CASE HISHORY OF

EROSION AND PROTECTION WORKS IN RIVER GANGA UPSTREAM AND DOWNSTREAM OF FARAKKA BARRAGE

S. K. Mazumder
Adviser, ICT AND SWI Pvt. Ltd., NEW DELHI
(Former AICTE Emeritus Professor of Civil Engineering, DCE

ABSTRACT

It is necessary to understand river behavior upstream and downstream of hydraulic structures for proper planning designing and maintaining anti-erosion works. Morphology of the river, its aggradation /degradation and the meandering processes have been discussed. Uncontrolled erosion and deposition of sediments creates lateral instability of river, meandering and migration of river course. Continued erosion of the river banks and deposition of sediments has resulted in gradual migration of river Ganga towards the left bank (in Malda district, West Bengal) upstream of Farakka barrage and the right bank (in Murshidabad district, West Bengal) causing loss of life and destruction of properties and subjecting the poor people living near the river banks to unimaginable miseries, Hydraulic analysis is made of the behavior of river Ganga upstream and downstream of Farakka barrage as a result of sediment deposition upstream and inadequate energy dissipation. The protective measures adopted so far are found to be, by and large, ineffective. The underlying reasons for the failure of the anti-erosion works adopted by the project authorities have been critically examined and some alternative measures for erosion control have been suggested

INTRODUCTION

Farakka barrage(2.6 km long) was constructed in the year 1967 across river Ganga with the objective of forcibly diverting flow from the parent river Ganga to its tributary river Hoogly. The river Hoogly (initial stretch of which is known as Bhagirathi) was drying up due to silting of its off take point at a place called Jangipur (at a distance of about 40 km downstream of the barrage), resulting in gradual reduction of fresh upland flow from Ganga. Hoogly River flows through West Bengal for a length of about 500 km from its off take to its outfall in Bay of Bengal. It is the lifeline of west Bengal as it is the principal source of water for drinking and industrial uses for Kolkata and Howrah cities and many other important towns located on either bank of Hoogly which is a navigable and a tidal river. Kolkata port located on river Hoogly was drying up due to siltation. Under the recommendation of CW&PRS, Pune, and advise of experts from India and abroad, Ministry of Water Resources, Govt. of India, decided to construct the Farakka barrage on Ganga and Jangipur barrage on Hoogly for diverting 1135 cumec flow to Hoogly river through a Feeder canal which is about 34 km long. as shown in Fig.1(a). The cost of the project at 1973 price index was nearly Rs.2, 000 million.

After Sahebganj (in Jharkhand state) where the River Ganga changes its course from west-east to north-south direction, the river had been changing its course even before the construction of the barrage, except at two nodal points, namely, Rajmahal (about 40 km upstream of barrage) and Farakka - places where the river course was found to be more or less stable. During the pre-barrage period, the main course of Ganga between Rajmahal and Farakka was along the right bank and the stretch was almost straight. Downstream of Farakka, however, the main course shifted towards the left bank of the river. After the barrage was constructed, the main course of the river upstream of barrage has shifted towards the left bank and that on the downstream side it has shifted towards right bank as shown in fig.1 (a) and 1(b).With continued erosion of its left bank upstream and right bank downstream of the barrage, the river has developed a typical meander with left bank on the outer side of upstream bend and the right bank on the outer side of downstream bend of the meander. There is a severe embayment of river Ganga upstream of the barrage and it may cause outflanking of the barrage if the erosion upstream can not be arrested immediately. It has already merged with river Pagla, one of its tributaries and it may finally join another mighty river Mahananda (Fig. 1a), whose high flood level is about 1 m below that of Ganga at Faarakka.

