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Prof. (Dr.) Saumen Kumar Mahapatra

MINISTER-IN-CHARGE
IRRIGATION AND WATERWAYS DEPARTMENT
GOVERNMENT OF WEST BENGAL
JALASAMPAD BHAWAN, 1ST FLOOR,
SALT LAKE, SECTOR -I, KOLKATA - 700 091
PHONE : (033) 2321 5103,
TELE FAX : (033) 2321 5104,
E-mail : mic@wbiwd@gov.in

Message

The River Research Institute, under Irrigation & Waterways Department, Government of West Bengal, Mohanpur, Dist. Nadia was established in 1943 by the great effort of Late Prof. Meghnad Saha, eminent scientist and Late S. C. Majumder, renowned Engineer. Since its inception, this institute actively helped in the formulation and execution of different multipurpose River Valley Projects like Farakka Barrage Project and extended technical and research guidance to many other projects. The Institute carries out research works mainly on hydraulics of flow through open channels and on engineering properties of soil. Presently the research teams of this institute are engaged in making Physical and Mathematical model studies in different river entineering problems and in hydrology along with topographical observational work using modern survey instruments with the active support of the state Government.

I am glad to know that the River Research Institute under the Irrigation and Waterways Department, Govt. of West Bengal is going to publish its Journal “River Behabiour & Control” volume 39th, 2018-19.

I would like to thank all the research personnel working in different fields for their valuable contribution to enrich this publication.

I wish all success of the Journal.

Prof. (Dr.) Saumen Kumar Mahapatra

Prabhat Kumar Mishra, IAS
Principal Secretary

Government of West Bengal
Department of Irrigation & Waterways

No. 041-PS

dated 30th July 2021

The River Research Institute, under Irrigation & Waterways Department, Government of West Bengal located in Mohanpur, Nadia is actively engaged in research on various issues of river management and has rendered valuable contribution in the design and construction of various irrigation, flood control, drainage, coastal erosion and other similar projects in West Bengal. The Institute's work on important problems of the Dam Project, Barrage, Beach Erosion and Embankment protection of delta region in against the action of sea tides & waves etc. are some examples of the many useful activities of the Institute.

Irrigation & Waterways Department, Government of West Bengal established seven Quality Control Laboratories recently for testing various materials used in construction and other civil engineering works of the Irrigation & Waterways Department as well as other Government Departments. Various categories of officers and staff of River Research Institute have been engaged in these Laboratories and they are playing a significant role in quality assurance work of the departments. Modern Instruments and latest software have been used for RRI to enhance its capacity of modelling and analysis.

Various short term courses and seminars in different fields of water resources can be organised in this Institute, after upgradation of infrastructure of the RRI, WB in the last few years.

I am glad to know that River Research Institute, West Bengal is going to publish 39th volume of the Journal "River Behaviour & Control" 2018-19.

I am extending my best wishes to the Institute for all its future endeavour.

(Prabhat Kumar Mishra)
Principal Secretary

JALASAMPAD BHAVAN, Block DF, Bidhan Nagar, Kolkata - 700 091
Telephone : +91 23215616 / 23340251 (F), e-mail : iwd.prsecy@gmail.com

OURSELVES

It is happy to be able to bring out this present issue of the journal "River Behaviour and Control" which constitutes its 39^{th} Volume. The total number of papers published so far have crossed 285 and hope that all the personnel working in different fields of Water Resources including the Research Institute, will come forward with eager enthusiasm in the years to come and use this journal as a forum for expression of new ideas. Invitations to this effect are once again extended to all concerned with the greater number of valuable and significant contributions would be coming forth in the near future.

The views expressed in the articles published in this issue are singular to the respective authors and they are open to discussions. Comments on any article, if any, may be sent to us, which may be published in the next issue of the journal. It is confident that these publications will be of considerable help in the exchange of stimulating ideas amongst the Research personnel, Academicians and Field Engineers.

Dipankar Pal,

Sri Dipankar Pal
Director
River Research Institute
West Bengal
Irrigation & Waterways Directorate
Govt. of West Bengal

CONTRIBUTIONS

(i) River Behaviour and Control', the Journal of River Research Institute, West Bengal, Irrigation & Waterways Directorate, shall be published once in a year during May-June.

(ii) Contributions for publication in this journal should be authoritative containing interesting approaches on subjects like irrigation, drainage, navigation, hydraulics, hydraulic engineering, soil mechanics, application of remote sensing, foundation engineering, statistical application, hydrology, etc.

(iii) Author must certify that the paper submitted in this Journal has not yet been published or will not be submitted for publication elsewhere if accepted for publication.

(iv) Manuscript Requirements:

- The title of the paper should be a brief in bold capital letters.
- The names of all authors with professional affiliation and mailing address should be mentioned in the footnote of the title page.
- A short synopsis (80 to 100 words with italic font) should precede the introduction.
- The text of the paper should be typed double spaced in single column format within 10 pages.
- Reference should be cited in the text with surname of the author followed by the year of publication within the first bracket, viz. Mukherjee and Rao (1996).
- References to the literature should be placed in numerical order at the end of the paper as follows:

    1. Nagraj, T. S. and Srinivasa Murthy, B. R. (1985): Compression Index of Mixed Soils, *J. Geotech. Engg. ASCE*, **3**, 937-942.
    2. Magnus, W. and Obehettinger, F. (1943): *Formulas and theorems for the functions of Mathematical Physics*, Chelsea Publishing Co., N.Y.

(v) Two copies of the complete paper should be sent to "The Editorial Secretary, River Behaviour and Control, River Research Institute, West Bengal, Haringhata Central Laboratory, Mohanpur, Nadia, Pin-741 246".

(vi) Authors are encouraged to submit a copy of the paper on disk in *MS WORD* Format or by E-mail: dyutidolai@gmail.com, dyutidolai@yahoo.co.in, dir-rri@wbiwd.gov.in

(vii) Original ink drawings or Computer printed photographs of the figures should be attached to each copy of the manuscript.

RIVER BEHAVIOUR AND CONTROL

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Mohanpur, Nadia, Pin-741 246
Phone Nos. 91 033 25872222/2233/8395
E-mail: dir-rri@wbiwd.gov.in

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CONTENTS

CORRELATIONS BETWEEN COMPACTION, PERMEABILITY PROPERTIES AND OTHER PROPERTIES OF SOILS OF DAMS IN WEST BENGAL

Som Shankar De Dalal[1], Abhijit Roy[1] & Sukhendu Chattopadhyay[1]

Synopsis

Some data on the soils investigated in connection with different irrigation projects/ schemes of the western districts of West Bengal have been assembled and treated with statistical methods. Some regression equations have been developed with the compaction and permeability characteristics and different index properties of the soils. The accuracy of the prediction has been found reasonable.

Introduction:-

The western districts of West Bengal comprise the Rarh plain and the fringe areas of the Chotanagpur Plateau. Several irrigation projects/schemes have been executed and some others are intended here to makeup the seasonal water deficiency of the region and to control the floods of the downstream districts to some extent. Several small, medium big dams have been constructed on the rivers and their tributaries. The earthen portions of the dams are made of the soils collected from the borrow areas and the borrow areas are usually chosen within the areas to be submerged to achieve less haulage and to deepen the reservoir.

Most of the soil tests in connection with the construction of the dams have been conducted by River Research Institute, West Bengal (RRI). In this paper the results of a statistical treatment on some soils of these dams and embankments for the period 1960-2002 have been presented. The aim is to understand the soil properties in a better way and to help in prospecting of proper soils, if required, during construction of any dam in future. The use of these results may be extended to other types of embankment like road or railway embankment etc. in the region.

Study Area and Soils:-

The irrigation projects / schemes, the soils of which are used in this study are given below:

a) Purulia- Parga, Hanumata, Bandu, Futiyari, Turga, Harai, Dambera, Montorejore,

1. River Research Institute, I & W Directorate,Govt. of West Bengal, Mohanpur, Nadia.

Kumari, Taragonia, Tatko, Golamajore, Lipania, Ramchandrapur, Patloi, Saharajore, Karru.

b) Bankura- Silabati, Joypanda, Tarafeni, Kangsabati-Kumari, Bhairabbanki, Dwarakeswar, Gandheswari.

c) Birbhum- Bakreswar, Hinglow, Siddheswari (Santhal Parganas).

d) West Midnapur- Subarnarekha (Bhasraghat).

Table-1 : The Locations of the Projects

District	Irrigation Projects Site Name	Latitude	Longitude
Bankura	Kangsabati Kumari Dam	22.963889	86.789167
	Gandheswari	23.237373	87.084180
	Shilabati	22.999655	87.099753
	Joypanda	23.052547	87.046350
	Tarafeni	22.671620	86.792270
	Bhairabbanki	22.764841	86.824840
	Dwarakeswar	23.231973	87.035003
Birbhum	Hinglow Dam	23.822500	87.193889
	Bakreswar	23.825664	87.416303
	Siddheswari	23.824730	87.416403
Purulia	Turga Dam	23.197892	86.062639
	Kumari Dam	23.156478	86.284611
	Taragonia Dam	23.478008	86.387589
	Parga Dam	23.437656	86.082028
	Ramchandrapur Dam	23.587617	86.837678
	Montorejore Dam	23.580178	86.587022
	Patloi Dam	23.362258	86.483847
	Golamarajore Dam	23.427444	86.365067
	Tatko Dam	22.929089	86.512747
	Futiary Dam	23.384558	86.567283
	Hanumata Dam	23.110569	86.264317
	Lipania Dam	23.466953	86.460111
	Saharajore Dam	23.449461	87.199750
	Bandu Dam	23.302029	86.195946
	Karru River	23.200000	86.050000
	Harai	23.478053	86.51756
	Dambera	23.559967	86.060248
West Midnapur	Subarnarekha, Bhasraghat	22.037720	87.174600

The soils in the region are lateritic, residual and partly alluvial (both old and new alluvium). These soils were tested to check their suitability in placing in the core portion of the dams. The soils are generally loamy, loamy sand, loamy silt, loamy clay and loam. The soils are generally yellowish brown, brown and reddish brown in colour. Some silty clays and clayey loam are also there.

Standard Proctor Test was done on the said samples passing 4.76 mm sieve to get dry density versus moisture content curves. From these curves the values of maximum dry density and optimum moisture content were obtained. Constant head permeability test was performed on the samples compacted at or near the optimum values. Grain size distribution was obtained using pipette and sieving methods conjointly. Other index properties like Atterberg limits were determined following standard methods. The values of median grain size, d_{50} in mm were obtained from grain size distribution curves.

Background:-

Databases are often used to develop correlations among different parameters of engineering materials. The relationship between compression index and the liquid limit given by Skempton (1944) for remoulded clays and by Tarzeghi & Peck (1948) for normally consolidated clays are popular in engineering practices. The prediction of permeability co-efficient of sands using effective size (d_{10}) is also well known. Sherard, et al (1963) found on the basis of a statistical study on the US Dams that less is median grain size (d_{50}) of a dam soil; more is the chance of failure/deformation. The correlations help in reducing work load of further investigations or monitoring works. Recently developed Artificial Neural Network (ANN) techniques have emerged as an useful tool in the field of prediction. Satyaj Rao, et al (2003) have developed multiple linear regression (MLR) and ANN models on ground water quality parameters of Kankinada town, Andhra Pradesh, that have been expected to help in water quality monitoring in the region.

Generally, soil tests are done before the start of a project but during construction further prospecting of suitable soils may be required. If reliable correlations are available, such work may be lessened. This work is aimed at that direction. However, such attempt does not reduce the importance of classical investigation.

Methodology:-

In this work the independent data consist of soil texture (% finer than 2, 75, and 425 micron size.), Liquid limit (LL), and median grain size, d_{50} in mm etc. Out of these data some decision making output data namely Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and Permeability Coefficient (k) etc. have been calculated.

In this attempt out of more than 300 odd data only 180 (~60%) have been taken to find out multiple regression equations for each of the output variables [MDD, OMC, $-\log_{10}(k)$] using an online statistical tool provider *'Xuru'* (https//:www.xuru.org). Here from the multiple linear regression equations the predicted values of Y, $\widehat{Y} = \sum_{i=1}^{n} \beta_i X_i + \beta_0$ have been obtained along with Residual Sum of Squares (RSS) and coefficient of determination (R^2) for each output variable using the whole dataset. The errors have also been calculated.

Table-2A: The Independent and Dependent Variables used for Regressions

Independent Variables	Dependent Variables
X_1=Percent Clay/ Percent finer than 0.002mm	Y_1= Maximum Dry Density in gm/cc
X_2= Percent Fines (Silt+Clay)/ Percent finer than 0.075mm	Y_2= Optimum Moisture Content in %
X_3= Percent (fines+ fine sand)/ Percent finer than 0.425mm	Y_3= $-\log_{10}(k)$, where, k= Permeability Co-efficient, cm/s
X_4= Median Grain Size, d_{50}, mm	
X_5= Liquid Limit in percentage	

Table-2B : The Independent and Dependent Variables used for Dataset

Descriptive Statistics	<2µ in %	<75µ in %	<425µ in %	d_{50} in mm	Liquid Limit in %	Maximum Dry Density in gm/cc	Optimum Moisture Content in %	$-\log_{10}(k)$ K = Permeability co-efficient in cm/s
Variables	X1	X2	X3	X4	X5	Y1	Y2	Y3
count	180	180	180	180	180	180	180	180
mean	27.329	62.770	87.384	0.048	41.371	1.777	15.407	6.773
min	9.6	27	55.5	0.002	24	1.46	10.3	3.444
25%	20.675	52.6	81.85	0.0168	34	1.72	13.475	6.171
50%	26.75	61.1	90	0.0355	41	1.78	15.1	6.766
75%	33.325	72.625	95	0.0645	46.25	1.84	17	7.554
max	49.7	94.2	99	0.33	72	1.97	25	9.155

Choice of limits:-

The practical utility of these regressed equations have been checked by noting how much the predicted values tally with the actual test values. For this purpose some limits have been chosen. Obviously more the predicted values fall within the range specified by the limits, better is the prediction. There are some limits for construction control given by USBR (P-514, Ref.5). These are suggested for safe construction and good service of a dam. The limits used in this study are given in Table-3. Some of these have references to those of USBR and others are reasonably chosen values.

Table-3: Limits Used in this Study

Predicted Variable	Upper Limit	Lower Limit
MDD ($\widehat{Y}_1$)	$1.05*\widehat{Y}_1$	$0.95*\widehat{Y}_1$
OMC($\widehat{Y}_2$)	$\widehat{Y}_2$+2	$\widehat{Y}_2$-2
$-\log_{10}(k)(\widehat{Y}_3)$	$\widehat{Y}_3$+1 (10 times k)	$\widehat{Y}_3$-1 (0.1 times k)

Results and Discussion:-

The results are presented below

<u>For **combination-1** $\widehat{Y}_i$ as function of $X(X_2, X_3, X_5)$</u>

$\widehat{Y}_1 = -0.00048X_2 - 0.00255X_3 - 0.00555X_5 + 2.25918;$ $R^2 = 0.621$ (163/180)

$\widehat{Y}_2 = 0.02763X_2 + 0.04948X_3 + 0.14985X_5 + 3.14897;$ $R^2 = 0.561$ (148/180)

$\widehat{Y}_3 = 0.00805X_2 + 0.02074X_3 + 0.01491X_5 + 3.83940;$ $R^2 = 0.125$ (130/180)

<u>For **combination-2** $\widehat{Y}_i$ as function of $X(X_2, X_3)$</u>

$\widehat{Y}_1 = -0.00428X_2 + 0.00061X_3 + 1.99204;$ $R^2 = 0.394$ (156/180)

$\widehat{Y}_2 = 0.13007X_2 - 0.03565X_3 + 10.35737;$ $R^2 = 0.368$ (137/180)

$\widehat{Y}_3 = 0.01824X_2 + 0.01226X_3 + 4.55674;$ $R^2 = 0.114$ (126/180)

The other correlations involving the other variables have not yielded much better accuracies. Secondly the index parameters like percent fines, percent finer than 0.425mm and liquid limit are more easily obtained than the others. So these two sets have been presented for this attempt.

It has been found that regression equations involving X_2, X_3 and X_5 are better in prediction accuracy (shown within brackets above) in comparison with those involving X_2 and X_3 only. The values of R^2 are not good for prediction of permeability coefficient.

