. Here is the need for remedial measures arise to prevent the unpredictable events which may arise due to river erosion. Flood flows with high velocity results in deep scouring which undermines the bank of the river. Spurs and groynes constructed at right angle to the embankment are used for protection of river erosion [4].

II. STUDY AREA

This paper focuses on the hydrological and geomechanical hazards of the river Kosi in Bihar and river Brahmaputra in Assam, as shown in Fig.1. It also briefs the remedial measures taken in both the rivers over the past few decades. In both the study areas, the nature of the geomechanical hazards of river mitigation was found to be similar as well as the remedial measures taken were in multi-level and multi-phases.

The river Kosi originating from Sun Kosi near Triveni in Nepal is a trans-boundary river flowing through Tibet, Nepal, and India. It is also called ‘Saptakoshi’, the Seven Rivers. It stretches for a length of 42 Km in Nepal, crossing across the mountainous terrains and then enters India at Bhimnagar, Bihar. It then flows for a length of 260 Km until it reaches the river Ganga near Kursela. The accumulation of sediments in the Kosi River is one of the world’s largest alluvial fans. It has a lateral shifting of over 120 Km and surrounded by ridges heavily attributed with silt charge especially during monsoon season [5].

The Brahmaputra River originating from the Kailash Manasarover flows through Tibet as the Yarlung Tsangpo River and enters India through the Upper Siang District of Arunachal Pradesh. It covers the North-Eastern parts of

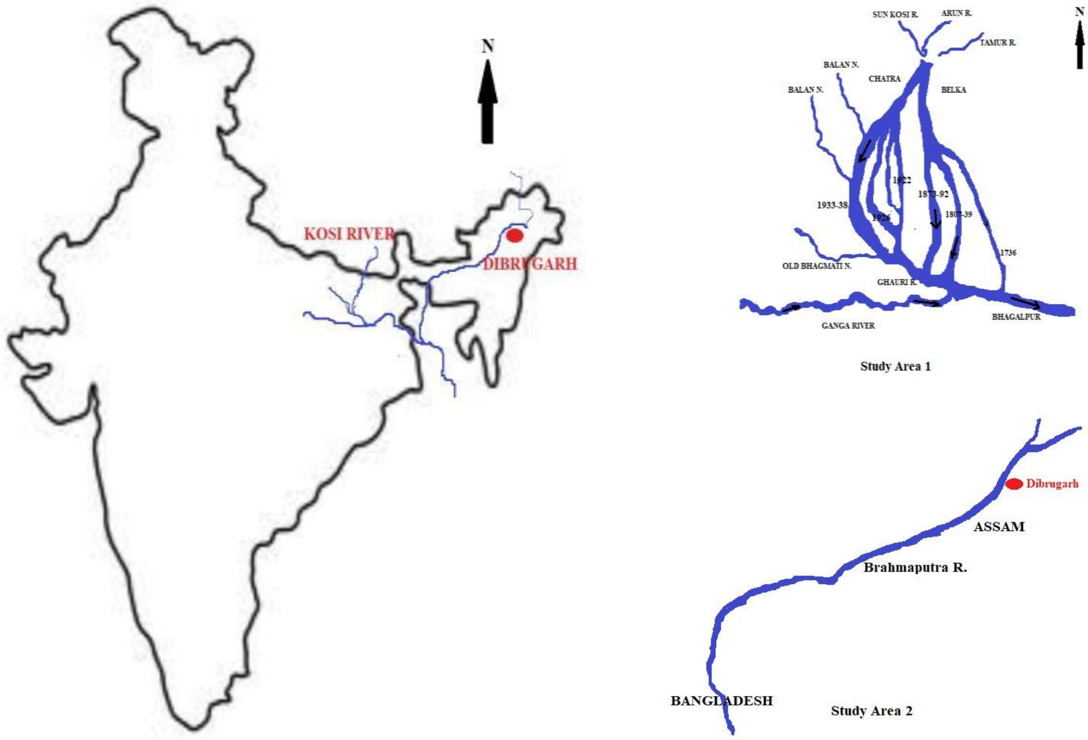

Fig 1. Case Study Areas

India and extends up to Bangladesh. In India, it is bounded by the Great Himalayan range on the North, the Patkai and Naga hills on the East and the Khasi hills on the south. It flows westward in India and joins the Padma River in Bangladesh. It is considered as one of the largest rivers of the world. It is ranked fifth all around the world in terms of average annual discharge, annual sediment load, and catchment area and for its length. Also, the river has highest specific yield in the world with 0.22 cumec/km^2 [6].