During the period 1968 to 1990, the upstream meander has migrated towards left bank by about 3 km eastward with an average migration rate of about 136 m per year. Between 1990 and 2005, it has further migrated about 4 km eastward which corresponds to an average migration rate of about 266.m per year. This unprecedented rate of meander migration is about 10 times more than that predicted by Hickin and Nanson (1984), perhaps due to the interaction between the river Ganga and the barrage. On the downstream side, the right bank of the river also has similar erosion problem. Several towns have been completely wiped out and in certain stretches the distance between the railway line and bank has reduced to 200 m or so compared to an earlier distance of 5 km and more. Continued erosion of the river upstream and downstream of the barrage has resulted in colossal loss of agricultural and household properties and subjected the poor people living on the banks to unimaginable sufferings. Properties worth several thousand million rupees have been lost or damaged both upstream and downstream of the barrage If the river course changes upstream, the barrage and the feeder canal will be useless and the Hoogly River will again go dry. On the other hand, if the erosion of right bank continues downstream, the railway, the roadway, the feeder canal and the Jangipur Barrage are likely to be washed out. The river may either join parent Ganga or may merge with Hoogly River. In either case, there will be further loss of life and properties and the purpose of the barrage and the feeder canal will be lost. Considering the gravity of the situation and complexity of the problem, it is necessary that an in depth analysis of the erosion problem should be made with all relevant field data, especially regarding incoming and outgoing sediment load and sediment deposition upstream, since the river course, the meandering and the erosion of the banks are inter- related.

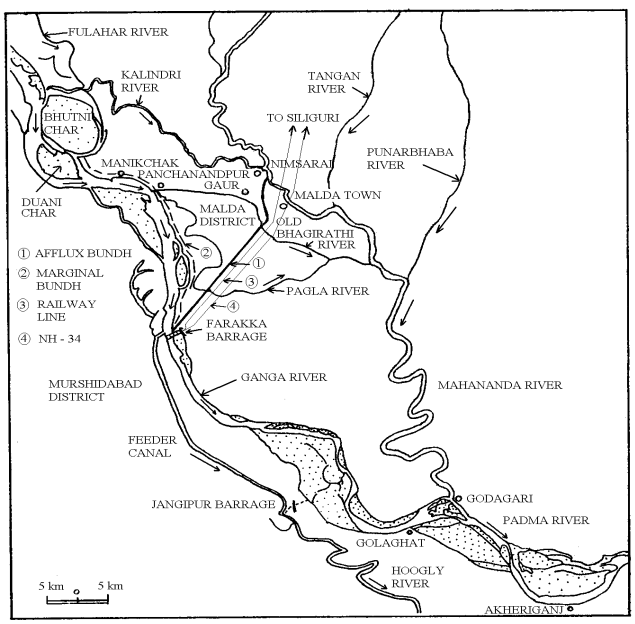


Fig.1 (a) River Ganga and its Tributories Near Farakka Barrage.

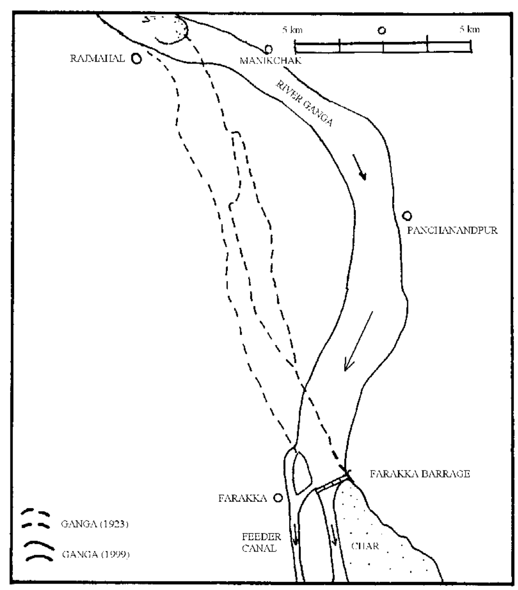


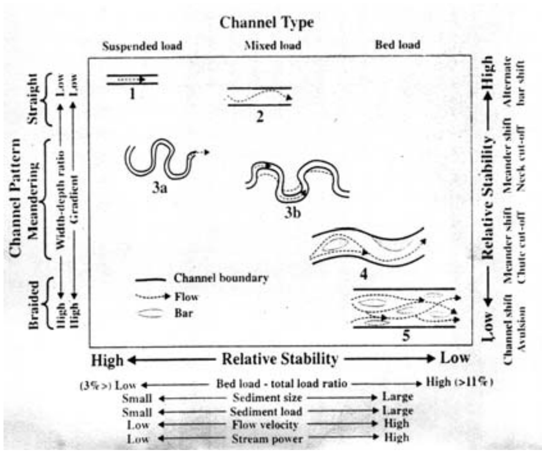
Fig.1(b) Change in Course of River Ganga Upstream of Farakka Barrage (1923-1979)