<u>For Combination-1 (X2, X3, X5)</u>

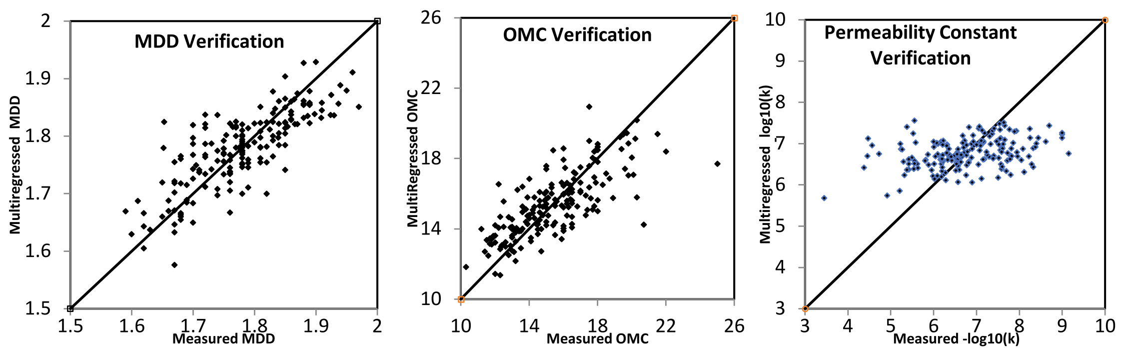

Fig-1(a) **1(b)** **1(c)**

<u>For Combination-2 (X2, X5)</u>

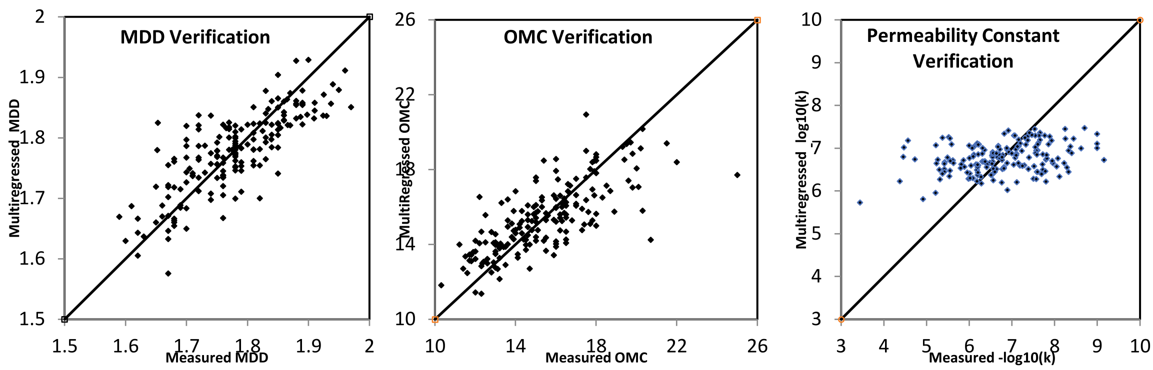

Fig- 1(d) **1(e)** **1(f)**

The prediction accuracy i.e. data within limits is quite reasonable in case of compaction characteristics. The predicted data are 87-91% within limits for MDD, 72-82% for OMC and 70-72% for permeability coefficient. The prediction seems reasonable considering that this is a statistical treatment on routine test data on different types of soils. Predicted-vs-experimental values are shown in Fig 1 (a to f). Much more accuracy may be obtained using Multiple Linear Regression algorithm used in Machine Learning/ Neural Network methodologies under Artificial Intelligence technology.

Conclusion:-

Some useful relations have been developed for the soils of western districts of West Bengal. Using index properties the compaction and permeability characteristics may be estimated. The relations may be useful for other types of embankment also besides dams.

Such correlation uses may be extended to other fields of Civil Engineering viz. monitoring arsenic affected ground water quality of Southern Bengal.

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MORPHOLOGICAL CHANGES OF RIVER GANGA UPSTREAM AND DOWNSTREAM OF FARAKKA BARRAGE AND RESULTANT EROSION IN THE STATE OF WEST BENGAL

Mayuraksha Bardhan[1]

Synopsis

The Himalayan Rivers continuously change courses in their lower reaches and the Ganga and its tributaries are no exception. The river Ganga has continuously changed its geometry of meandering in West Bengal during the last three decades. Migration of river Ganga towards the left bank upstream and right bank downstream of the barrage has resulted in unprecedented erosion of the left bank towards Malda district upstream of the barrage and its right bank towards Murshidabad district downstream of the barrage. In an uncontrolled regime, the changing course of the river is governed by skewed hydrography, bank-stratigraphy, influent and effluent seepage, sediment load. After construction of Farakka barrage, the dynamics of bend migration changed appreciably. The sequential maps help to understand how the river Ganga has changed its course. 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. Two Experts Committees, P. Singh Committee in 1980 and G. Keskar Committee in 1996, constituted to explore the possible remedial measures to combat erosion, submitted their reports. Both committees recommended revetments with boulders to protect the banks from impinging currents and construction of spurs to deflect the flow towards the opposite bank. The measures taken as per report of the Expert Committee achieved limited success. It is necessary to understand the basic mechanisms of aggradations / degradation, flow instability and meandering processes in a river like Ganga near Farakka for proper planning and design of river training works. An in-depth analysis of erosion mechanism and failure of the protective works are necessary.

Keywords: River Bank Erosion; Sediment Load; Skewed Hydrography

1.0 Introduction

River is a general term applied to a natural stream of water flowing regularly or intermittently over a bed in a definite channel following the slope of the land. River changes its own course and shapes the surrounding landscapes in different stages by continuous changing its

1.River Research Institute, P.O- Mohanpur, District-Nadia, West Bengal, Pin-741246, India.

hydrodynamic and morpho-dynamic processes following the slope, terrain characteristics, rock and soil characteristics, vegetation cover in the region. The river Ganga, the most important river of India, emerges from a glacier at Gangotri , about 7010 m above mean sea level in the Himalayas and flows down to the Bay of Bengal covering a a distance of about 2525 km. Ganga starts its old stage while entering West Bengal (Parua 2010) and swings the Rajmahal hill range and then flows towards south. The Ganga has continuously changed its geometry of meandering in West Bengal during the last three decades. There are instances when the Ganga has gone back to its former courses after reaching the limit of its meander belts, but there is no specific time for these reversals. The bed and suspended load carried by the rivers were trapped in barrage-ponds. The bed of the Ganga experienced uninterrupted sedimentation in the reach upstream of Farakka Barrage (Mandal 2015). After the construction of Farakka barrage, the dynamics of bend migration changed appreciably. What apparently seems to be bank failure is largely the response by the river system to the massive engineering intervention which impedes the flow of water and sediment load.

2.0 Review of Literature

Some literature or Articles are studied by me for preparation of this paper.There are many articles, Case study or documentary available in different Internet sources .Many governmental and non-governmental organisationsare work on Impact of Farakka Barrage and water diversion through Feeder Canal on its upstream and downstream areas. They indicate the different impacts-like-hydrological, geomorphological, social and economical. A report by Banerjee M, on "the impact of Farakka Barrage on the human fabric" emphasis the problem of the rural marginalization and response to the situation faced by the human beings (Banerjee 1999). According to the official report by Irrigation and Waterways Department, Govt. of West Bengal, there could be number of reason for the culmination of left swing and initiation of the right swing of main channel. One of the possible reasons could be the progressive diversion of flow from the main channel. A particular channel might have dominated over the other in course of time due to its more favourable orientation and ultimately became the carrier of main flow (Ray 2004). The official records regarding land erosion are available in Malda since 1931, which also took note of the fact that the river *Ganga* is slowly shifting its course in Malda district (Rudra 2006). Laha Chalantika and Bandyapadhya Sunando indicate-How Ganga Channel is shifted with the time in upstream and downstream of Farakka Barrage (Laha Chalantika 2013). Parua P.K says how the river bank is eroding for construction of Farakka Barrage in Malda and Murshidabad districts. He described the causes of bank erosion and role of Farakka Barrage (Parua 1999, 2002). Chakrabarti and Nag (2015) reported on the mechanism of bank failure in upstream and downstream of Farakka Barrage that retreat of water after the initial high discharge, removal of fine materials (sand/silt) by the water force accelerates the process of bank failure. Rudra (2000) discussed on the bank failure issue of Malda district that un-working of almost 54 sluice gates of Farakka barrage by the side of Malda has been obstructing the flow of Ganges during rainy season and leads to emerge a long strip of land in upstream of the barrage which is also responsible for severe erosion in Malda district. Dhulian and its surrounding areas in the downstream section of Farakka Barrage have been facing the problem of bank erosion by river Ganga and total municipality area lies in highly risky zone caused by severe bank erosion problem of river Ganga. Ghosh (2018) reported on the problem of erosion in Dhulian. According to Flood Preparedness and Management Plan (2014), Government of West Bengal, Dhulian town has been shifted four times due to devastating bank erosion problem. The present paper deals with morphological changes of river Ganga upstream and downstream of Farakka Barrage and resultant erosion in the state of West Bengal.

3.0 The Ganga in West Bengal

The entire 174 km stretch along the Ganga, from Bhutni in Malda to Jalangi in Murshidabad has been facing erosion . The mighty river, after its long eastward journey of more than 2000 km, enters the plains of Bengal and begins to throw off distributaries. The Ganga divides into two major distributaries, Padma and Bhagirathi-Hugli, in a village called Giria (in Murshidabad district) which is located about 40 km downstream of Farakka. The Padma carries the bulk of the discharge, flows about 65 km along the Indo-Bangladesh border and finally leaves Indian territory at Jalangi. The Bhagirathi-Hugli branch flows southward from Giria for about 500 km and ultimately discharges into the Bay of Bengal. Fig 1 shows river Ganga and its tributaries near Farakka. Fig 2 shows average longitudinal slope of river Ganga.

Farakka barrage-about 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 it's off take point at a place called Jangipur 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 outfallin 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, as the fresh water upland discharge was reducing. The Farakka barrage was constructed with the objectives of flushing the sediment load into the sea, making the Bhagirathi-Hooghly channel free from navigational hazard.

In post Farakka period, the intensity of erosion by the Ganga in Maldah and Murshidabad districts increased rendering thousands of people homeless (Rudra 2009). In the reach between Rajmahal and Farakka, the Ganga flows between outliers of the Rajmahal Hills along the right bank and the old alluvium of Barind tract along the left bank. Three moribund distributaries, Kalindri, Chota Bhagirathi and Pagla, mark the old course of the Ganga. Three other channels flow through newly emerged riverine islands, locally known as char. At the time of construction of the Farakka barrage, from the early 1960s the Ganga formed a mighty bend encroaching eastward. However, since the monsoon season of 2007, the river has started to swing westward. In the section downstream of the Farakka Barrage, where the river followed the Indo-Bangladesh border in 1947, the encroachment was southward (i.e. towards India) in most of the reaches.

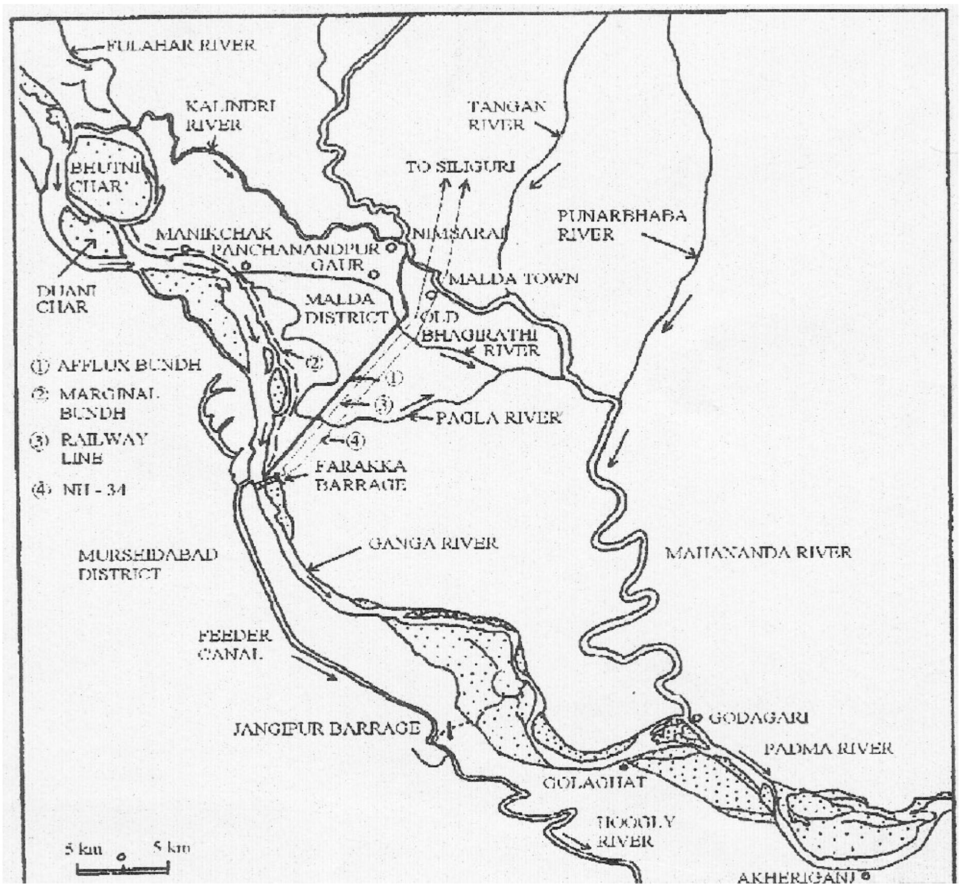


Fig 1 : River Ganga and its tributaries near Farakka

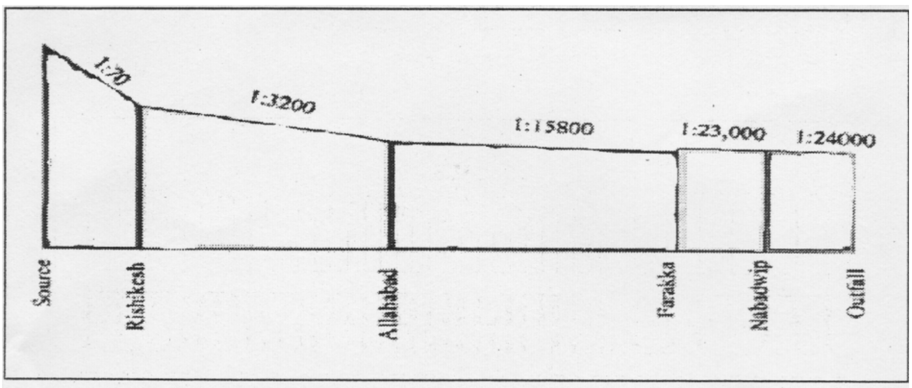
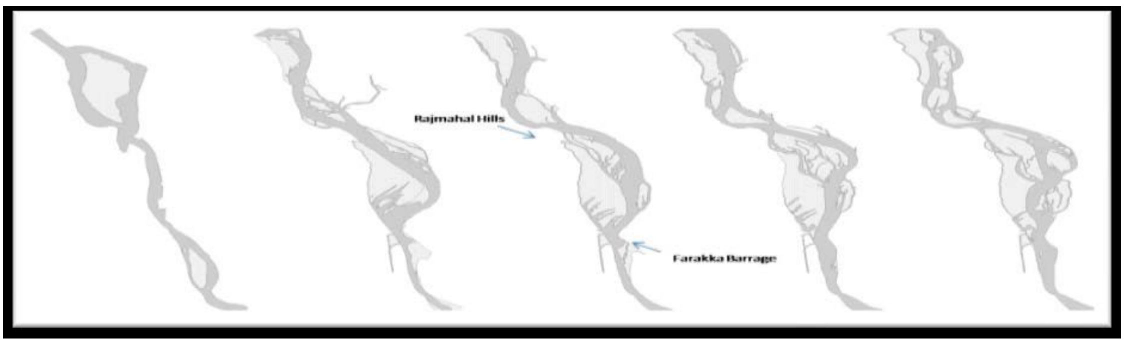


Fig 2 : Average longitudinal Slope of Ganga (after Parua 2010)

4.0 Morphological changes of river Ganga

4.1 Between Rajmahal and Farakka upstream of the barrage

In the second half of the 18th Century, the Ganga was bifurcated near Rajmahal with a riverine island called Bhutni. The situation remained unchanged until the mid-19th century. The Ganga then flowed flanking the northeastern side of Bhutni. Today, the river flows along the southwestern side of the island. Furthermore, the shape of the island has changed appreciably. In the stretch between Rajmahal and Farakka, the changing course can be understood with reference to the site of Gaur, which was the mediaeval capital of Bengal. Its archaeological ruins, along with Kalindri and Bhagirathi, two moribund distributaries of the Ganga, are still recognizable. Mukherjee (1938) reported ''Leaving the hills of Rajmahal the Ganges seemed to have passed north-wards through modern Kalindri, and then southwards into the lower course of the Mahananda, east of the ruins of ancient Gaur''. Rennell (1793) wrote in his Memoir of a Map of Hindustan, ''No part of the site of ancient Gour is nearer to the present bank of Ganges, than four miles and a half; and some parts of it, which were originally washed by the river, are now 12 miles from it”. The abandoned channels found in the western part of Ganga have depicted the fact that before the year 1973, Ganga shifted up to this extent in west, then again moved on towards east and occupied the position of 1973. In the year 2010, the left bank has engulfed some abandoned channels located in the eastern part of the course of 1973. The distance between the right bank and the western side abandoned channels has also become less, which means that Ganga has shifted eastward and widened its course from 1973 to 2010. Fig 3 depicts shifting of course of river Ganga from the year 1920 to 2010. Fig 4, 5 and 6 show the course of river Ganga between Rajmahal and Farakka for the years 1982, 2006-2007 and 2020. *Since 2007, the main flow of the Ganga has followed the middle channel, impinging the land along the left bank just upstream of the Farakka Barrage.* The older maps further show that the sites of Rajmahal and Farakka are two nodal points where the river has not changed its course. This was presumably one of the reasons for selecting Farakka as the site of the barrage. It is clearly understood from the recent satellite images that the Ganga water has been flowing through four channels below Rajmahal and the middle channel is most active now.