III. CASE STUDY: 1

A. Kosi River

The state of Bihar in India is surrounded by Nepal in the north, while the states of Jharkhand, West Bengal and Utter Pradesh in the south, east and west, respectively. Bihar is a flood prone state with nearly 50% annual loss due to flood. Every year, the river Kosi in Bihar with their number of tributaries, initiate flood devastation in the monsoon period by inundation and erosion. The recurring annual disaster of the state of Bihar in India is particularly associated with flood of the Kosi River in the northern part. On account of the resulting huge damages and suffering of the people, the river is named as the 'river of sorrow', like the yellow river of China.

B. Hydrological and Geomechanical Hazards

Bihar is a flood prone state. The river Kosi, with its numerous tributaries causes recurring floods especially in the monsoon season as a result of inundation and erosion. This recurring flood causes huge damages to the structures and loss to human lives. Therefore, the river is also called as 'The River of Sorrow'. During the last 150 years, it has been observed that the river has been migrated 110 Km westward. Due to this migration, siltation took place in an area of about 13,000 Km2 in India and 1000 Km2 in Nepal. In the upstream of Chhatri, a very steep gradient of 1V:5H were likely found to be refilled during dry seasons. Borehole data taken from the study area near Belka hill region with borehole sample 2650 mm indicated 900 mm medium sand layer, 125 mm coarse sand and boulders, 150 mm of medium sand and 1475 mm of gravels and boulders in sequence. It gives a clear indication that as the river enters plain terrain, the coarser materials accumulate first and then the smaller ones [7]. It was found that the average flood gradient of 8.73 x 10-4 downstream of the barrage constructed at 42 Km reach from Chhatri to Bhimnagar was gradually flattened to 0.61 x 10-4 at about 130 Km downstream. The average migration rate of the river observed is shown in Table 1 and Fig 2.

TABLE I. AVERAGE RATE OF MIGRATION OF KOSI RIVER

Year	Period of movement (years)	Approximate distance migrated (km)	Rate (km/year)	Total westward migration (km)
1736-1770	34	10.7803	0.3171	10.7803
1770-1823	53	9.3322	0.1761	20.1125
1823-1856	33	6.1142	0.1853	26.2267
1856-1883	27	12.872	0.4767	39.0987
1883-1907	24	18.5035	0.7710	57.6022
1907-1922	15	10.9412	0.7294	68.5434
1922-1933	11	28.962	2.6329	97.5054
1933-1950	17	17.699	1.0411	115.1744

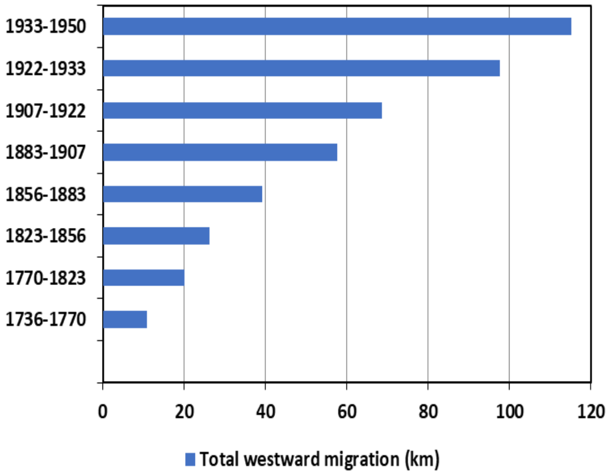

Fig 2. Year-wise westward migration

The existing transverse slope in the terrain of the study area might be the possible reason of the westward migration. Also, the direction of the open channel flow occurring at the right angles to the contour increased the tendency to scour and erosion, which in turn aided the expansion of the channel and river migration. Similar observations are also found in the case of erosion gullies, which also cross the contours at right angles [8]. Excessive sediment load (about 0.43 million ton/year/km2) during flood is another reason for river migration which may also attribute to large variation in stream variation, slope, and geological young rock formation [9].

C. *Remedial measures*

To overcome the geomechanical hazards, extensive construction of marginal embankments was taken up from the year 1955 onwards. On the eastern side of the river, an embankment of 101 Km was built downstream of Bhimnagar and 118 Km on the western side. The spacing between the eastern and the western embankments varied from 5 to 8 Km. Afflux bunds were constructed on both the sides of the barrage having 40 Km length on the east and 14 Km on the west [10]. Also, a sluice-type barrage of about 2 Km length and 54.25 meter width was constructed. It was provided with multiple gates and facilities for pedestrian and vehicular passage. As observed, a sluice-type barrage is an effective river training work [11]. Spurs were also provided on both the upstream and downstream of the barrage. This construction of embankment effectively reduced the flood occurrence as it shifted the main current from western bank to the eastern bank.