RIVER MORPHOLOGY / AGGRADATION / DEGRADATION

Understanding the behaviour of any given river is complicated due to interrelated geomorphologic, hydraulic and hydrologic parameters (Mazumder,2004). The interrelation between plan form, hydraulic and sediment parameters and relative stability of a river is illustrated in Fig.2 (a) & 2(b) (Schum, 1981). It may be seen that the different plan forms of a river e.g. straight, meandering and braided course depend on the geometry, sediment load, slope and discharge of the river. Interrelation between stream form, bed slope and mean discharge is also illustrated in Fig. 2(a) (Lane 1957). A decrease in discharge combined with increase in sediment load will result in decrease in flow depth and increase in flow width as mostly observed upstream of hydraulic structures e.g. barrages and bridges Prediction of stream response to climatological or watershed changes is based on the fundamental relation given by equation- 1 (Lane (1955), Garde (2004)).

$$QS_e \ \alpha \ Q_s d_{50} \ldots \qquad \ldots\ldots\ldots(1)$$

Where Q is the discharge, S_e is energy slope, Q_s is sediment transport rate and d_{50} is median sediment size. .



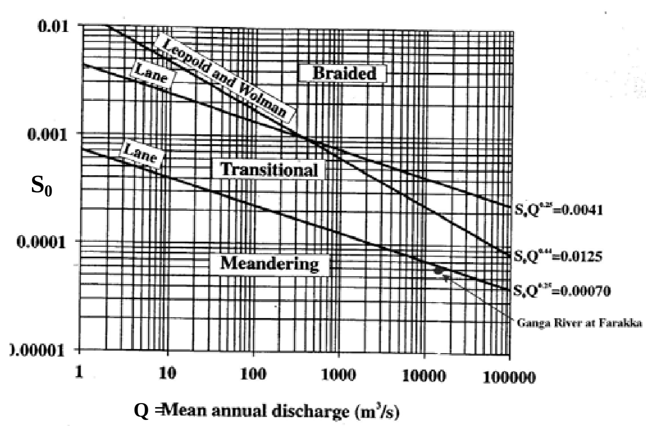


Fig.2(a)Interrelation between channel type,hydraulic and sediment parameters and relative stability of streams (Schwam, 1981)

Fig. 2(b) Interrelation between stream forms, bed Slope and mean discharge (Lane, 1955)

When waterway is restricted, there is afflux and back water upstream of the structure resulting in reduction in energy slope (S_e). Q and d_{50} remaining same, the stream power (Q.S,) and the sediment carrying capacity of the river are reduced. As a result, there is deposition of sediments resulting in aggradations upstream of the hydraulic structure (as observed upstream of Farakka barrage), till such time the original slope is restored and the balance given by equation (1) is satisfied. In all diversion structures (like Farakka barrage), comparatively clear water is withdrawn from upstream resulting in decrease in Q downstream. As a result, stream power (Q. S_e) gets reduced and hence the sediment carrying capacity (Q_s) is reduced, d_{50} remaining the same. Obviously, sediments will be deposited downstream of such diversion points and there will be aggradations. (Heavy silting has occurred on the left bank side of Ganga in the vicinity of Farakka barrage pushing the river towards right bank side downstream).There is erosion of stream bed and degradation due to release of comparatively clear water (due to sediment deposition upstream) as well as higher turbulence level. downstream of all hydraulic structures Choking of flow results in hydraulic jump formation downstream (Mazumder 1993). If energy dissipation is insufficient, residual kinetic energy of flow causes non- uniformity and distortion of flow since the only way a stream (with given depth and discharge) can carry excess kinetic energy downstream is through flow non-uniformity and increase in Corrioli's coefficient (α) (Mazumder,1985). It is also established that clear water causes more erosion compared to silt laden water due to decrease in drag (silts provide damping of turbulence). It is well known (Mazumder, 1995) that higher turbulence level causes greater erosion, other parameters remaining the same.