1920 1977 1990 2005 2010

Fig 3 : Migration of river Ganga with time. (Source : Laha Chalantica & Bandyapadhyay Sunanda 2013)

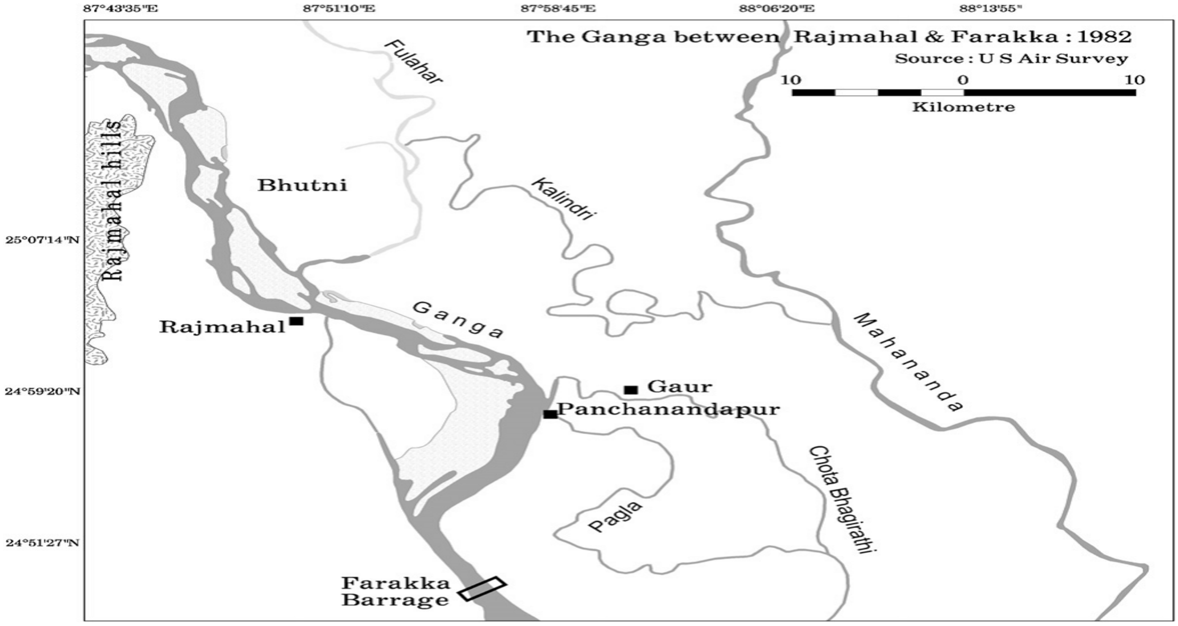


Fig 4 : Course of river Ganga between Rajmahal and Farakka 1982
(Source : Google Search) 2013)

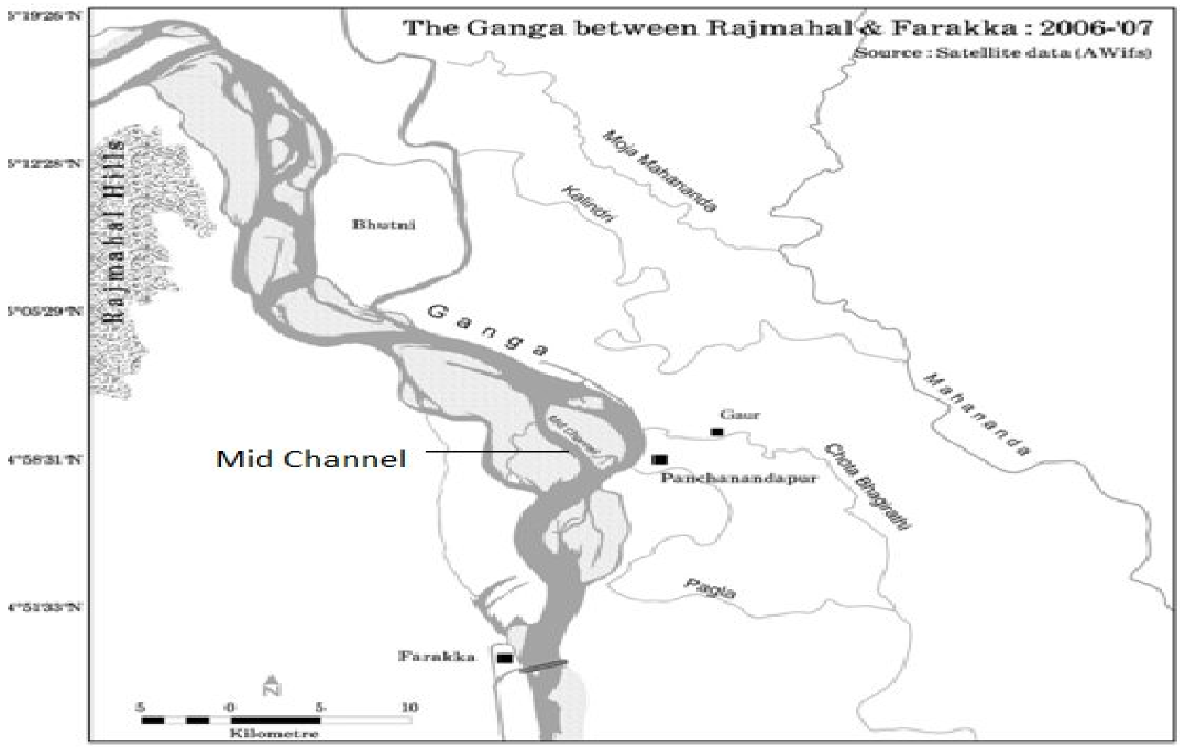


Fig 5 : Course of river Ganga between Rajmahal and Farakka 2006-2007
(Source : Google Search)

Fig 6 : Course of river Ganga between Rajmahal and Farakka 2020.
(Source : www.scihub.copernicus.eu)

4.2 In Murshidabad district downstream of the barrage

Fig 7 depicts the change in the course of river Ganga between Farakka and Lalgola from the year 1972 to 2018. Fig 8, 9 and 10 depict the course of river Ganga between Akheriganj and Jalangi for the years 1982, 2006-2007 and 2020.. The river Gange has a bank-line of 94 km along its right bank from downstream of Farakka Barrage to Jalangi. Severe erosion occurs all along this bank. Since the inception of the Farakka barrage, the hydraulic gradient of the river has been changed, relatively silt-free water released from the under sluices incised the valley deeply in the downstream section and the river has became progressively deep and narrow. The water released from the barrage eroded the right bank and the channel gradually shifted further west. This is clearly visible by comparison of the US Air Survey Map of 1982 and the satellite images of 2006–2007. The Farakka Barrage Authority has dumped huge boulders to protect the structure from imminent danger of erosion.

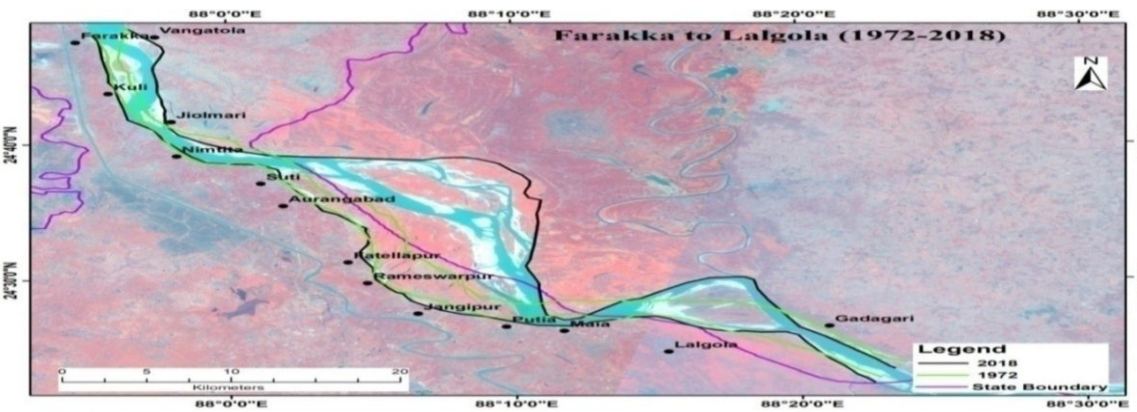


Fig 7 : Changes in the course of River Ganga between Farakka and Lalgola (after Sen 2019)

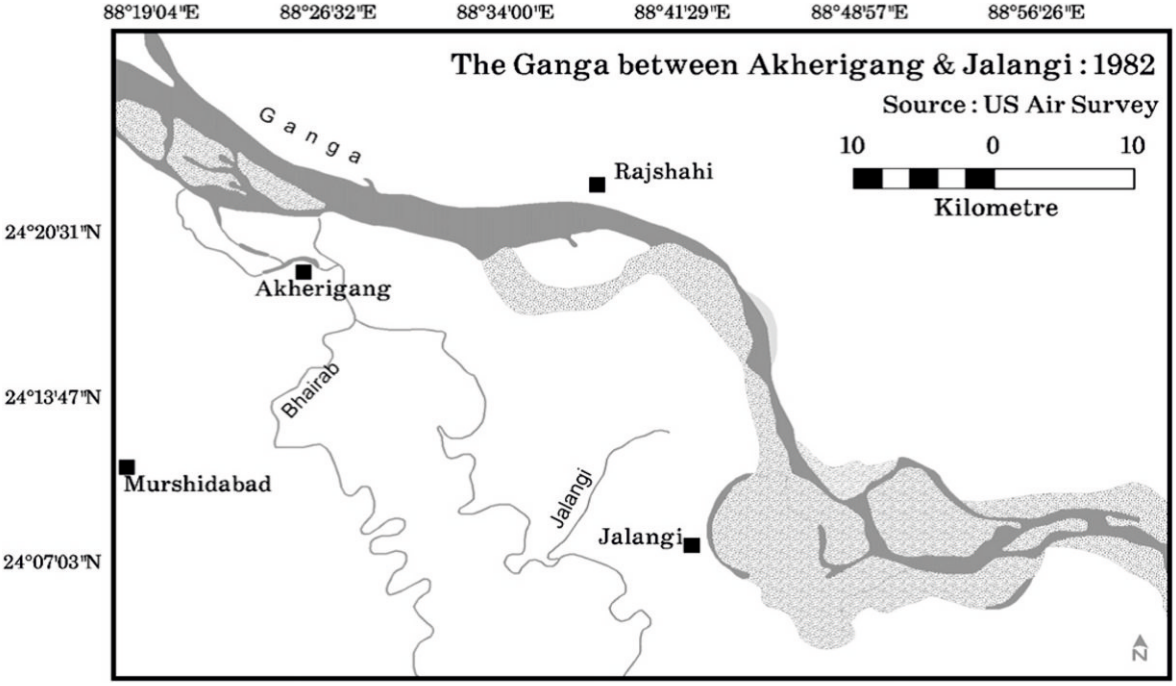


Fig 8 : Course of the Ganga between Akherigang and Jalangi 1982
(Source : Google Search)

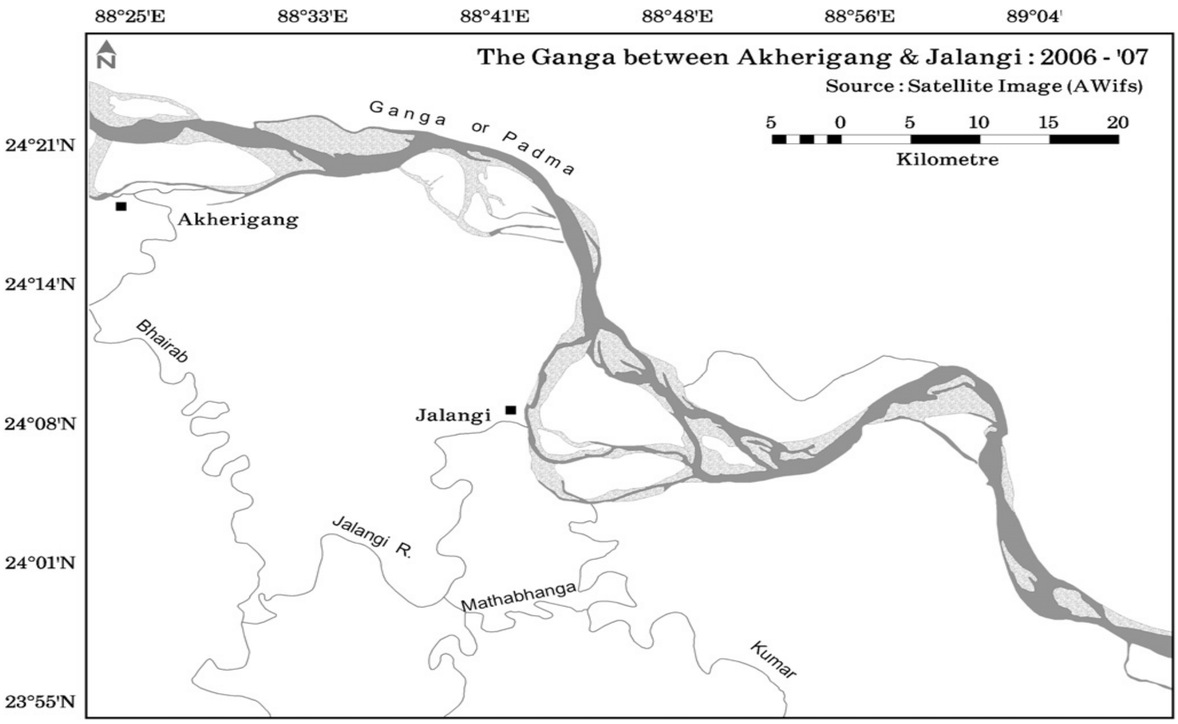


Fig 9 : Course of the Ganga between Akherigang and Jalangi 2006-2007
(Source : Google Search)

Fig 10 : Course of Ganga between Akherigang and Jalangi 2020
(Source : Google Search)

5.0 Erosion due to shifting of river course

5.1 Erosion in Maldah district upstream of the barrage

The massive structural intervention across the Ganga at Farakka started in 1962–1963, and the barrage was completed in 1971. Since then, 87 Mm^3 of water was impounded above the barrage and the water level was raised by about 6.71 m. The river adjusted by widening, and backflow reached beyond Bhagalpur (Parua 1999, 2002). The river formed an eastward meander bend. The eastward encroachment of the Ganga continued until the rainy season of 2006, when the river reached the limit of its meander belt. In the process of easterly flight, during the period 1969-1999, 4.5 lakh people were affected by left bank erosion of the Ganges in Malda district, upstream of the Farakka Barrage. River Ganga engulfed 22 mouzas in Manickchak, Kaliachak I and Kaliachak II Blocks. Other affected areas were in Kaliachak III, Ratua Iand Ratua IIBlocks. The worst-hit areas lie in the left bank of the river stretch between Bhutnidiara and Panchanandapore in the Kaliachak II block. The Ganga Bhangan Pratirodh Action Nagarik Committee's survey revealed a loss of 750 square km area in Kaliachak and Manikchak. 60 primary schools, 14 high schools, coveted mango orchards were engulfed by the river Ganga leaving 40,000 affected families. During the period 1990-2001 Hiranandapur, Manikchak, Gopalpur of Manikchak Block and Kakribondha Jhaubona of Kaliachak III Block were badly affected by river bank erosion. In 2004-05 large scale erosion took place in Kakribondha Jhaubona and Panchanandapur-I gram panchayats of Kaliachak II and Dakshin Chandipur, Manikchak, and Dharampur gram panchayets of Manikchak Block. Kakribondha Jhaubona, a gram panchayat, was totally lost by river bank erosion. Fig. 11 shows erosion of river Ganga at Chakbahadurpur in Kaliachak Block 3 in Malda District during pre-monsoon period as observed on 2.7.2020. Fig. 12 and Fig.13 show river bank erosion in Manikchak Block I and Manikchak Block-II of Maldah district.

Fig 11 : Erosion of river Ganga at Chakbahadurpur in Kaliachak Block 3 in Malda District during pre- monsoon period as observed on 2.7.2020.
(Source Anandabazar Patrika dated 3.7.2020)

Fig 12 : River Bank Erosion in Manikchak Block-I in Maldah district

Fig 13 : River Bank Erosion in Manikchak Block-II in Maldah district

5.2 Erosion in Murshidabad district downstream of the barrage

During the late 1960s and 1970s, the towns located downstream of the Farakka such as Dhulian, Nimtita, Sankopara, and Suti, and adjoining areas, suffered from severe erosion

(Ghosh 2018) and the railway connecting North and South Bengal and the national highway was realigned further west. The present Dhulian town is a relocated site after the original site was engulfed by the river. In the late 1980s and early 1990s, severe erosion was observed in Akherigang. The local market area, high school, bank and many villages were plunged in the river. The road connecting the site with Berhampur, the district headquarters, was damaged. The engineering measures to protect the bank proved futile. Now Akherigang is a relocated cluster of settlement. The original site which now lies on the other side of the river is at least 3 km north of present site. A large number of erosion victims have settled on the newly emerged land, locally known as Nirmal Char, along the northern bank of river. The impinging river eroded 207 square km of land in Murshidabad during the period 1988–1994 and more than 79,000 people were displaced (Rudra, 1996). Since erosion at Akherigang ceased, the point of severe erosion was shifted further east to Jalangi. Jalangi situated 50 km east of Baharampur district headquarter has suffered tremendously in 1994-95. At Jalangi Bazaar, severe erosion started in September 1995 engulfing nearly 400 metre width of land within a week and then high built up homestead land thereby destroying Jalangi High School, Gram Panchayat Office, Thana and innumerable buildings rendering nearly 12000 people homeless. Even the road leading to Karimpur collapsed into the river. Fig 14 shows severe bank slip on right bank of river Ganga upstream side of Sankopara under Maheshpur GP Block –Farakka District Murshidabad as observed on 6.9.2014. Fig. 15 shows erosion of river Ganga in Mondalpara area in Samserganj Block in Jangipur Sub-division in Murshidabad District as observed on 5.9.2020. Fig 16 shows erosion along the right bank of river Ganga in Samserganj area of Murshidabad district as observed on 11.9.2020. Fig. 17 and Fig. 18 show river bank erosion at Dhulian.

Fig 14 : Photograph shows severe bank slip on right bank of river Ganga upstream side of Sankopara under Maheshpur GP Block –Farakka District Murshidabad as observed on 6.9.2014.

Fig 15 :Photograph shows erosion of river Ganga in Mondalpara area in Samserganj Block in Jangipur Sub-division in Murshidabad district as observed on 5.9.2020. Villages namely Dhanghara, Kuldiar and Purono Shibpur disappeared completely.
(Source Anandabazar Patrika dated 7.9.2020)

Fig 16 : Erosion along the banks of river Ganga in Shamserganj area of Murshidabad district as observed on 11.9.2020. (Source : Hindustan Times dated 13.9.2020)

Fig 17 : River Bank Erosion at Dhulian as observed on 3.10.2020

Fig 18 : Vulnerable pocket at Dhulian as observed on 25.9. 2020.

6.0 Mechanism of river bank erosion

River bank erosion is a natural and inevitable phenomenon of river and can be defined as a dynamic natural process which involves the removal of materials from the banks of a river. The bank erosion will be occurred when the magnitude of flowing water exceeds the strength or shearing resistance of materials or sediments on the basal part of a river bank. The sediments at basal part of the bank are washed out by the running water (rising stage of discharge or effluent flow of ground water into the river) leads to form vacuum at the base and form a steep wall or cliff above which ultimately collapses by hydraulic pressure, geotechnical events or combined effect of both. Bank erosion mainly occurs in meandering river. In meandering river, river shifting takes place through bank erosion and deposition on the point bar.