Before the construction of the barrage, up to a reach of 102 Km downstream of Chhatri, the river was found to be degrading followed by aggrading. After the construction of the barrage, up to a reach of 42 Km was found to be aggrading. From the barrage, up to 16 Km, the river was found degrading and further downstream up to 100 Km was found to be aggrading [12], as shown in Fig 3. The estimated annual sediment load of 95 Mm3 was reduced to about 15.6 Mm3. However, measurements after banking indicated an average deposit rate of 84 Mm3/year [13].

Other remedial measures were also undertaken and improvised. Study of the past river discharge and water level data were done to investigate the overbank spilling due to rise in the flood level. Study was also done to control the erosion of the riverbank to mitigate the risk involved. According to the National Commission of Agriculture (1976), the change in cropping pattern would reduce the damage from flooding. The population of the area were provided awareness about the limitations of flood protection and given proper guidance to be followed during emergency to protect their life. Also, adequate public services were provided to the people affected by flood and erosion by providing shelters and livelihoods.

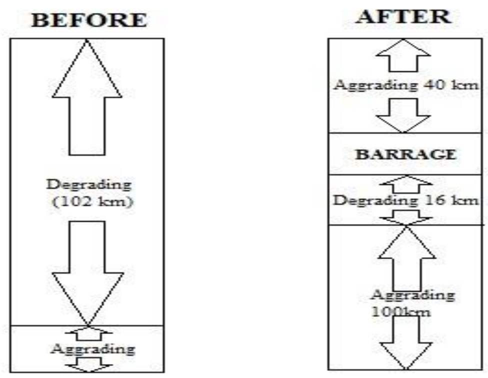

Fig 3. Sediment load comparison of river Kosi near Chatra

IV. Case Study: 2

A. *Dibrugarh Town*

Dibrugarh is a town in the state of Assam of Northeastern region of India. It is located near the basin of river Brahmaputra. The river Brahmaputra originates from the glaciers of Manasarover Lake, Kailash Ranges in Tibet. From its origin to the outfall in the Bay of Bengal, it stretches over a total length of 2,880 Km. The river enters India through the Yang-Yap pass in the state of Arunachal Pradesh. The river flows with the name Siang in Arunachal Pradesh and then enters Assam with other two tributaries namely Dibang and Lohit. From this confluence point, the river is called as Brahmaputra. The river passes through major cities and town like Dibrugarh, Jorhat, Tezpur, Guwahati, Dhubri, etc., and finally enters Bangladesh, covering a stretch of 720 Km of alluvial plains. While travelling through Bangladesh, it swings at nearly right angle towards south and merges with river Jamuna. The united river Jamuna (Ganga) and Padma (Brahmaputra) merges together to form river Meghna, which finally falls in the Bay of Bengal [14].

B. *Hydrological Hazards*

The total catchment area of Brahmaputra in India is approximately 240,000 Km2 with average monsoon discharge of about 40 x 103 m3/s. The river shifted its course over the period due to this high discharge and sediment load. The river, before reaching India follows a very steep gradient and drops to 4.8 Km in the stretch of 2000 Km. The average gradient of the river has been reduced from 2.4 x 10-3 in Arunachal Pradesh to 0.1 x 10-3 in the valleys of Assam.

This sudden change in the gradient leads the river to be braided [15].

Earlier Dibrugarh town was located on the bank of river Dibru. The river Brahmaputra and Dibru were few kilometers away from each other, but due to scouring of river Brahmaputra towards the southern bank, paved the way for river Dibru to merge with Brahmaputra. Dibrugarh, which is located on the bank of river Brahmaputra, is under highly erosion prone zone. The earthquake of 1930 in Assam is one of the main reasons for the creation of this erosion prone zone. It has caused several landslides especially on the southern bank of Dibrugarh town. At the same time, the flow of river was attacking the riverbank at 60˚, resulting in excessive erosion of the bank. The river migration rate was observed to be 1.32 km2/year. These hydro-geological hazards caused significant damage to the buildings, civil infrastructure, open lands and tea gardens of the Dibrugarh town [6, 14, 15].