Due to deposition of sediments upstream of Farakka barrage, flow downstream is comparatively clear. There is also high intensity of turbulence due to imperfect jump (at low pre-jump Froude's number (F_1=2.4 in Farakka barrage at design flood). All these coupled with highly non-uniform flow distribution (due to skewed jump downstream) have caused heavy erosion of right bank downstream of the barrage.

RIVER STABILITY AND MEANDERING PROCESSES

Interrelation between stream form and bed slope is schematically illustrated in Fig. 2(a) and 2(b).

Quantitative relationships between channel bed slope (S_o) and mean flows (Q) are presented by Lane (1957). A non cohesive stream bed composed of silts and sands is predicted to meander when

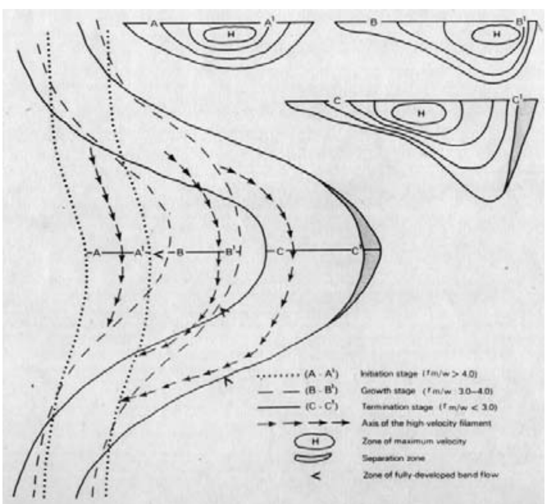
$$S_o\, Q^{0.25} > 0.00070 \ldots\ldots\ldots \quad (3)$$

and braided when

$$S_o\, Q^{0.25} > 0.0041\ldots\ldots\ \ldots.. \quad (4)$$

A typical straight stream is rarely stable. As shown in Fig. 2 (a), streams with very small sediment load, low gradient and low velocity, low variability in flow and low aspect ratio (width to depth ratio) may be stable for some distances. Development of lateral instability associated with erosion and deposition give rise to meandering processes as illustrated in fig. 3 (a). A lot of research work on bends in a meandering river have been carried out by eminent river scientists like Rozovsky (1957), Zimmerman and Kennedy (1978), Engueland (1973), Oddgard (1986), Wang (1994), Yalin (1999), Chitale (1981), Garde and Raju (2000). Centrifugal effect of flow curvature in a river bend results in the development of secondary current which when superimposed with axial flow causes spiral motion in a bend. Wang (1992) developed a mathematical model of the meandering processes to prove that the typical cross-slope as observed u/s and d/s in a meander with lower bed elevation on the outer side of the bend (due to erosion of outer bank) and higher elevation of bed on the inner bank side (due to deposition of the eroded materials on the inner bank) provides stability to the stream. Hickin and Nanson (1984) described the lateral migration rate (M) of a meandering stream by the functional relation:

$$M = f\,(\Omega, b, G, h, \tau_b) \quad (5)$$



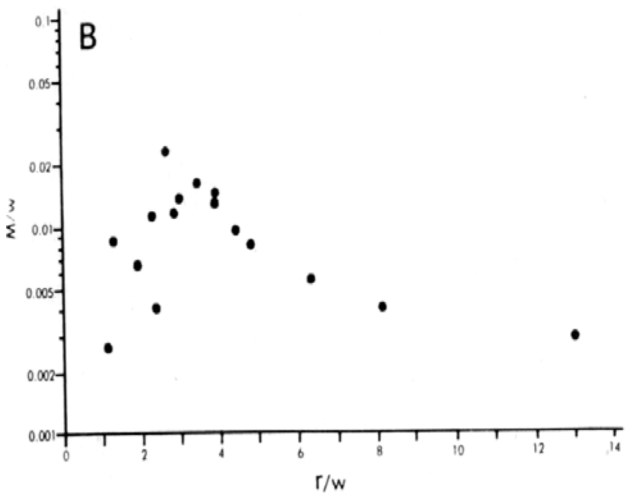


Fig. 3(b) Variation of Migration Rate,M (m/yr) with Relative Curvature (r/w) in a Meander