The rivers continuously transfer water and sediment load in the downstream direction. Tropical rivers such as the Ganga have some unique fluvio-geomorphological characteristics. The hydrograph of the Ganga as recorded and plotted is extremely skewed because more than 80% of annual discharge passes during the monsoon months of June–September. The suspended sediment load carried annually by river Ganga has been estimated by many experts. It is stated to be 800 million tons by Abbas and Subramaniam (1984). Each year in Malda, the riverbed is rising at the rate of 50 cm resulting in declining slope in the opposite direction between Farakka and Rajmahal (Mandal 2015). Fig 19 shows sedimentation on river bed upstream of Farakka Barrage. Human intervention into the fluvial regime impairs dynamic equilibrium and the processes of changing course is often delayed or accelerated. In an uncontrolled regime, the changing course of the river is governed by skewed hydrography, bank-stratigraphy, influent and effluent seepage, sediment load and the ratio between peak and lowest discharge. The width of the meander belt is related to the discharge flowing in the river: the greater the discharge, the wider the meander belt. The shelving bank of Ganga exposed during lean months shows a layer of loose and unconsolidated basal layer of sand with a comparatively thin layer of silt-clay on top. The impinging current of the monsoon erodes the basal sand-layer during the rising stage and leads to collapse of the bank. When the river is in spate, the influent seepage recharges the ground water pool. The effluent seepage towards the river creates voids in the basal layer during the falling stage, resulting in extensive bank failure (Ghosh 2018).

Fig 19 : Sedimentation on river bed upstream of Farakka Barrage (after Mandal 2015)

7.0 Protective Measures

Fig 20 and Fig 21 show photographs (pre-monsoon and post-monsoon) of bank protection works carried out at Moya, Lalgola in Murshidabad district during the year 2017 and the said protection work was effective in reducing bank erosion at that location. Fig 22 shows bank protection work at Dhulian in Murshidabad district using bed bars, The bed bars are constructed to save the populated right bank at Dhulian, Fig. 23 shows bank protection work using stones in wire crates in Murshidabad district.

Fig 20 :Bank Protection Works (before monsoon) in 2017 at Moya, Lalgola in Murshidabad (after Sen 2019)

Fig 21 : Bank Protection Works (after monsoon) in 2017 at Moya, Lalgola in Murshidabad (after Sen 2019)

Fig 22 :Bank Protection Works at Dhulian using Bed Bars.

Fig 23 :Bank Protection Work using Stones in Wire Crates in Murshidabad District

8.0 Formation of Expert Committee

Two Experts' Committees (P. Singh Committee in 1980 and G. Keskar Committee in 1996) constituted to explore the possible remedial measures to combat erosion, submitted their reports. Both committees recommended revetments with boulders to protect the banks from impinging currents and also construction of spurs to deflect the flow towards the opposite bank. Total cost of the short term and long term measures suggested by the committee was about Rs.10,000 million based on 1996 price index (Mazumder 2000). A master plan of riverbank protection, both upstream and downstream of the barrage, was drawn to control erosion of river banks and prevent further migration of the river at a cost of about Rs. 927 crores as per the recommendations of Pritam Singh and Keskar Committee. Unfortunately, the recommended conventional protective measures, consisting of impermeable earth-core type spurs protected with stone pitching and crated stone bed spurs over stone mattress, have miserably failed to perform. Most of the impervious spurs are destroyed due to heavy erosion at their heads and toes. They settle (due to scouring/winnowing of foundation soil) ,crack and the high velocity current flows through the cracks eventually washing out the spurs. The river banks made of very fine non-cohesive alluvial soil are subjected to the fury of the river causing erosion of the bank. The sand and silt layers underneath the bank get eroded first and the top clayey bank caves in the scoured area due to lack of any support from bottom (Mazumder 2004).

9.0 Conclusions

In spite of elaborate and very costly river training measures adopted so far, river Ganga is creating unforeseen problems due to uncontrolled erosion of its left bank upstream and right bank downstream of Farakka barrage. Uncontrolled erosion and deposition process in the vicinity of Farakka barrage has resulted in development of meanders and its migration towards Malda district in West Bengal (on left bank) upstream of the barrage and Mushidabad district in West Bengal (on right bank) downstream of the barrage resulting in flooding, loss of life, agricultural lands and other properties on both the banks. It is necessary to understand the basic mechanisms of aggradations / degradation, flow instability and meandering process in a river like Ganga near Farakka for proper planning and design of river training works. Conventional measures consisting of embankments, stone mattresses and groynes are found to be ineffective due to deep scour near the river banks. An in-depth analysis of erosion mechanism and failure of the protective works are necessary. *Each vulnerable zone possesses a distinct nature of its own and requires remedial measures accordingly. It is felt necessary that geomorphological changes are required to be superimposed and detailed scientific and technological studies including hydrological and hydrographic observations are to be made to predict the remedial measures on long term basis.*

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RESTORATION OF WATER RESOURCES IN THE LOWER REACHES OF SOME TIDAL RIVERS OF WEST BENGAL

S. S. De Dalal[1], B. C. Barman[1], S. Basak[1], T. Payra[1], S. Chattopadhyay[1] and S. C. Lahiri[2]

Synopsis

In the lower reaches of the rivers, sea water intrusion during high tide causes salinity mainly in post monsoonal months due to poor upland discharge. The state of West Bengal is densely populated and agriculture provides livelihood of millions of people. Ways are being thought to restore sweet water resources by resectioning decaying / derelict channels / rivers or providing control structures to regulate salt water ingress. This paper deals with some studies on the tidal reaches of the river Keleghai and Ichhamati in search of suitable solution and on the Hooghly in post Farakka barrage period.

Keywords : River water, Tide, Salinity, Tolerance limits, Human use

Introduction:

Many Indian rivers are snow fed but most others run with rainwater. The northern rivers are mostly perennial, while the others are lean generally. All these rivers run in torrents in monsoon. These rivers ultimately drain into the sea. After the recession of the monsoon the rivers run in lean stream. Result is occurrence of a phenomenon of salinity increase in lower reaches where these meet the sea. Sea water or saline water moves inward during high tide to some length causing salinity in river water. The extent depends on the river discharge, river slope, phase of the moon etc. In post monsoonal months the river discharge is low and hence salinity results and the effects are considerable in some lower reaches of the rivers. The salinity causes limitation / hindrance in human consumption and agricultural use in particular. In addition to variations of precipitation across the year, some other natural and human causes (namely control structures like dams and barrages in the upper reaches) aggravate this situation. An example of natural phenomena is the course shift of the Ganga. Since the sixteenth century gradual eastward shifting of the Ganga has rendered the Padma that runs through Bangladesh, as the main carrier leaving the Bhagirathi-Hooghly a spill channel only (Singh, 1991). The right arm receives water only during the monsoon months. Not only choking of the mouth of the Bhagirathi, siltation on the start of the Bhairab, Mathabhanga and Jamuna have caused decadence of the Nadia rivers like the Jalangi, Churni

1.River Research Institute, I&W Directorate, Govt. of W.B., Mohanpur, Nadia.
2. Department of Chemistry, Kalyani University, Kalyani, Nadia.

etc. The Same phenomenon has happened in North 24-Parganas' rivers like the Ichhamati, Nowi, Sunthi, Nonagang etc. These rivers ultimately fall into the Sunderban estuaries. As a result salinity of the rivers and creeks of the Sunderban has increased. These affect the bio-diversities of the region and hence tell upon the socio-economic status of the inhabitants. Gradual depletion of the mangroves with trees like Sundari has resulted in increase of vulnerability of the region against natural disasters like cyclones. Other bio-indicators of salinisation of surface water are gradual disappearance of shoals of Hilsa fish and Gangetic Dolphin in this area.

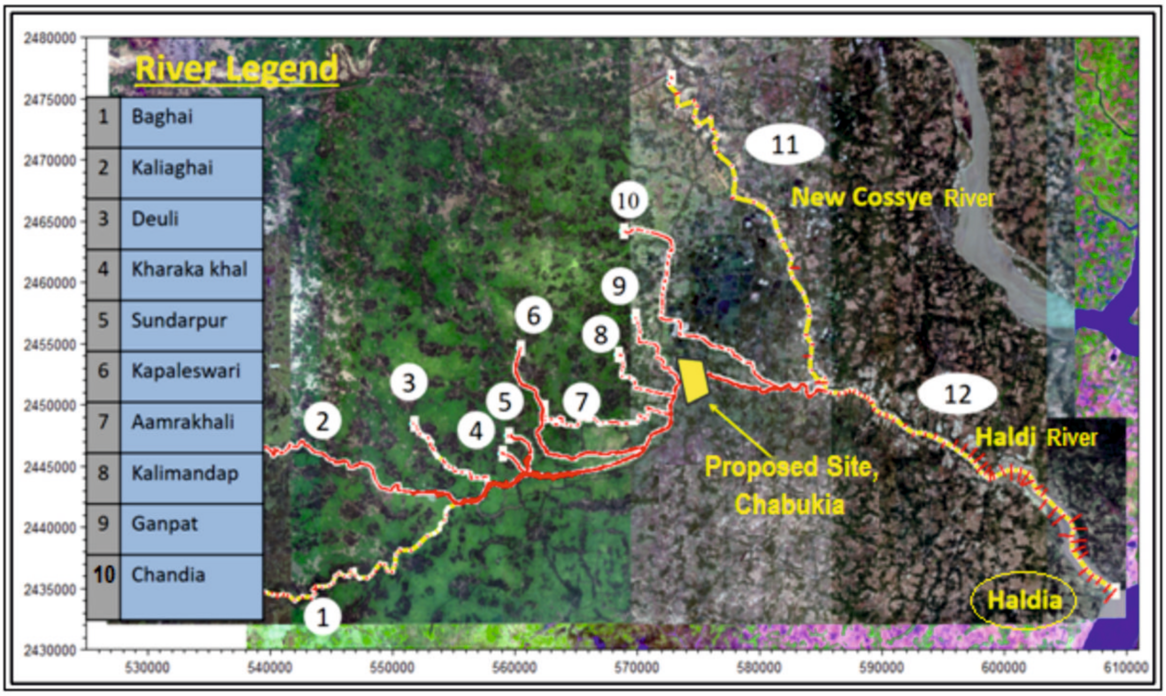

Fig-1: River Network of the river Keleghai showing the proposed site (Source : Google)

Another river affected by salinisation is the river Keleghai (*Kaliaghai)* of East Midnapur district. The Keleghai has originated from the high lands near Kharagpur in West Midnapur district and during travel it meets with the Kapaleswari, Ganpat, etc from the left and joins with a branch of the Kasai (*Cossye*) to form the river Haldi (Fig-1). The river Haldi falls into the Hooghly estuary. Haldia Port is situated on the outfall. Some stretches of the Keleghai-Kapaleswari are silted up; consequence is advancement of saline water of the river Haldi during high tide particularly in post monsoonal months towards the Keleghai. As a result agricultural activity gets affected after monsoon in some areas.

This paper deals with chemical investigations on river water of tidal reaches of the Hooghly, Ichhamati and Keleghai. Discussion has been made on the extent of salinity effect and on the ways and means regarding restoration of river water for human use.

Instances of Some Rivers of West Bengal:

a) Bhagirathi - Hooghly

Since the commissioning of the feeder canal of the Farakka Barrage Project in 1976 the Bhagirathi-Hooghly river system has become the life line for the development of water supply, irrigation, industry and power generation in adjacent districts on both the banks of the river system. Before 1976 the river did not have any upland flow during dry season from December to May. Saline tidal waters used to intrude deep inside, even upto Katwa in the district of East Burdwan. Gradual deterioration of the river prevented any development in water supply, irrigation and power in the region. The quality of water supplied by the existing plants like Tallah-Palta system of Calcutta Corporation became practically brackish (Bose, 1994).

Commissioning of the Farakka Barrage Project brought about a revolutionary change in the above scenario. The river was flushed by an upland discharge even during the lean season by 40,000cusec (max), the ecology of the system vastly improved and the tidal reach was drastically reduced. Now the tidal effect is felt only upto Swarupganj in Nadia district. The salinity of water has greatly decreased by dilution by the upland discharge fed through the feeder canal during dry season. Limit of salinity intrusion is now at Nurpur in the district of South 24-Parganas, that is salinity front has been pushed down to about 100 km southward.

b) Ichhamati River:

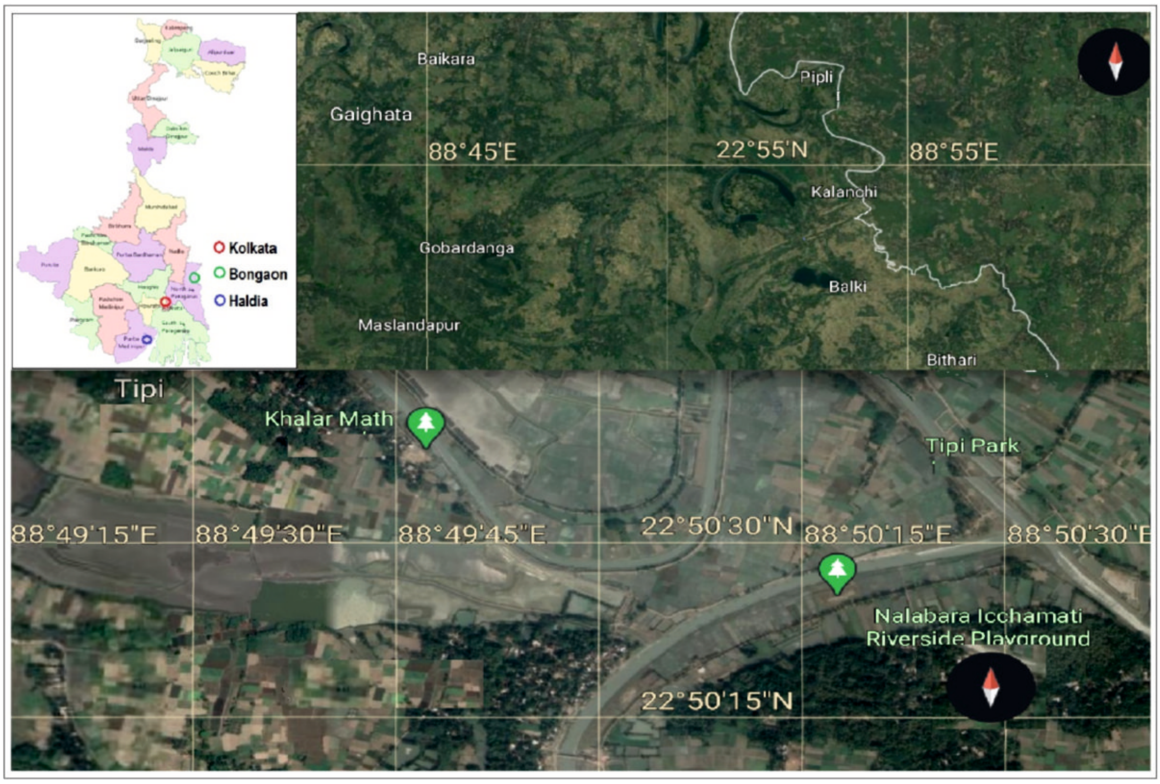

Fig-2: Photograph of site Kalanchi, Pipli & Tipi near Bangaon on the Ichhamati river (source : Google)

Some lengths of the Ichhamati downstream of Bongaon in the district of North 24-Parganas (Fig 2) were dredged and bed soils were removed by I&W Directorate, Govt of W.B. to enhance the carrying capacity of the Ichhamati. After some months monitoring works were done. In this connection river sections were taken and some water samples were collected (2011- 12).

c) Keleghai River:

Some stretches of the Keleghai – Kapaleswari were dredged in recent years (2013-18) to increase the carrying capacity. Subsequently it has been planned to construct a control structure at Chabukia in the district of East Midnapur, so that beyond that saline water intrusion in post monsoonal months is restricted or regulated and the impounded water is utilised in agricultural purposes. To ascertain the period of the year, during which the water is fit for use, a chemical study has been done.

Test Programme:

Some tests were done years back and some others have been done recently in River Research Institute, W.B. All these are being presented sequentially.

a) The quality of river water of the Hooghly was studied by River Research Institute (RRI,WB) at some selected locations in post Farakka barrage period as a part of a CBI&P sponsored research project (completed, unpublished). Since January 1977 water samples were collected from the river Hooghly at 16 selected sites covering a stretch of 74 km from Tribeni (BTPS) to Budge Budge Oil Depot. Later the study was confined to 7 sites covering the same stretch. The water samples were collected from mid stream and near both the banks. All the pertinent parameters of the water samples were determined according to standard methods of analysis. Techniques following which water analysis was carried out included gravimetric, volumetric, colourimetric and flame photometric procedures. Some typical results of the river water of some sites are shown in Table-1.

b) Laboratory tests were done (2011-12, 2019) in RRI, West Bengal to determine some physico-chemical characteristics of the river water of the Ichhamati. The samples were collected from mid stream and within 30cm from top of the river. Total dissolved solids and suspended load were measured following gravimetric method and chloride contents were measured by Mohr's method (Titration). The results are presented in Table-2. The sites are on the Indo-Bangladesh border, a few kilometres downstream of Bongaon and a few kilometres upstream of Tipi (Confluence of the river Ichhamati and Jamuna).

c) Water samples of the Keleghai were collected across the years 2018-20. Chloride content was determined by Spectro-photometric Method(Hach-DR-6000). Conductivity was determined by Conductometer(Hach-Sension EC-71) and pH by pH meter(Hach-Sension MM340) . Some results are shown in Table-3.

d) controlled batch test in laboratory

A batch test was done to assess the amount of water needed to make brackish water usable.