C. Remedial Measures

The Government of Assam together with Government of India undertook several remedial measures to mitigate such hazards. In 1953, Government constructed a stone revetment of about 460 meters length on the worst affected bank of river Brahmaputra, which was washed away by the 1954 flood, due to high erosion. Therefore, the Government entrusted the Central Water Commission and the Central Water and Power Research Station to investigate and study the affected area and come up with a better proposed designs for protection work [16]. Thereafter in 1954, 5 stone spurs with slope 1V:1.4H to 1V:1.5H was constructed. The length of the 4 spurs were 61 meter each and one spur with 122 meter length. Timber pile spurs were also constructed normal to the bank. Initially each of the timber pile spur were 61m long, which was later shortened to 30m-45m, and six numbers of timber pile spur were added. Also, brush wood protections of the banks were provided between the spurs.

Few minor construction works were executed during the year 1955-1961. Additional stone spurs of 42.7 m length were constructed on the upstream of first stone spur and 610 m length on the downstream of the fifth stone spur for the purpose of flow diversion. To further protect the town from flooding, a 10 Km long earthen dyke was also constructed. Butt heads at pile spurs were provided along with additional double rows of T shaped piles. The protection works of 1963-1964 consisted of two phases. In the first phase, two semi-permeable spurs each 45.8 m long and 6 permeable spurs were constructed. Along with, additional revetments of length 55 m and 36.6 m were provided on the upstream and downstream respectively. After the first phase construction, heavy erosion took place. Therefore, in the second phase, additional 1 semi-permeable and 7 permeable timber spurs were constructed along with 1 subsidiary dyke on the downstream. The secondary work of 1965-1966 included few more impermeable spurs of 15 m length each. Boulder aprons were provided, and revetments were constructed between the spurs to strengthen the pile spurs.

The major protection works of 1967-79 consisted of five phases. The reason for this major protection work was the hydro-geological hazard of 1967-1969, where a vast area including Mathola tea garden was eroded by river Brahmaputra. The first phase was undertaken in 1970, where 3 timber spurs and 29 stone spurs were constructed at the critically affected riverbank. The second phase of 1973 included construction of three bank heads, under the recommendation of the Government, to control the erosion of the riverbank. The erosion continued, therefore in the third phase (1975), 8 permeable spurs with stone apron were constructed to strengthen the river bends. However, the flood of 1977 eroded about 300 m deep chunks of bed area resulting severe damage to this structure. As the post-flood protective measures, the fourth phase (1977-1978) was undertaken. Ten timber dampeners with boulder apron were constructed. These structures were also damaged in the next flood. After further Government recommendation, the fifth phase (1978-1979) was undertaken. A land spur was constructed having length of 299 m with 3.5 m apron width and 1.5 m apron thickness. It was also provided with crest level of 1.5 m above high flood level and side slope of 1 vertical to 5 horizontals. This land spur is still the key structure in guarding the river from erosion and flood control under the entire Dibrugarh Town Protection Work.

V. Critical Analysis

The geomechanical and hydro-geological hazards in the above two case studies have been observed to be varying though in both the cases river migration takes place accompanied with scouring and erosion. Therefore, the remedial measures undertaken were also different. In the case of Kosi River, the hydraulic structures constructed were firm and stable, whereas in case of the Dibrugarh town, the hydraulic structures were unstable. Hence, it is analyzed that the protection of river and flood control measures are necessarily site specific, and they vary from place to place.

VI. Conclusion

Geomechanical and hydro-geological hazards can lead to serious disaster if proper mitigation measures are not embraced. In the first case study, the alluvial river basin of Kosi River was observed to be migrating westward. The peak migration rate was found to be as high as 25,744 Km/year. The migration of river caused several recurring floods, which lead to scouring in the monsoon season and siltation during the dry season. The construction of the barrage across the river was found quite effective in controlling flood and erosion of riverbanks in the downstream. The annual sediment loss was also reduced after the construction of the barrage. Thus, construction of appropriate barrage helped in mitigating the risks of geomechanical and hydro-geological hazards in the Kosi River.

In the second case study, the geomechanical and hydro-geological hazards of the Brahmaputra River in the Dibrugarh town of Assam was considered. The frequent flood accompanied with erosion of the riverbed and riverbank was found to be the most concerned hazard. It also led to the migration of the river channel. The remedial measures undertaken included construction of spurs, dykes, head butts, boulder apron and Bankhead’s. The hydraulic structures were found to be unstable due to rigorous flooding each year, until the construction of the land spur in1979. After 25 years of trial-and-error construction of hydraulic structures, land spur was found to be most effective, standing firm and stable.

From the above two case studies, it can be concluded that the hazards from the river hydraulics and the required river protection works are necessarily site specific. The scope for future study in the selected sites is wide open in the field of hydrology, geology, flood control measures, river training works, erosion and many more. The study would benefit immensely to both the researchers and practicing engineers.

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