Where Ω is stream power (τ.v), b is a parameter expressing plan form geometry of the stream, h is the height of outer bank (degree of incision), τ_b is the erosional resistance offered by the outer concave bank undergoing erosion. Plotting measured migration rate (m/year) against relative curvature (r/w, where r is the radius of curvature and w is the stream width), as shown in fig. 3(b), Hickin and Nanson concluded that the migration rate is maximum when meander stabilizes at an approximate value of r/w =2.5 and got the relation

$$M_{2.5} \text{ (m/year)} = \rho g \, QS / \tau_b h \qquad ..(6)$$

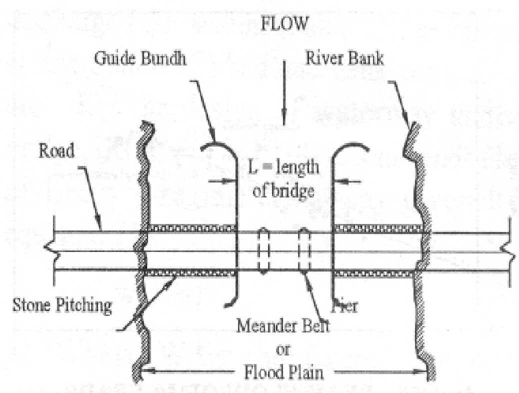
Where, $M_{2.5}$ is the maximum rate of migration corresponding to r/w = 2.5. Migration of meander, as illustrated in fig. 3(a) occurs on the outer bank side subjected to higher stream flow concentration and consequent erosion of outer bank. Migration of meander, as illustrated in fig. 3(a) occurs on the outer bank side subjected to higher stream flow concentration and consequent erosion of outer bank. Uncontrolled meandering may lead to outflanking of hydraulic structures and flow avulsion when the river shifts its course and it may join other low lying rivers - tendencies as observed in the case of Farakka barrage.

In north and north - east India, most of the streams are found to be moving in a wide flood plain formed principally due to the formation of meandering/braided channel. At Farakka, the width of flood plain (also called khadir) of river Ganga at design flood varies from 6 to 8 km.

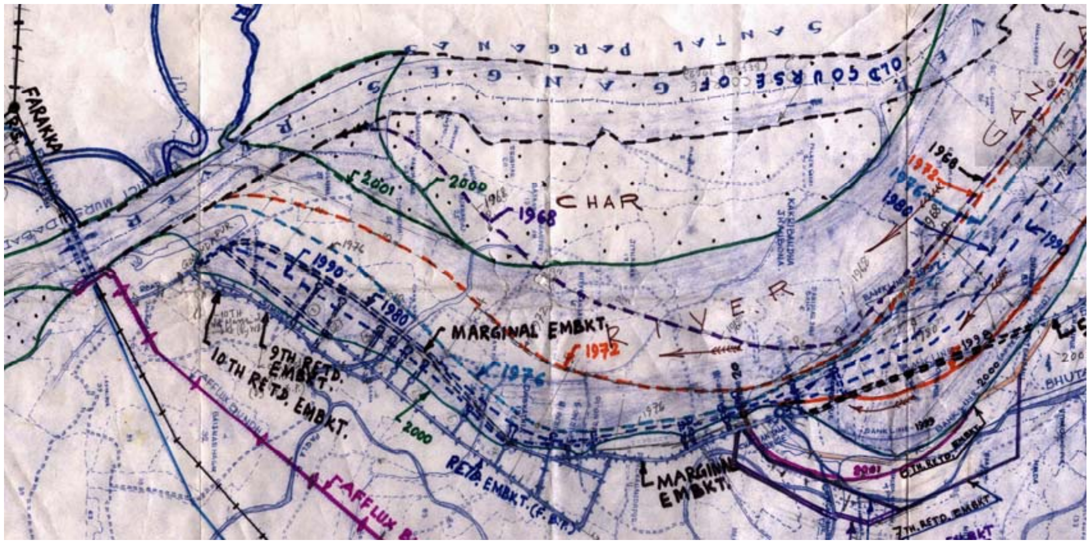
When a bridge or a barrage is constructed on such a wide flood plain, it is an usual practice to provide waterway of these structures limited