The results of dilution test (2019-20) in a batch performed in RRI laboratory are given in Table-5. Some volume of river water was mixed with different volumes of distilled water. The mixture was stirred for 10-15 minutes and left to mature for another 15minutes. Then the samples were tested. TDS was obtained by gravimetric method and conductivity by conductometer.

Discussion on Test Results:

a) It is found in Table-1 that even in lean period (March, May) the quality of the water of the Hooghly is good for human consumption.

b) It is evident that in post monsoon (particularly after February) there is considerable ingress of salinity in the river water of the Ichhamati obviously due to poor upland supply (Table-2).

c) Some typical laboratory test results on the water of the Keleghai are shown in the Table-3. The average values of Total Dissolved Solids (TDS) of different months have been plotted in the figure (Fig.3). As the variations of TDS values are very high, ordinate has been plotted in log scale to afford all the values. It has been found that from peak monsoon to some period of winter, the water is free from salinity. So the water of this period may safely be used for agricultural purposes. The status of river water may be compared with the given tolerance limits and the TDS scale given in Table-4.

d) From the batch test (Table-5) it is found that considerable amount of clean water is needed to reduce the salt concentration meaning that high amount of upland discharge is required to retreat the saline front during the lean period of the year.

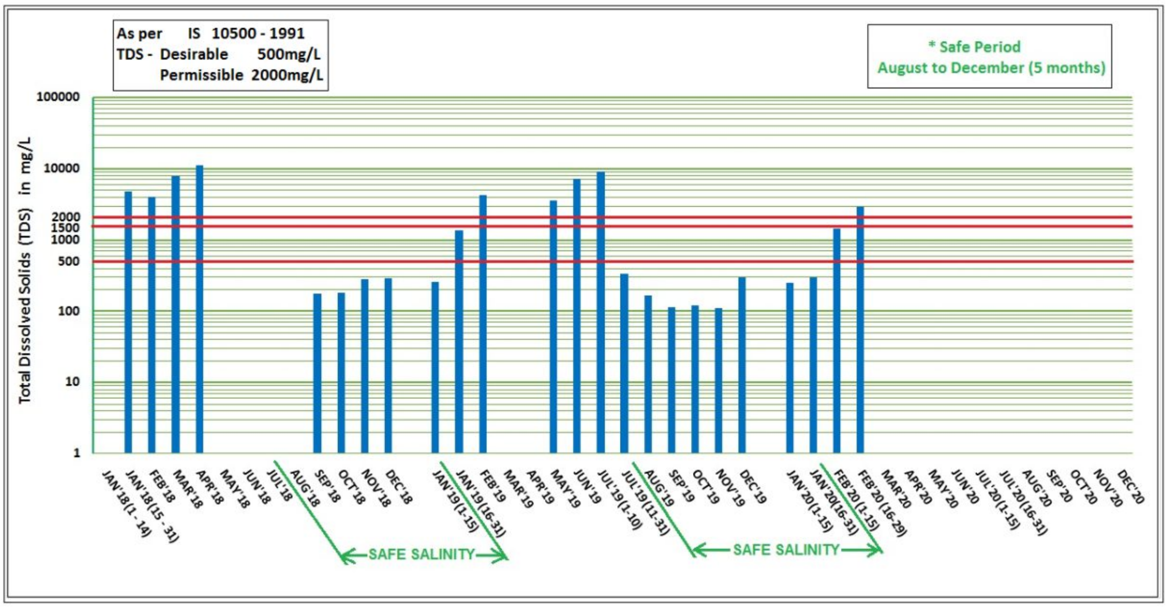

Fig.3. Variation of TDS of the River Keleghai at Chabukia East Midnapur Across Different Months of Recent Years

Conclusion:

1. The water quality of the right arm of the Ganga that is Bhagirathi-Hooghly was found more or less good but due to polluting effects of certain reaches by municipal and industrial effluents it is felt that constant monitoring of water quality is required.

2. After February the Ichhamati water shows high TDS. To reduce it further revival of the Jamuna and the Ichhamati is required.

3. The water of the Keleghai is good for 5 to 6 months. For the rest period it is brackish. Control structure may help in restricting propagation of salinity.

4. The salinity ingress in tidal reaches of the rivers is mainly a natural phenomenon. It may be controlled by restricting the movement of the saline front or by supplying fresh water in lean period. However, the prospect of getting fresh water from the Bhagirathi-Hooghly, the main river of the State of West Bengal is not aspiring at present. For the rivers falling into the Sunderban estuaries some combined ways like reviving the silted / derelict river courses and water bodies (by dredging / desilting) may be tried in patches to improve the overall scenario to certain extent. Recharging ground water seems to be doubtful proposition as soils here are clayey i.e. impervious and safe water bearing aquifers exist at greater depths. Of course ground water recharging may reduce salinity level of shallow aquifers to some extent. As a whole, conservation of sweet water should be stressed upon. The region is populated and agro-based. Sustenance of surface water regimen should be given prime importance by policy makers for the development of the areas.

Acknowledgement:

The authors gratefully acknowledge the contribution of laboratory staff as well as establishment staff of River Research Institute, West Bengal in this work and for preparing the paper.

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Table -1. Water Quality of the river Hooghly in Post Farakka Barrage period

Characteristics	Values at Site			Tolerance Limit	
	Naihati	Howrah Bridge	Shibpur Ferry Ghat		
pH	7.8	8.3	8.0	6.5 – 8.5	Class C
D.O. ,mg/L	5.0	5.0	4.0	Minimum 4.0	Class C
B.O.D., mg/L	2.0	2.0	2.0	Maximum 3.0	Class C
Hardness as $CaCO_3$, mg/L	116	138	131	Maximum 300	Class A
Chloride (as Cl), mg/L	9.0	17.0	16.0	Maximum 600	Class C
Suspended Load, mg/L	398	Trace	311		
Total Dissolved Solid (TDS), mg/L	144	268	168	Maximum 1500	Class C
Sp. Conductivity, micro mho/cm	225	287	234	Maximum 2250	Class E
% Sodium	35	18	14	Maximum 60	Class E
Sodium Adsorption Ratio (SAR)	1.2	0.4	0.5	Maximum 26	Class E
Collection Date	24/03/1981	12/05/1981	12/05/1981		
Tide Condition	Ebb	Ebb	Ebb		

** Tolerance limits for Inland Water subject to pollution (IS 2296 – 1982)

Class A – Drinking water without conventional treatment but after disinfection

Class C – Drinking water with conventional treatment and disinfection

Class E – Irrigation, Industrial cooling, etc.

Table-2. Physico-Chemical Analysis of Water Samples of the river Ichhamati at some sites near Gobardanga, North 24Parganas

Date of Collection	Site	pH	Total Dissolved Solids ppm	Suspended load ppm	Chloride as Cl ppm	Conductivity
	Pipli(P)	7.08	327	386	107	
09-08-2011	Tentulberia(T)	6.92	756	396	290	
	Kalanchi(K)	7.05	424		143	
21-09-2011	T	7.04	228	72	76	
	K	7.09	168	63	68	
14-12-2011	P	8.19	672	94	281	
	T	7.70	732	97	296	
	K	7.84	644	89	257	
15-02-2012	P	7.70	796	132	327	
	T	7.51	836	100	373	
	K	7.69	868	104	364	
19-04-2012	P	7.40	5700	30	2758	
	T	7.50	6164	43	3170	
	K	7.55	7592		3727	
13-09-2019	P	7.0	840			1.48 ms
	T	6.70	972			1.75 ms
	K	6.80	1084			1.91 ms

ms - milli Siemens & mics - micro Siemens

Table-3. Results of Physico-Chemical Analysis of Water Samples of the river Keleghai at Chabukia, East Midnapur.

Date of collection	pH	Total dissolved solids ppm	Suspended load ppm	Chloride as Cl ppm	Conductivity
31-01-2018	7.8	5100	405		
15-02-2018	7.7	3400	200		
09-03-2018	8.0	8500	70		
27-04-2019	6.4	626		156	1.02 ms
11-05-2019	6.8				11.94 ms
18-05-2019	6.8	3570		1182	5.40 ms
03-06-2019	6.7	7914		2951	11.10 ms
10-06-2019	6.6	6424		2397	9.61 ms
21-06-2019	7.5	9638		3858	13.55 ms
02-07-2019	7.0	9000		3860	13.22 ms
10-08-2019	6.9	204		31	397 mics
30-08-2019	7.0	106		16	143 mics
19-09-2019	6.9	94		14	156 mics
23-10-2019	7.0	110			225 mics
01-11-2019	7.0	98		15	185 mics

Date of collection	pH	Total dissolved solids ppm	Suspended load ppm	Chloride as Cl ppm	Conductivity
12-12-2019	6.8	468		84	
15-01-2020	6.7	348			
14-02-2020	7.2	2286			
23-02-2020	7.0	2872			
28-02-2020	7.4	4356			

ms - milli Siemens & mics - micro Siemens

Table – 4. Type of Water - Gorrell, 1958 (Davis and De Wiest, 1966)

Name	Concentration of TDS (Total Dissolved Solids) in (ppm)
Fresh Water	0 – 1000
Brackish Water	1000 – 10,000
Salty Water	10,000 – 1,00,000
Brine	>1,00,000

Table-5. Batch Test in Laboratory/ Source of water: Keleghai River, Chabukia (2019)

Sample No-	Volume of River water, CC	Volume or distilled water, cc	pH	Total dissolved solids, ppm	Conductivity
10	50		7.81	9340	13.85 ms
20		50	6.60		1.70 mics
11	50	10	7.80	7780	11.85 ms
12	50	20	7.78	6670	10.25ms
13	50	30	7.76	5840	9.08 ms
14	50	50	7.71	4670	7.47 ms
15	50	100	7.32	3120	5.09 ms
16	50	250	7.08	1560	2.77 ms

ms - milli Siemens & mics - micro Siemens

A FIELD OBSERVATION OF BEACH EVOLUTION AT DIGHA, WEST BENGAL

S.S. De Dalal[1], B.C. Barman[1] and S. Chattopadhyay[1]

Synopsis

Excepting natural calamities like cyclones periodic erosion deposition cycles are responsible in forming the beach profile of Digha. A field study at a particular location of the beach at Old Digha has been presented in this paper. The variations of the beach level in different seasons and different years together with the variation of sand size have been presented. Once this evolution process is understood it seems to be easier to take protective measures for restoration of the beach.

Keywords : beach, evolution, natural agents, sand size

Introduction:

Digha (Fig.1) has been emerging as a sea resort in eastern India since independence and many developmental works have been done so far. At the same time erosion deposition cycles in each year with net result erosion of the beach material and shore line shift have been noticed (Ref.2). In the sediment cell between the Subarnarekha mouth and the Rasulpur outfall there are several draining channels, but the Subarnarekha is the main sediment source. It has been reported earlier (Ref.2) that the beach sand has some similarities in colour (yellowish brown) and mineralogical composition (mainly quartz, little hornblende, plagioclase, microcline and trace muscovite) with that of the Subarnarekha river sand (site – Bhasraghat), while the Hooghly estuarine sand (site – Sagar Island) is slightly different (grey in colour, mainly quartz, some other minerals and considerable muscovite). In recent decades some dams have been constructed on the Subarnarekha system of rivers in upstream states causing less sand flow with the river discharge out falling into the sea. This probably results in paucity of sand in sustenance of beach by littoral movement.

As a part of developmental works hard walls are usually opted as protection of shoreline because of preference of long uninterrupted beach by the fishermen, tourists and people of other interests. Cross structures have been chosen only at stray locations as for example, the jetty with tetra pods at Digha Mohana and the groyne field at end of Sankarpur (executed by the dept. of fisheries). Another point is the removal of dunes and natural

1. River Research Institute, I&W Directorate, Govt. of West Bengal, Mohanpur, Nadia.

vegetations during development of various infrastructures in the region. It is seen that the beach level is lowered during monsoon and deposition takes place in winter. In addition cyclones play havoc in removing dunes and beach material within a short period. In the surveys of 2008 and 2009 by RRI it has been found that the beach has been lowered considerably (above 2m) compared to that of 1965, between Digha Border and Mohana.

For the sustainability of the sea resort and its economy, constant watch on the beach level and shoreline is needed so that palliative measures can be planned and implemented in right time.

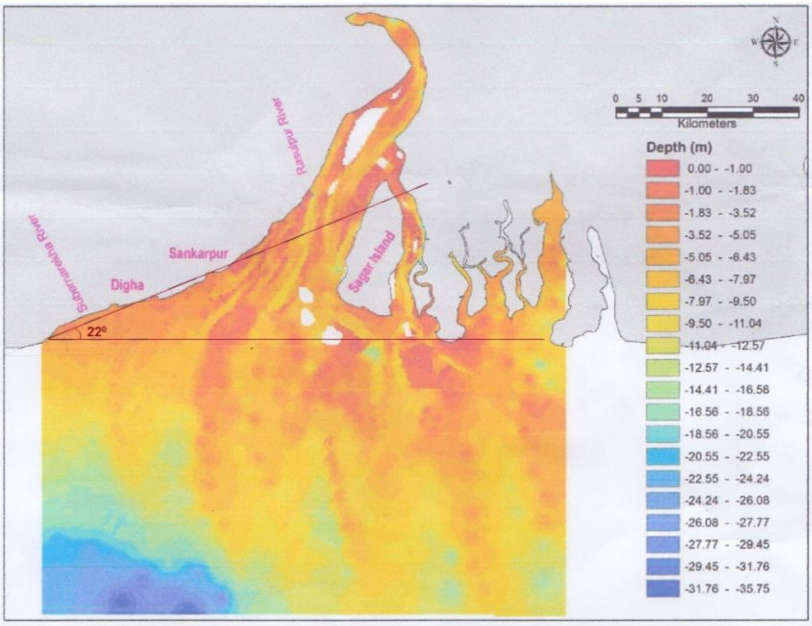

Fig.1. Orientation of Digha – Geographical Map (Source: ICZM Report)

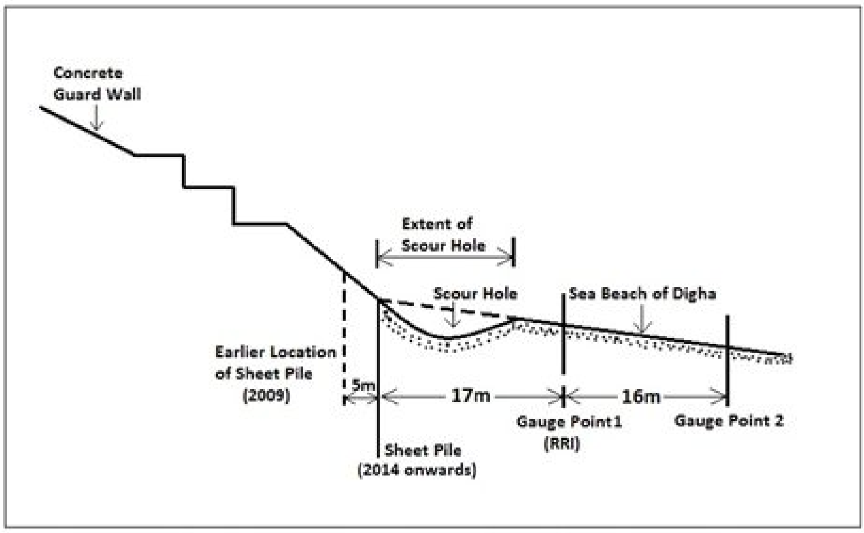

Fig.2. Location of Observation Points at Old Digha in front of Irrigation Bungalow

Scope of Work and Methodology:

It was decided (2009) to observe the level of the beach (when exposed) throughout a year at the RRI gauge point-1 in front of I&W Bungalow situated at Old Digha. At the same time the level of the beach at the face of the sheet pile and the extent of scour hole in front of the sheet pile (Fig.2) were included in this observation programme. The observations went on regularly since 2009. A new line of sheet pile was erected in 2014; 5m seawards from the old line and the observations have been going on till date to assess the variation of beach level across a year and over the years. In addition, sand samples in each new moon and full moon were taken near the gauge point-1 to determine particle size variation in different seasons over the years. These sand samples were sent to Haringhata Central Laboratory, RRI for sieve analysis. In some early years wind speed and direction data were collected using anemometer installed at RRI Meteorological Station within I&W Bungalow campus. The values of HWL (Highest Water Level) and LWL (Lowest Water Level) were observed using 3 gauges of RRI installed within the beach. In addition some observations were taken to assess the wave period that is the time between the crests of two consecutive waves.

Results and Discussion:

The levels were obtained using the measured depth and the reference level set on the post. The levels of different depths were then plotted for different periods of different years (Fig.3A to 3D). The sand samples collected were sieved in laboratory. Initially the beach sand samples for different new moon and full moon periods were dried and sieved. The salts adhered to sand grains created problem in sieving. Later the samples were washed, dried and then sieved. From the particle size distribution curves the values of D_{50}, median grain size were obtained. Similarly, the dune sand samples were sieved and D_{50} values were obtained.

A. Different Observations:-

a) Wave period (shown in Fig.3A) – It is less in monsoon, higher in non-monsoon period. So energy imparted on beach is more in monsoon.

b) Wind direction (shown in Fig.3C) - 1st quarter of a year – dominant wind directions are NE & SE (% being just less than 20). Average wind speed is 17.1km/hr, 27.4 km/hr in the dominant directions. 2nd quarter – dominant wind directions are SW & S (% being 48.3 and 25.9). Average wind speed is 25km/hr, 21.9 km/hr in the dominant directions. 3rd quarter (peak monsoon) – dominant wind directions are SW, W and S (% being 43.2, 14.3 and 4.9). Average wind speed is 35.1km/hr, 21.4km/hr and 14.6 km/hr. 4th quarter (post monsoon) – dominant wind directions are NE, N, S and SW (% being 28.8, 19.2, 7.3 and 6.4). Average wind speeds are 15.7km/hr, 15.7km/hr, 15.7km/hr and 15.7 km/hr. So directions of wind during erosion are SW, S and W (monsoon), during deposition these are N, NE, SE (post monsoon).