A master plan of riverbank protection, both upstream and downstream of the barrage, has been drawn to control erosion of river banks and prevent further migration of the river meander at a cost

up to



Z



Lacey's regime waterway by providing approach embankments and guide bunds as shown in fig-4.(Length of Farakka barrage is only 2.6 km with guide bunds on either side). Such restriction of waterway (which may or may not be symmetrical) results in considerable afflux (Mazumder, 2003) and back water upstream of the hydraulic structures causing sedimentation and lateral instability of flow (Mazumder et al,2002). The stream is found to form meandering/braiding flow pattern within the flood plain, depending on the slope, discharge, sediment inflow etc (Fig.2). The main channel is often found to move along one of the banks eroding the same and deposition of sediments takes place on the opposite bank resulting in a meandering course. Uncontrolled erosion on the outer bank side and deposition on the inner bank side of such meandering approach flow lead to migration of meander on the outer bank side (Fig.3), especially where the banks are made of fine alluvial soil of extremely poor shear strength (τ_b) as in Farakka (d_{50} of bed material is about 0.15mm). Non-uniformity (obliquity) of approaching flow causes not only deep scour due to high flow concentration on the outer bank, it creates large cross-slope along the river width resulting in stronger secondary current and greater scour.

Similar behavior of river Ganga is observed upstream of Farakka barrage. The main channel (about 1.2 km width flowing along the left bank) is carrying almost all the flood discharge resulting in extremely high flow concentration and colossal erosion of the left bank lying on the outer side of the meandering bend upstream of the barrage The eroded materials as well as the large volume of incoming sediments have been deposited on the right bank forming a number of shoals (also known as bed bars) upstream of the barrage. With the progressive growth of the shoals over the years and development of cross-slope, Ganga has already shifted about 7 km towards the left bank (Fig.1(b) and Fig.5). Deep scour to the extent of 50 m was observed on 3^{rd} October, 2000 (shown in Fig. 6(a)), resulting in wash out of almost all the spurs on the left bank constructed for the protection of the marginal embankment. There is an embayment and obliquity of main channel flow approaching the barrage. The flow separates at the head of left guide bund and shifts towards the diversion works on the right bank causing deep scour on the right side and silting on the left side in the vicinity of the barrage structure, threatening the safety of the barrage and causing difficulty in operation of almost 50% of the barrage gates on the left side.

Submerged weirs/barrages of low solid obstructions (like Farakka barrage) are generally made of low crest height with high head gates for the purpose of storage and sediment flushing. The flow over such low level barrage crests may be either free or submerged depending on crest height and modular limit (Mazumder, 1981) of the structure. Depending on whether the flow is choked or not, hydraulic jump may or may not form. But the fact remains that there is always a difference in energy level (ΔE) across the structure. In case the actual energy loss ($\Delta E'$) within the jump (free or submerged) is equal to the drop in energy level (ΔE), there is no residual kinetic energy of flow downstream of the structure (Mazumder 1993) and the flow is free from any distortion downstream and it remains more or less uniform. If the energy dissipation is inadequate, there is residual kinetic energy of flow (ΔE- $\Delta E'$), which causes non - uniformity in the flow distribution downstream. Author found (Mazumder and Sen, 1991) that in many of the low height barrages (e.g. Farakka) in India, the pre-jump Froude's number of flow(F_{1}) lies between 2 to 4. (At design flood, F_1=2.4 in Farakka barrage). It is known that the hydraulic jump in this region of Froude's number is either undular or oscillating in nature and the jump efficiency is very low. As a result, the flow downstream has high degree of non-uniformity and flow distortion. Such distorted flow often swings periodically to either left or right bank side due to flow instability (Mazumder 1993). It becomes highly turbulent causing erosion of bed and banks on the side where the turbulent wall-jet like flow adheres to. Deposition of sediment occurs on the opposite bank creating cross- slope and meander formation.

Similar phenomenon is observed on the downstream side of Farakka barrage, where high velocity jet like flow is found to erode the right bank after a skewed hydraulic jump- partly due to oblique approach flow (explained earlier) and partly due to inadequate energy dissipation in a skewed jump at low pre-jump Froude's number (F1) of flow. The eroded materials have deposited on the right bank causing strong cross- slope and meandering of the river downstream of the barrage. The main jet like flow is found to move along the right bank causing deep erosion and meander migration towards the right bank as illustrated in Fig.1 (a) and Fig.6 (b).