Grain Size:-

c) Wind sorted sand particles causing the formation of dunes are uniform fine sand (D_{50} – 0.11- 0.15mm). But wave sorted sand particles forming the beach are uniformly graded fine sand to medium sand (D_{50} – 0.072 to 0.266mm).

d) Beach level near gauge point – Lowering / Erosion – Start of March to September. Bulk erosion March – April, then gradual. Raising / Deposition – end of September to February. Bulk deposition September – October, then gradual.

* Beach level near sheet pile (end of guard wall)–

Erosion – March to September

Deposition – October to March

* Width / Extent of Scour hole near sheet pile – Width more in premonsoon – monsoon; Width less or hole closed in post monsoon – winter.

* [Details are not given in this paper]

B. Dune sand-

Sweeping winds take with them finer fractions of the beach sand. The sand particles after traversing some distance get intercepted by the trees, bushes and other vegetations and deposited. Wind sorted sand that form the dunes is uniform and fine in size, generally fine sand with some or trace silt. The dune sand samples of different locations (Talseri to Junput) of the region are similar.

Location	D_{50} (mm)	D_{60} / D_{10}
Talseri, Odisha	0.11	1.30
Old Digha	0.15	1.60
Mandarmoni –		
East Side	0.11	1.10
West Side	0.11	1.20
Haripur, Junput	0.11	1.20

C. Beach Sand:-

The beach sand size varies considerably from time to time. The average value of D_{50} (median grain size) is as low as 0.072mm (2013), and as high as 0.266mm (2019). It has been found that in 70% cases D_{50} values range between 0.10mm to 0.20mm, in 22% cases the values are above 0.20mm as in 8% cases these are below 0.10mm. However, in recent years the values are slightly higher than those of the earlier years, at the observation point. It is worthy to mention that there is continuous process of developmental works along the coastline; these possibly have influence on the evolution process of the beach profile.

In first quarter of a year (January – March / winter – premonsoon) deposition dominates. The average value of D_{50} is 0.178mm (range 0.122 – 0.290 mm). In 80% cases the values are over 0.14mm and the rest below that size.

In second quarter (April – June / premonsoon – start of monsoon) erosion is dominant. Physical removal of beach sand occurs, the beach is lowered. The average value of D_{50} is 0.161mm (0.092– 0.234 mm). In 67% cases the values are above 0.14mm, the rest below that.

In third quarter (July – September / peak monsoon) erosion (by sorting mainly) occurs. The average value of D_{50} is 0.170mm (0.072 – 0.266 mm). In 89% cases the values are above 0.14mm and the rest below that size. In this period no noticeable physical removal (en-masse) occurs. Rather finer fractions are sorted out and go in suspension. Result is high size of in-situ sand. It is corroborated by the fact that breaking sea waves look dirtier near the shoreline in peak monsoon.

In fourth quarter (October – December, receding monsoon – post-monsoon) deposition dominates. The average size is 0.159mm (0.111 – 0.243 mm). In 56% cases the size is above 0.14mm and the rest below. The favourable condition helps to deposit finer fraction once again.

D. Laterite Fragments:

In 1995 the previously (8 – 10 years back) placed laterite boulders were found disintegrated. So big stone blocks were placed along the shoreline of Digha. Subsequently hard concrete wall supported at end with sheet piles (with steps and ramps at some locations) were constructed. Some fragmented laterite grains were collected and analysed in the RRI laboratory (1995). Laterite fragment remains before placement of stone blocks – Gradation of these fragments satisfies filter requirements against beach sand. These fragments were not carried away by the sea. So if any flexible structure is chosen in protection work, filter will be an integral part

E. Tidal Fluctuation:

The variation of highest water level (monthly average value) of a peak monsoon month, August and the lowest water level are shown in Fig.3B. Similarly those of a winter month, February are given in Fig.3A. From 2009 – 2019 the variation is not much but in monsoon the tidal fluctuation is 7.12m while it is 5.5m in February. The highest water level assumes an R.L. almost 5m in peak monsoon and it is more than 1.5m less in winter.

Conclusion:

Excepting major storms / cyclones causing sudden erosion the natural agents like wind driven waves, tide, current (regional phenomenon) have major contribution in forming the beach profile. Geographical location of Digha is at an angle 22^0 with East-West direction. In monsoon waves are quicker, southerly wind with higher speed and higher tidal fluctuations result in erosion of beach top and the sands are carried to somewhere within sea (away from Subarnarekha mouth). In post monsoonal months / winter a major portion of the sand returns back (towards Subarnarekha mouth) in congenial atmosphere, that is, slower wave, northerly wind and lesser tidal variation. In premonsoon / monsoon erosion is en-masse but in peak monsoon particle sorting occurs i.e. finer particles move with breaking waves without much lowering of beach. As a whole no beach lowering has been noticed at this point in this decade. Rather, a depositing tendency with coarser size of sand has been found.

It is felt that though longer beach is preferred by people resulting in long shoreline protection, cross structures like groynes, flexible structures with filters behind, restoration of sand dunes and natural vegetation should also be encouraged at suitable places to provide variety and to sustain the beauty of the beach and the shoreline.

Acknowledgement:-

Credit for collection of soil samples, gauge level and beach level data and all other types of data on regular basis for so many years goes solely to Sri Bimal Kumar Adak, Senior Observer of Digha M.O.S., River Research Institute. His sincerity and commitment in collecting, assembling and preserving different types of data are gratefully acknowledged. Sincere thanks are due to Sri Gautam Sen, Senior Observer, RRI and other staff of Soil Mechanics Laboratory for helping in different analyses.

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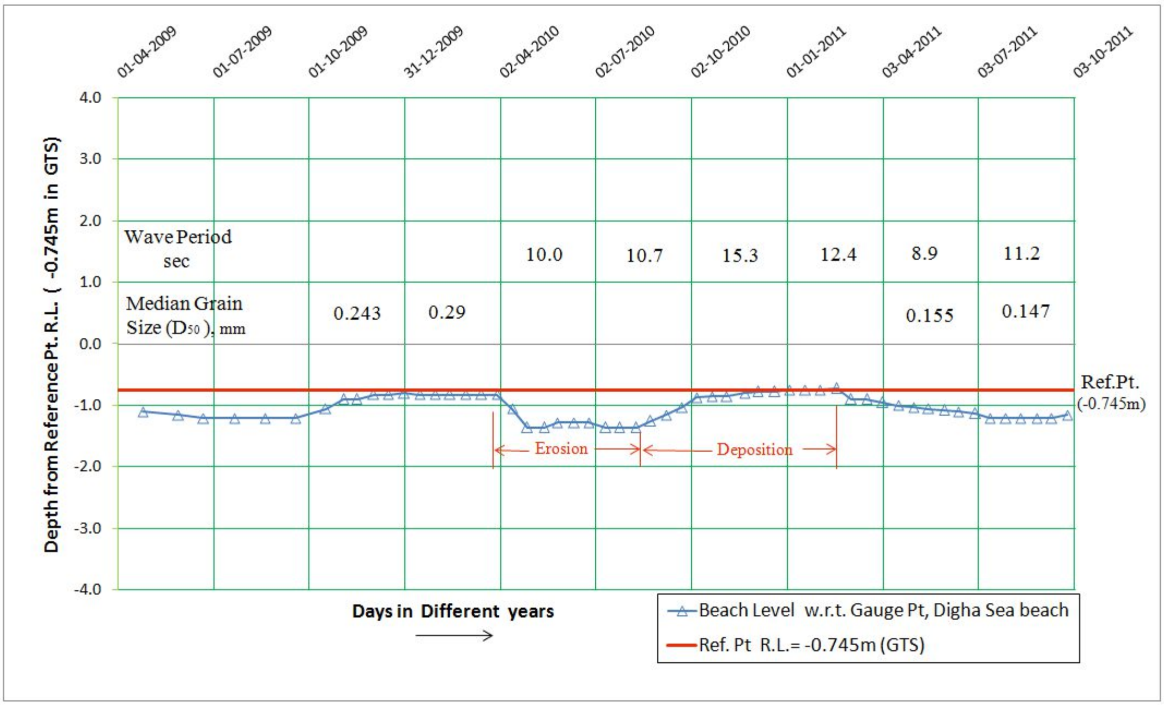

Fig.3A. Variation of beach level near RRI Gauge Point-1 in different times of different years (2009 – 2011)

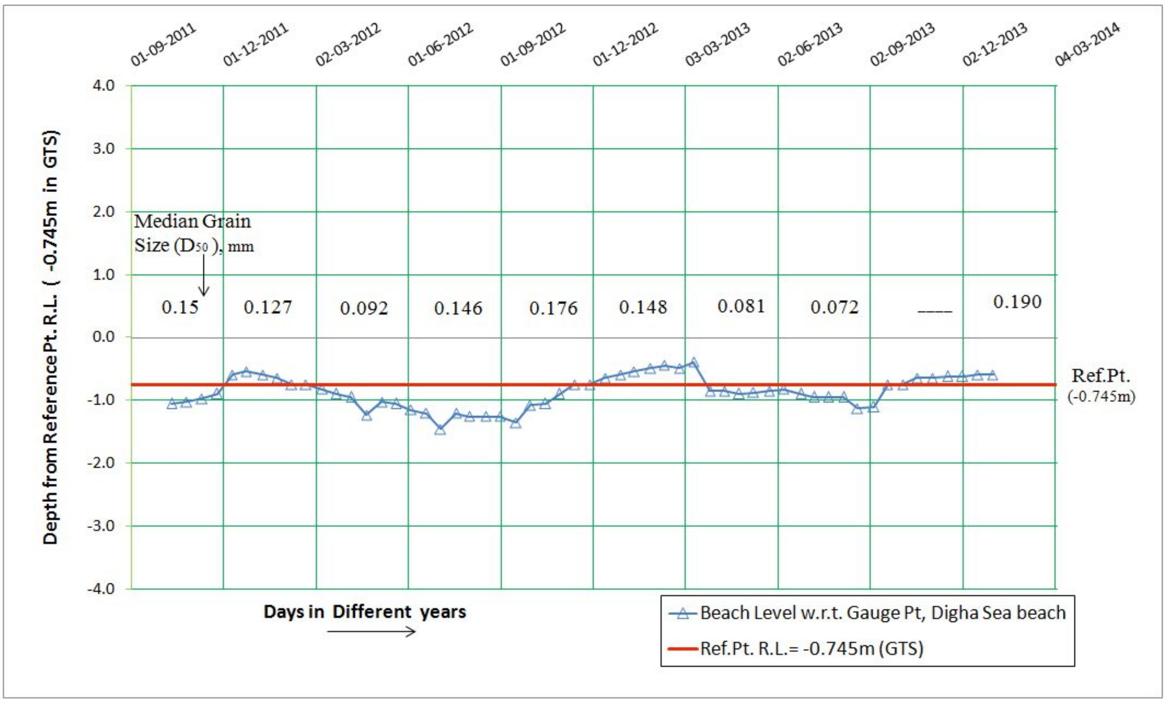

Fig.3B. Variation of beach level near RRI Gauge Point-1 in different times of different years (2011 – 2014)

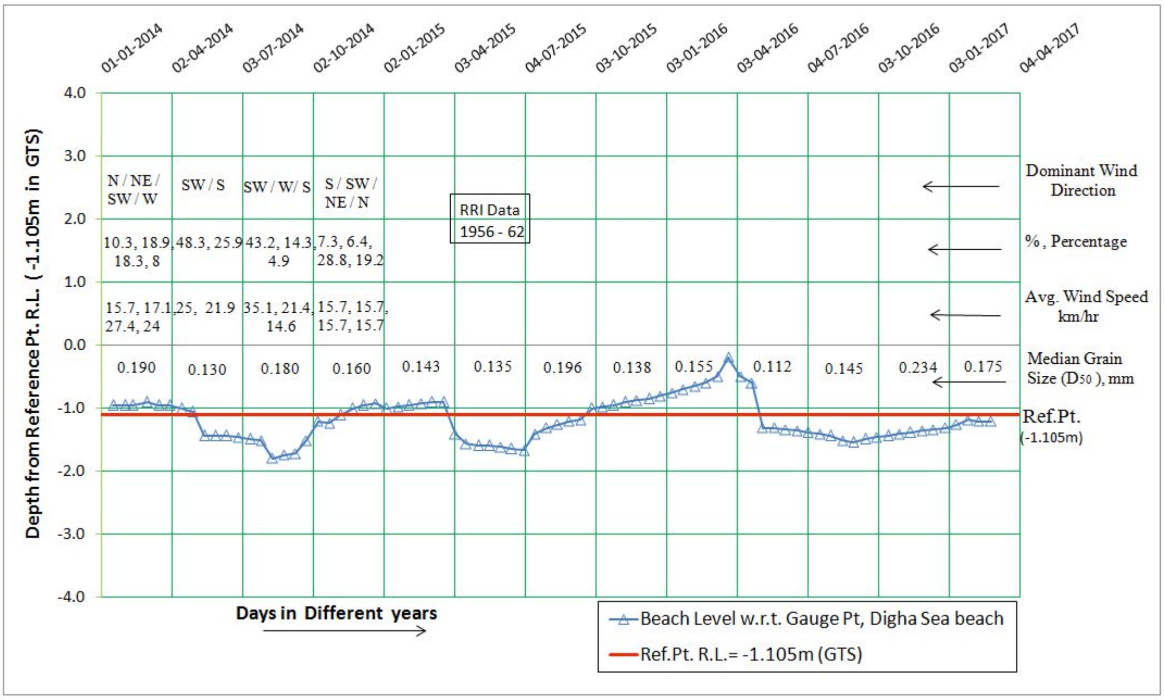

Fig.3C. Variation of beach level near RRI Gauge Point-1 in different times of different years (2014 – 2017)

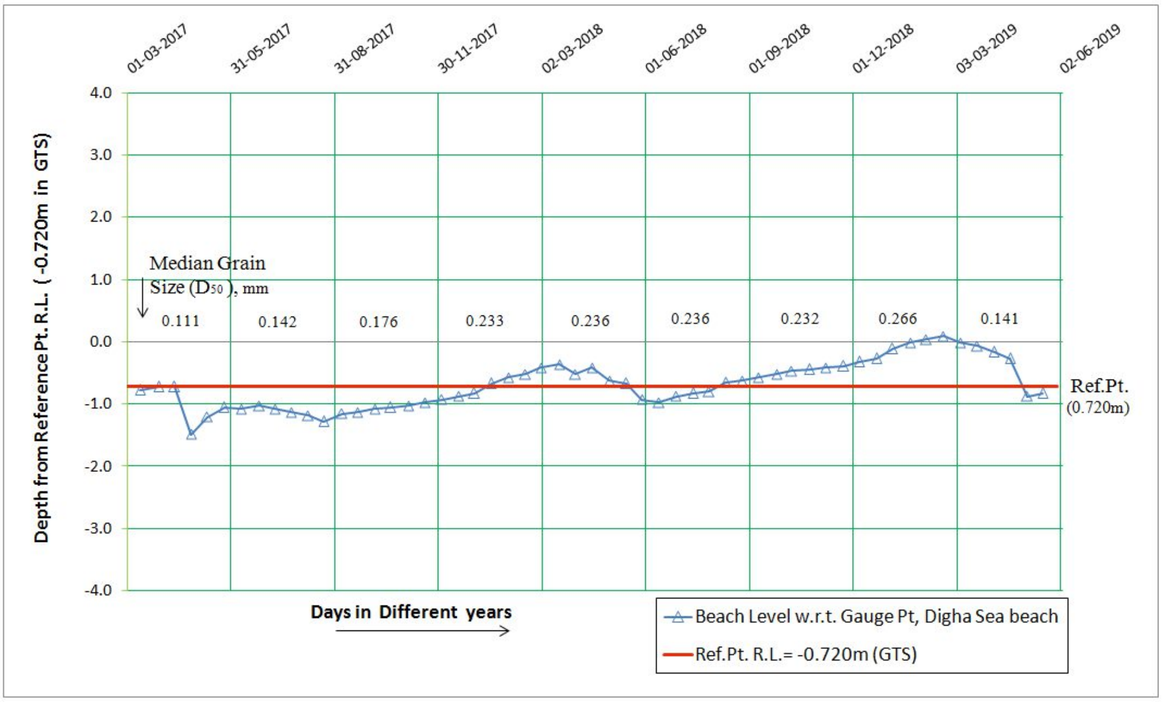

Fig.3D. Variation of beach level near RRI Gauge Point-1 in different times of different years (2017 – 2019)

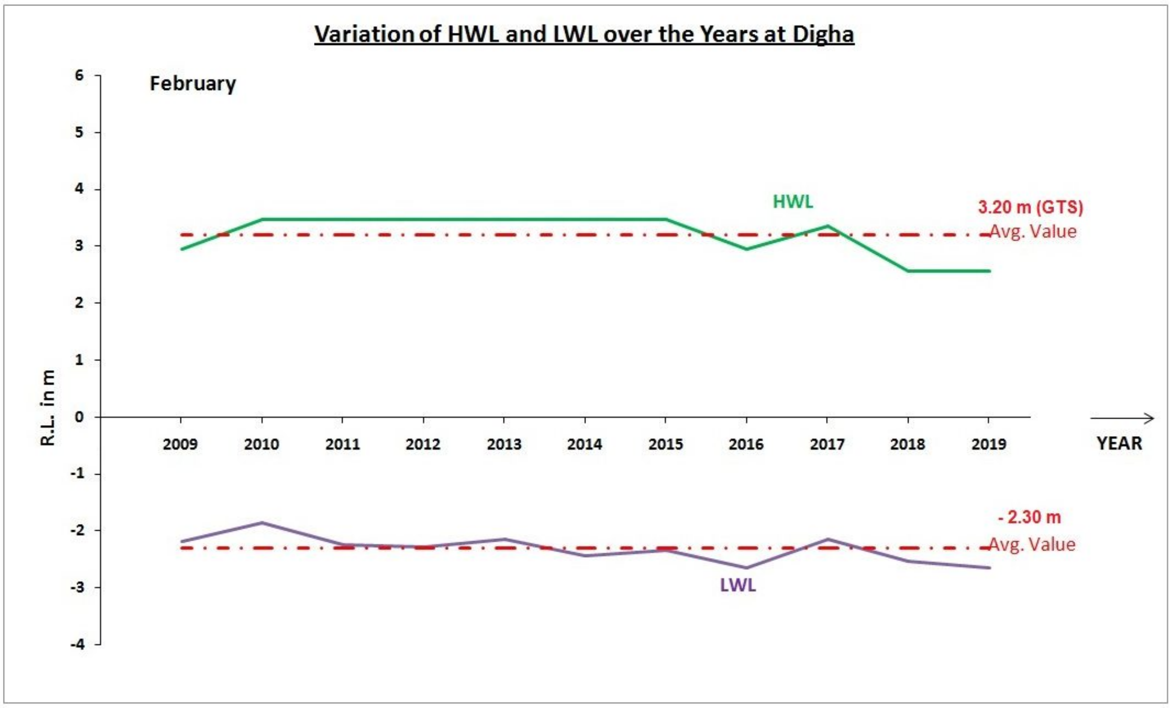

Fig.4A. Variation of HWL and LWL in different years (February – Winter)

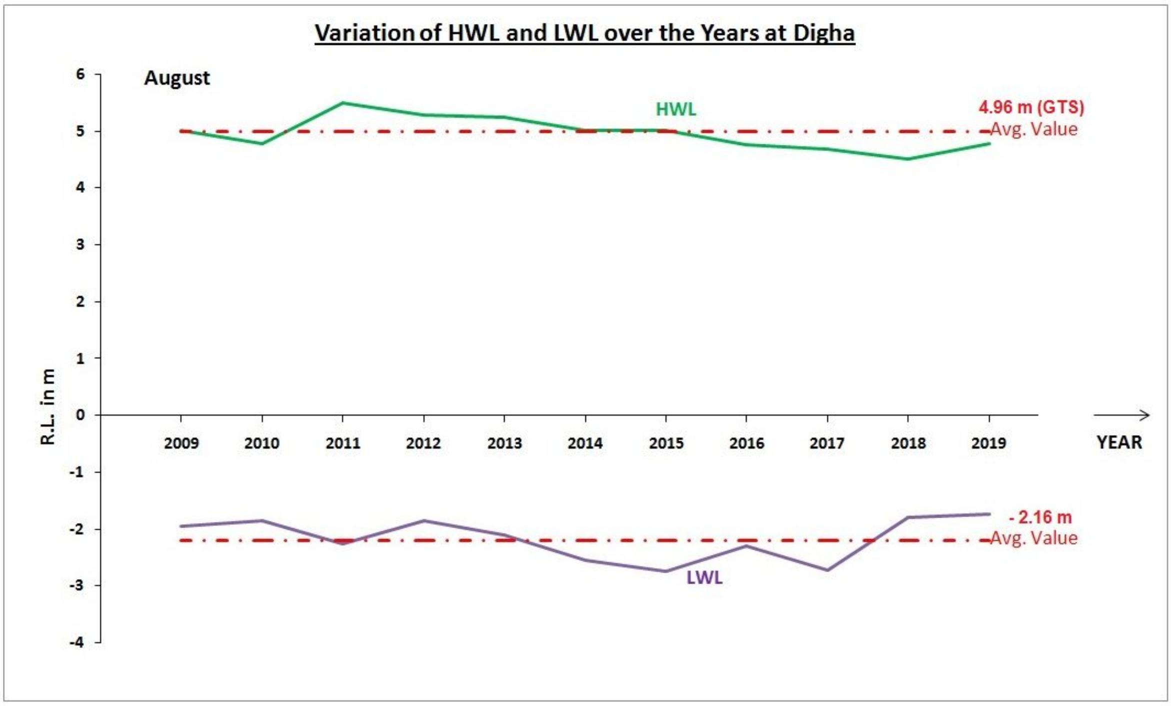

Fig.4B. Variation of HWL and LWL in different years (August – Peak Monsoon)

STUDY ON LIFETIME OF SOME RESERVOIRS AND THEIR CAPACITY LOSS DUE TO SILTATION IN PURULIA DISTRICT, WEST BENGAL

Sudip Kumar Chatterjee[1] and Sukhendu Chattopadhyay[1]

Synopsis

The development and remedial measure activities within the reservoir watershed result in large variations in the discharge of volumes of sediment to the reservoir, which in turn affect the useful life of the reservoir. The information of the loss of storage capacity and the period of time over which the sediment would interfere with the useful functioning of the reservoir are obtained the reservoir sedimentation studies. In this study the empirical equation given by Taylor is used to determine the useful life of reservoirs with the help of survey data of twelve such reservoirs in Purulia, West Bengal.

Keywords: siltation, sediment, reservoir, lifetime.

Introduction:

The significance of dams in present and future of the society has been discussed by *Veltrop* [1]. A dam is an important infrastructure, since it produces a regulated water supply and its value tends to increase with time as water supplies become increasingly scarce relative to demand. The importance of reservoirs to society is expected to increase over time as population, economic activity, and irrigation demand grow. While modern hydraulic systems consist of many elements to appropriate both surface and groundwater supplies, in many regions reservoirs are the single most important component. In terms of consumptive use volume, irrigation is the most important user of water from reservoirs. Irrigated acreage has been expanding at the rate of about 30 percent per decade. One third of the global harvest comes from that 17 percent of the world's crop land receiving irrigation and irrigation deliveries worldwide now equal 5 times the average flow of the Mississippi River [2]. However, uncontrolled sediment accumulation makes storage reservoirs the key non-sustainable component of modern water supply systems. Sedimentation is a major unavoidable phenomenon in all the reservoirs. Many empirical studies have been done for reservoir sedimentation since 1950's. Prediction of useful lifetime of a reservoir is the final target of all the reservoir designers making the issue as an important subject within hydraulic research.

1. River Research Institute, I &W Directorate, Mohanpur, Nadia, West Bengal.

Sediment transport is the general term used for transport of materials like silt, sand, gravel, boulders, etc., in rivers and streams. The transported material is called the sediment load. The total sediment means the volume of sediment particles in motion. This includes the sediment transported by bed load and by suspension as well as the wash load. Siltation is the accumulation of silt (fine particles of sand, silt, clay, and other materials) in the reservoir. This phenomenon of sediment transport can affect substantially the design life of reservoirs. Many cases have been recorded where reservoir siltation rendered water storage structures useless in less than 25 years. Sedimentation problems were observed predominantly with small to medium size reservoirs (catchment area less than 100 Sq.km) [3]. Reservoirs created by dams on rivers, get silt through river flow. A significant proportion of the sediment settles down in the reservoir, thus reducing the space available for water storage and also produces structural damages to the dam and causes appreciable damage to any power generating turbine located within the area. Studies reveal that silts get deposited in both the dead and live storage areas. Siltation reduces the benefits from dams constructed with a huge amount of money by any nation. This could also have a number of impacts, including increased evaporation losses and could damage the power turbines [4]. Several Australian dams failed slowly because of reservoir siltation, although the authorities seldom acknowledge it [5].

All reservoirs are subject to sedimentation which, without adequate prevention and mitigation counter-measures, threatens their sustainability. Around 40,000 large reservoirs, worldwide, suffer from sedimentation and it is estimated that between 0.5% and 1% of the total storage capacity is lost per year. To assess the current storage capacity, land information, cross sectional area, present hold-up capacity, present live storage capacity, volume of silt deposition and the expected life time of some of the dams of Purulia, West Bengal, a programme was undertaken by River Research Institute, West Bengal. In this paper results of twelve of these reservoirs have been discussed, whose capacities were reduced due to siltation by varying extents [8].

Methodology:

The study covered all the technical aspects as per International standards with the help of automated Hydrographic survey system (using digital Echo sounder for depth measurement, RTK receivers for position fixing and Hypack software for data logging) at WGS'84 datum, Zone-45N.The parameters considered in the survey work were: Projection-UTM, Spheroid-WGS84, Vertical Datum-MSL, Grid-UTM North(45N), Scale Factor-As per requirements. Taylor's formula has been used to calculate the life span in addition to the estimation of the siltation rate of reservoir.

Estimation of the Life of Reservoir by Taylor's Method:

To estimate the life of a reservoir i.e., when the capacity of a given reservoir would be fully depleted due to sedimentation from the operational point of view one has to assess as the sediment begins to encroach on the dependable storage preventing the reservoir from putting up its guaranteed performance. The useful capacity of the reservoir is found to vary from 50% to 80% of the original of its total capacity [6]. The sedimentation survey was conducted to know the present position of the reservoir capacity and from the survey data it can be predicted about the life of the reservoirs. The life of reservoir may be estimated by *Taylor's* method as below:

$$V_n = V_0 . R^n \quad \text{...}(1)$$

Where, V_0 = Capacity of the reservoir at the time of impounding of water.

V_n = Capacity of the reservoir after n years of impounding.

R = Ratio of reservoir capacity at the end of one year to that of the capacity of the previous year, assumed to be constant and

Mean annual rate of siltation = $(1 - R) X 100\ \%$ ....(2)

Loss Index is defined as : -

$$Loss\ Index = \frac{Loss\ in\ storage\ capacity\ in\ N\ years}{Total\ catchment\ area\ of\ the\ reservoir}\ X\ \frac{100}{N}$$

Table-1. Salient Features of Different Reservoirs in Purulia :

Name of the Reservoir	Location	Full Reservoir Level – FRL (m)	Dead Storage Capacity (Ha-M)	Live Storage Capacity (Ha-M)	Catchment Area (Sq.km)
Dangra	Latitude- 23°27′10.48″ N Longitude- 86°46′59.62″E On river - Dangra	155.20	10.50	142.50	22.32
Dimu	Latitude- 23°25′29.65″N Longitude- 85°58′48.87″E On river - Dimu	308.00	24.92	67.68	8.19
Karrior	Latitude- 23°25′30.44″N Longitude- 85°56′44.47″E On river - Karrior	280.499	8.14	26.80	16.38
Parga	Latitude- 23°26′15.56″N Longitude- 86°04′55.30″E On river - Parga	282.31	64.16	157.99	17.79
Patloi	Latitude- 23°21′44.12″N Longitude- 86°29′01.85″E On river - Patloi	227.076	134.24	420.63	37.12
Rupai	Latitude- 23°18′36.03″N Longitude- 85°55′16.79″E On river - Rupai	271.10	5.98	155.73	51.20

Name of the Reservoir	Location	Full Reservoir Level – FRL (m)	Dead Storage Capacity (Ha-M)	Live Storage Capacity (Ha-M)	Catchment Area (Sq.km)
Saharajore	Latitude- 23°18′58.47″N Longitude- 86°03′35.30″E On river - Saharajore	326.52	98.72	739.57	42.88
Tatko	Latitude- $22^0$55′44.41″N Longitude- $86^0$30′45.90″E On river - Tatko	186.838	383.62	266.90	189.44
Kumari	Latitude- 23°9'23.32"N Longitude- 86°17'4.60"E On river - Kumari	235.67	185.00	653.70	96.00
Bandhu	Latitude- $23^0$16′49.6″N Longitude- $86^0$08′24.3″E On river - Bandhu	315.54	24.55	218.72	13.69
Barabhum	Latitude- $23^0$01′54.1″N Longitude- $86^0$18′32.2″E On river - Nagasai	225	233.99	604.48	102.81
Hanumata	Latitude- $23^0$06′36.4″N Longitude- $86^0$15′50.9″E On river - Hanumata	243.75	286.16	542.52	55.55

Result and Discussion :

At the time of impounding, the gross capacities of these twelve reservoirs in Purulia were estimated against Full Reservoir Level (FRL). While on the basis of present survey work carried out during Aug-Sept, 2017 and 2019 the gross capacities have been found to be decreased at the same FRLs' respectively. Therefore, the gross storage capacities of these twelve reservoirs have been reduced by some amount to considerable. In terms of percentage reduction in volume for the Karrior reservoir, it is as high as 64.63% over 31years, i.e. 2.08% per year but for the Hanumata reservoir, it is only 16.65% in 33 years; which means a loss of 0.5% per year. So, for the Karrior reservoir the percentage loss of volume per year is much higher than that of the Hanumata reservoir. Fig.1 and Fig.2 depict the variation of storage capacity and area along with elevation (R.L. in metre) between the span of years mentioned above of two reservoirs Hanumata and Karrior under consideration. It has been found that the Karrior is affected by maximum degree and the Hanumata by minimum amount among these 12 reservoirs. So detail plots of these two reservoirs have been presented here. Also Table-2 shows the comparison of live storage and the dead storage capacity of the twelve reservoirs including these two along with their loss of storage capacities in Ha-M and percentage respectively.

Table-2. Loss of Capacity of Different Reservoirs in Purulia :

Name of Reservoir	Zone	Capacity in the year of Survey (Ha-M)		Loss of Capacity		
		1982	**2019**	(Ha-M)	Ha-M/ Year	(%)
Dangra	Dead Storage Below DSL=150.50m	10.50	6.289	4.211	0.114	40.11
	Live Storage between FRL & DSL	142.50	83.831	58.669	1.585	41.17
	Gross Storage below FRL=155.20m	153.00	90.120	62.88	1.699	41.09
Dimu		**1989**	**2019**			
	Dead Storage Below DSL=304.50m	24.92	7.92	17.00	0.566	68.22
	Live Storage between FRL & DSL	67.68	64.25	3.43	0.114	5.07
	Gross Storage below FRL=308.00m	92.60	72.17	20.43	0.681	22.06
Karrior		**1988**	**2019**			
	Dead Storage below DSL=278.10m	8.14	0.389	7.751	0.250	95.22
	Live Storage between FRL & DSL	26.80	11.968	14.832	0.478	55.34
	Gross Storage below FRL=280.499m	34.94	12.357	22.583	0.728	64.63
Parga		**1982**	**2019**			
	Dead Storage below DSL=277.82m	64.16	33.62	30.54	0.825	47.60
	Live Storage between FRL & DSL	157.99	141.66	16.33	0.441	10.34
	Gross Storage below FRL=282.31m	222.15	175.279	46.87	1.266	21.09
Patloi		**2004**	**2019**	(Ha-M)	Ha-M/ year	(%)
	Dead Storage below DSL=223.78m	134.24	90.34	43.90	2.926	32.71
	Live Storage between FRL & DSL	420.63	366.11	54.52	3.634	12.96
	Gross Storage below FRL=227.076m	554.87	456.45	98.42	6.561	17.74
Rupai		**1982**	**2019**			
	Dead Storage below DSL=265.10m	5.98	0.00	5.98	0.161	100

Name of Reservoir	Zone	Capacity in the year of Survey (Ha-M)		Loss of Capacity		
	Live Storage between FRL & DSL	155.73	106.172	49.558	1.339	31.82
	Gross Storage below FRL=271.10m	161.71	106.172	55.538	1.501	34.34
Saharajore		**1982**	**2019**			
	Dead Storage Below DSL=317.68m	98.72	37.96	60.76	1.642	61.55
	Live Storage between FRL & DSL	739.57	508.91	230.66	6.234	31.19
	Gross Storage below FRL=326.52m	838.29	546.87	291.42	7.876	34.76
Tatko		**1985**	**2019**			
	Dead Storage below DSL=185.56m	383.62	167.509	216.111	6.356	56.34
	Live Storage between FRL & DSL	266.90	168.873	98.027	2.883	36.73
	Gross Storage below FRL=186.838m	650.52	336.382	314.138	9.239	48.29
Kumari		**1984**	**2019**			
	Dead Storage below DSL=232.93m	185.00	40.00	145.00	4.264	78.38
	Live Storage between FRL & DSL	653.70	350.00	303.70	8.932	46.35
	Gross Storage below FRL=235.67m	838.70	390.00	448.70	13.197	53.50
Bandhu		**1995**	**2017**			
	Dead Storage below DSL=303.05m	24.55	0	24.55	1.115	100
	Live Storage between FRL & DSL	218.72	135.89	82.83	3.765	37.82
	Gross Storage below FRL=315.54m	243.27	135.89	107.38	4.880	44.14
Barabhum		**1978**	**2017**			
	Dead Storage below DSL=220.43m	233.99	43.046	190.944	4.896	81.6
	Live Storage between FRL & DSL	604.48	544.507	59.973	1.537	10.00
	Gross Storage below FRL=225m	838.47	587.553	250.917	6.433	30.00
		1984	**2017**			

Name of Reservoir	Zone	Capacity in the year of Survey (Ha-M)		Loss of Capacity		
Hanumata	Dead Storage below DSL=240.64m	286.06	212.18	73.98	2.241	25.85
	Live Storage between FRL & DSL	542.52	478.55	63.97	1.938	11.79
	Gross Storage below FRL=243.75m	828.68	690.73	137.95	4.180	16.65