GANGA EROSION AND PROTECTIVE WORKS NEAR FARAKKA BARRAGE

Farakka barrage is designed for a flood discharge of 70,930 cumec (25 lakh cusec) with a design afflux of 0.5 m. Further details of the barrage are available elsewhere (Mazumer,2001&2004).With a longitudinal bed slope of 1 in 21,000 and a mean annual flow of about 14,000 cumec, the river is in a meandering state as indicated in Fig. 2 (b). On an average, Ganga carries 800 million tons of sediments (Sanyal, 1980) every year up to the barrage and it is estimated that approximately 13 lakh ha-m of sediments have already been deposited upstream of the barrage causing formation of several shoals/bed bars, meandering, cross-slope, strong flow curvature and lateral flow instability upstream of the barrage – the different morphological processes already discussed. With the continued erosion of its left bank upstream and right bank downstream of the barrage, a typical meander has developed with Malda on the outer side of the upstream bend (left bank) and Murshidabad on the outer side of the downstream bend (right bank) with Farakka Barrage (a rigid structure) at the centre acting as a nodal /fixed point (Fig.1 (a) &1(b)). As shown in Fig-5, the river has extensively eroded its left bank and developed a sharp curvature about 5 km upstream of the barrage. Figs.6 (a) shows a typical sketch of river cross-section n the meandering zone upstream of the barrage, indicating deep scour near the left bank. In 1972, a 30 km long marginal embankment was constructed along the left bank upstream of the barrage to stop erosion and further migration of the river towards the left bank. Subsequently, 27 numbers earthen core type impermeable spurs (duly protected with heavy stones in GI wire nets for preventing erosion), were constructed for protecting the marginal embankment with a view to train the river up to the barrage. But the embankment was breached on several occasion during high floods and most of the spurs have been washed out. The river has moved about 7 km inside Malda district (Fig. 2(b)) wiping out thickly populated villages near the left marginal embankment. 450 people died and properties worth about rupees 10,000 million were damaged. in 1998 flood alone (Mazumder 2000).

Near Panchanandpur, where the river has taken the sharpest bend and breached the marginal embankment on several occasion, retired embankments with stone pitching and submerged stone spurs were constructed eight times around the breaches (Fig.5) in order to protect the people and the properties from flood damage. However, all these retired embankments and majority of the spurs and the protective works have been swallowed by the mighty river Ganga year after year. The protection measures adopted for the 9 th retired embankment consist of similar stone pitching in GI wire net and loose boulders in between the crated ones up to a length of 50 meter starting from the bank at RL +25m and ending at a point in the river bed where the river bed level is +3 meter. The apron is laid over tarja mat made of the Assam bamboo skin. Submerged spurs of 3-meter height above the river bed and made of stones in GI wire net are constructed at a spacing of 100 meter. Since the marginal embankment (with its top at +27m) has already been washed out, the protective apron is ended at the existing bank level of 25m. If the design high flood with HFL +26.5 m occurs, the flood water will overtop the bank and it is likely to wash out all the protective works, particularly during back flow from country side to the river. If the erosion can not be controled, there is a possibility of avulsion of the mighty river Ganga bypassing the barrage. If it happens, river Ganga will change its course and it is likely to join the low lying rivers like Pagla, Kalindri and Mahananda on its left bank. The barrage will be ineffective and it will cause colossal damage to Malda district including the National highway (NH-34), railway line and afflux bund protecting Malda town.

Downstream of Farakka barrage, the river Ganga has extensively eroded its right bank in Murshidabad district of West Bengal. The downstream meander has already migrated about 4 km on the right bank side resulting in development of sharp bend (Fig.1a) and cross-slope and deep scour near the right bank as illustrated in Fig.6(b). Extensive erosion of right bank has resulted in flooding, loss of human and animal life, loss of valuable agricultural lands and household properties, damage to roads and communication system subjecting the people to extreme miseries. It is threatening the existence of several townships located on the right bank of the river. About 26 km length of river bank was protected with stone pitching and 87 nos. of submerged stone spurs were built on the right bank of the river to control river erosion. 26 spurs and 15 km of pitching have been washed out and a number of spurs and the stone pitching have been badly d