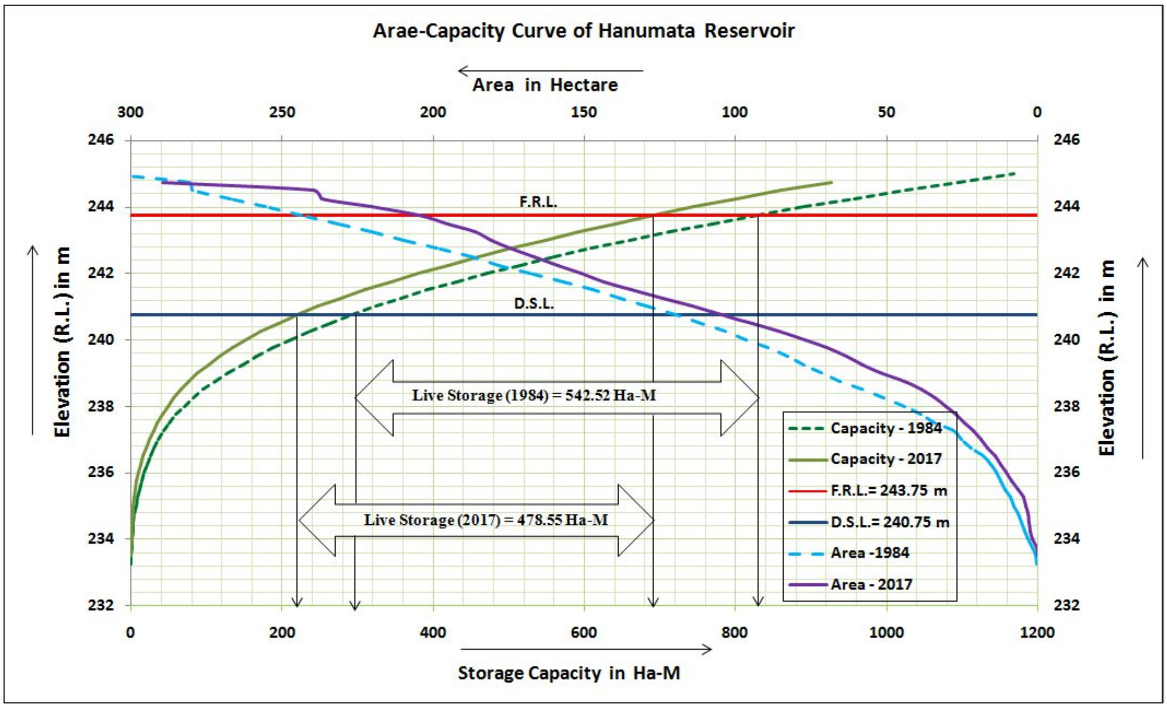

Fig.1. Showing the variation of Storage Capacity and Area with Elevation (R.L.) of the Hanumata Reservoir (between 1984 & 2017)

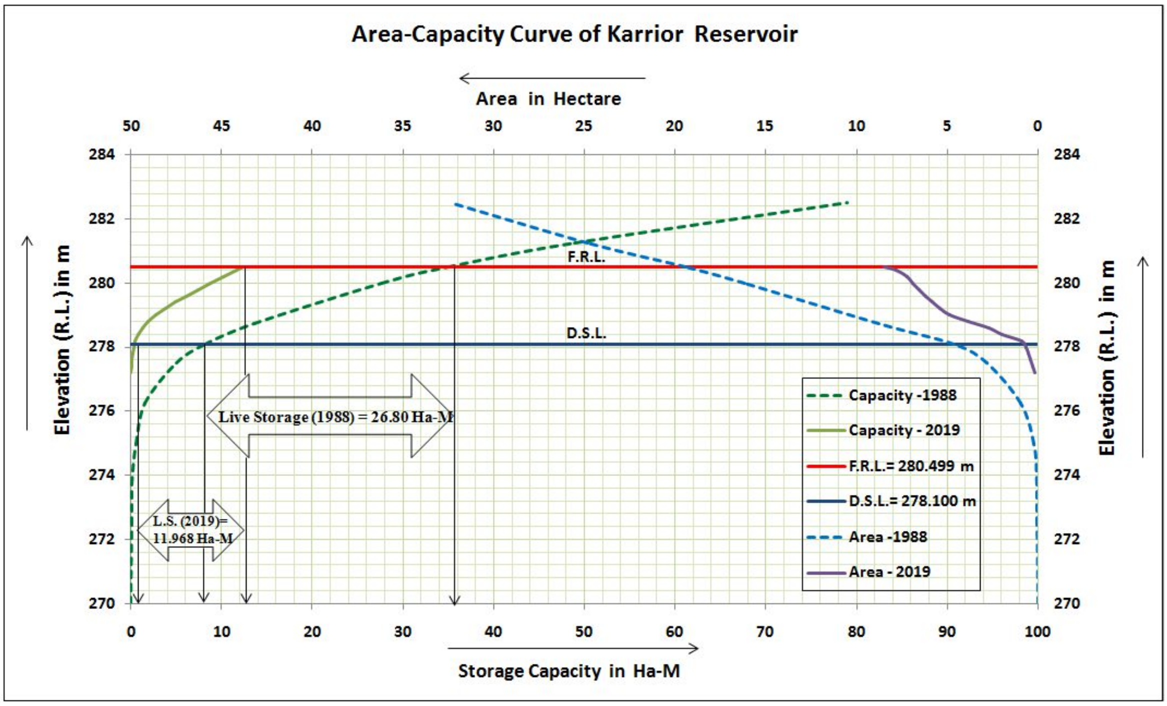

Fig.2. Showing the variation of Storage Capacity and Area with Elevation (R.L.) of the Karrior Reservoir (between 1988 & 2019)

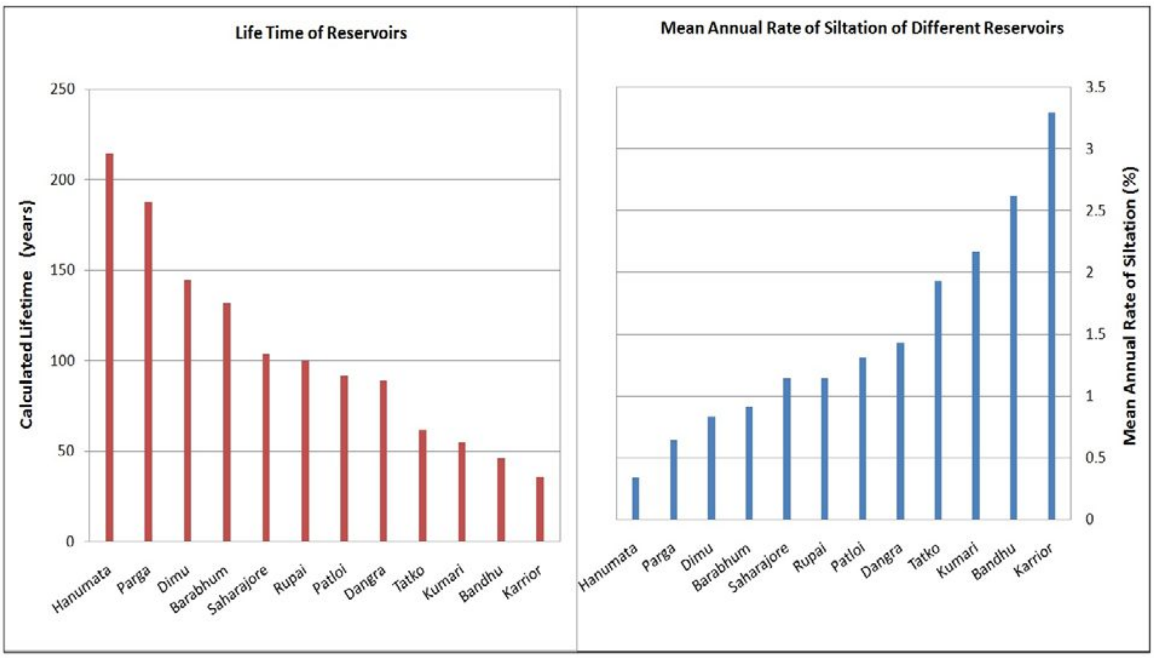

Fig.3. Graphical representation of Lifetime and Mean annual rate of siltation of different Reservoirs

Table-3. Life Time, Mean Annual Rate of Siltation and Loss Index of Different Reservoirs

Reservoir	Life Time (years)	Mean annual rate of siltation (%)	Loss Index (Ha-M / Year / Sq.km)	Catchment Area (Sq. km.)
Hanumata	215	0.34	7.52	55.55
Parga	188	0.64	7.12	17.79
Dimu	145	0.83	8.31	8.19
Barabhum	132	0.91	6.18	104.00
Saharajore	104	1.14	18.36	42.88
Rupai	100	1.14	2.93	51.20
Patloi	92	1.31	17.67	37.12
Dangra	89	1.43	7.61	22.32
Tatko	62	1.93	4.87	189.44
Kumari	55	2.17	13.35	96.00
Bandhu	46	2.62	35.65	13.69
Karrior	36	3.30	4.44	16.38

From the capacities of the observed year and the initial year, the 'R' value (stated earlier) has been evaluated. Again taking effective life of the reservoir (n years) as the time when 70% of the total storage capacity is lost, 'n' value has been calculated following Taylor's method. From the study of the sediments of some of the reservoirs it is evident that the sediment of the front region of any reservoir is brownish silty clay to loamy clay. In the rear portion the sediment is loamy sand to sand. The amount of sediment deposited depends on the soil forming the catchment, the shape of the catchment and reservoir, land use pattern, detention time, operating procedures, etc [7]. From Fig.3 it has been found that in majority of cases the mean annual rate of siltation is between 0.5 – 1.5% and expected life span is between 50 – 100 years. It is evident from Table-3 that for the top six reservoirs the range of effective life is 100 – 215 years (avg. 147 years) and for the other six it is 36 – 92 years (avg. 63 years). The mean annual rate of siltation and loss index of the first six reservoirs are 0.34 – 1.14% (avg. 0.83%) and 2.93 – 18.36 (avg. 8.4) Ha-M/yr/Sq.km. For the other six reservoirs (Table-3) these are 1.32 – 3.3% (avg. 2.13%) and 4.44 – 35.65 (avg.13.9) Ha-M/yr/Sq.km respectively. The low estimated life time of the Karrior reservoir (36 yrs) compared to that of the Hanumata reservoir (215 yrs) probably indicates higher land slope of the catchment, eroding soil cover, less forest cover, etc. It is obvious from Fig.3 that the life time of any reservoir is inversely related to the mean annual rate of siltation.

Conclusion:

The result shows that the magnitudes of capacity loss of the reservoirs are varying low to high. Mitigative measures like (i) catchment treatment by restricting the sediment inflow into the reservoir, (ii) de-siltation of the sediment from reservoir, (iii) counter bunding or building of removable check dams / sand traps, (iv) by passing of sediment or silt exclusion, (v) re-afforestation of eroded areas (increase the green cover/planned afforestation in the catchment areas) are suggested for those reservoirs in particular, whose siltation rates are high and alarming like the Karrior, Bandhu, Tatko, Kumari, etc.

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UPLIFT CAPACITY OF RANDOM FIBER MIXED GRANULAR ANCHOR PILE (GAP)

Partha Basu[1] & Som Shankar De Dalal[1]

Synopsis

Various methods of ground improvement technique can be enumerated from the point of view of improving bearing capacity and reducing settlement. Granular pile (GP) is one of the effective and efficient methods of ground improvement for soft soil. Conventional granular piles cannot be used as tension members to offer resistance under pull out loads. Structures like transmission towers or foundations on expansive soil are subjected to uplift forces. In such cases, granular anchor pile (GAP) may be used as an alternative of concrete pile economically to counter the uplift force. In a granular anchor pile (GAP), the footing is anchored to a mild steel plate placed at the bottom of the granular pile through a reinforcing rod or a cable. Literatures have shown that randomly fiber mixed GP increases the load carrying capacity and reduces settlement as compared to plain GP. The same concept has been tried for GAP in which the plain GAP has been replaced with randomly fiber mixed GAP. In the present study, numerical analysis is executed using finite element software PLAXIS-2D on uplift capacity of randomly oriented fiber mixed granular anchor pile (GAP). The analysis examines the influence of factors such as fiber content, depth of random fiber mixed sand in GAP, length to diameter ratio of GAP and consistency of surrounding soft soil on the uplift capacity of randomly oriented fiber mixed granular anchor pile (GAP).

Keywords: granular anchor pile, uplift capacity, random fiber, soft clay

INTRODUCTION

Development and utilization of poor and marginal sites with ground improvement techniques has become a subject of profound interest for geotechnical engineers. Among the variety of ground improvement methods, Granular Piles (GP) is being increasingly used to improve the bearing capacity and reduce settlement of soft soil. In real field situations like, limited area for foundation due to presence of existing structures, or where piling may not be adopted due to risks of settlement from vibrations, excavations/ loss of ground. In such situations, GP can be used as an economical and effective alternative. In many situations it is found that even with the provision of granular pile of adequate length, spacing and diameter, the target bearing capacity can't be achieved, while deep foundation gives over safe solution.

1. River Research Institute, West Bengal, I & W Dte., Mohanpur, Nadia – 741246

In these situations, reinforcement in to granular pile may be a good option to attain the desired capacity. It has been observed that the improvement of reinforced GP soil system can be further enhanced by introducing randomly distributed fibers in to GP (Al-Refeai, T. O., 1992, Basu P. *et al,* 2018).

Structures like transmission towers or foundations on expansive soil are subjected to uplift forces. In such cases, conventional approach is to adopt under-reamed pile foundation. Conventional granular piles cannot be used as tension members to offer resistance under pull out loads. In such cases, Granular Anchor Pile (GAP) may be used as an alternative of concrete pile economically to counter the uplift force (Pradeep Kumar *et al.,* 2018). GAP may be defined as the granular pile which is reinforced with anchor plate and anchor rod. An anchor plate is a circular steel plate embedded into a concrete pedestal at the bottom of predrilled hole. It is connected to a steel anchor rod which may protrude above pile head.

In the present study, numerical analysis is executed using finite element software PLAXIS-2D on uplift capacity of randomly oriented fiber mixed GAP. FEM analyses have been done on unreinforced GAP and as well as GAP reinforced with randomly distributed fibers. For analysis, GAP with diameter (d) of 50 mm and a length (L) to diameter (d) ratio of 8 is chosen. For random fiber mixed GAP, fiber contents (F_c) have been selected as 0%, 0.5% and 1%. The fiber lengths (F_l) have been kept as 0.6d. The depths of sand fiber mixture in GAP (F_d) are taken as 1d, 2d, 3d, 4d, 6d and 8d. Direct shear tests have been conducted on random fiber mixed sand to find out shear parameters. Load-settlement behavior has been studied.

Finite-Element Analysis

The analysis has been carried out using package PLAXIS 2D. Axisymmetric analyses have been carried out using Mohr-Coulomb's criterion considering elastoplastic behavior for soft clay, sand and sand with fiber. An undrained behavior has been assumed for all the materials. The finite-element discretisation has been done using 15-noded triangular elements with boundary conditions used to represent the GAP, surrounding clay. The initial vertical stress due to gravity load has been considered in the analysis. However, the stress due to column installation depends on the method of construction and the same has not been considered in the analyses. Along the periphery of the model boundary (vertical), radial deformation has been restricted but settlement has been allowed. Along the bottom of the model boundary both radial deformation and settlement have been restricted. At the interface between the GAP and soft clay, no interface element has been used as the deformation of the GAP is mainly by radial bulging and no significant shear is possible. Also the interface between a GAP and clay is a mixed zone where the shear strength properties can vary depending on the method of installation. As this is not precisely known, an interface element has not been used. Ambily and Gandhi (2007) carried out similar finite-element analysis on stone column without interface element. The input parameters are listed in Table no 1 (Basu *et al,* 2018).

In the present study, numerical analysis has been executed using finite element software

PLAXIS-2D on uplift capacity of randomly oriented fiber mixed GAP. The analysis examines the influence of factors such as fiber content (F_c), depth of random fiber mixed sand (F_d) in GAP, length to diameter ratio (L/d) of GAP and consistency of surrounding soft soil on the uplift capacity of randomly oriented fiber mixed GAP. Single granular pile of diameter (d) 50 mm and height 400 mm has been modeled at the center of the clay bed of size 530 mm x 530 mm and 400 mm depth (same as the steel tank size for the model study, Basu *et al,* 2016). For random fiber mixed GP, fiber contents (F_c) have been selected as 0%, 0.5% and 1% with fiber length (F_l) as 0.6d and depth of sand fiber mixture (F_d) in GP as 8d. Figure 1(a) and 1(b) represent the actual model for GAP analysis and FEM model for present analysis respectively. Depth of random fiber mixture in GP (F_d) has been used as 0d, 1d, 2d, 3d, 4d, 6d and 8d for fiber content 0.5 & 1.0% with F_l = 0.6d. Analyses have also been carried out for different L/d ratio as 4d, 6d, and 7d for F_c = 0.0%, 0.5% & 1.0% with F_l = 0.6d. Finally, consistency values of the surrounding clay bed have been varied as 30 kPa, 14 kPa and 7 kPa (Ambily and Gandhi, 2007) with F_d = 8d & F_l = 0.6d for F_c = 0.0%, 0.5% and 1.0% respectively.

Table 1. Input values in FEA

Material	E* [kN/m^2]	ν *	c ** [kN/m^2]	ψ * [0]	ϕ ** [0]	γ_{unsat} [kN/m^3]	$\gamma_{sat}/\gamma_{bulk}$ [kN/m^3]
Clay	3000	0.45	15	0	1	14.9	19.5
Sand with 0% fiber	18000	0.35	3.5	2	40	18.0	18.9
Sand with 0.5% fiber	19000	0.34	21.9	5	39.5	18.0	18.9
Sand with 1.0% fiber	20500	0.33	23.1	9.0	40	18.0	18.9

E: Young's modulus, : Poisson's ratio, : Friction angle, c : Cohesion, : Dilatancy angle

* Assumed value [reference Ambily and Gandhi (2007)],

** From direct shear test values, other values of FEA are taken from model test data of Basu *et al* (2018).

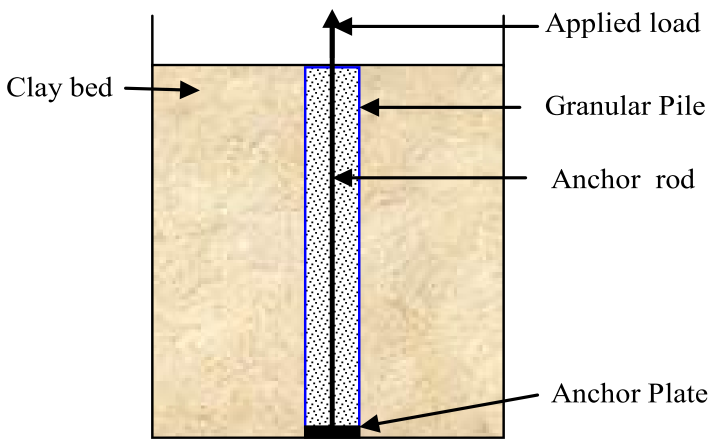

Fig. 1(a) Actual model for GAP analysis

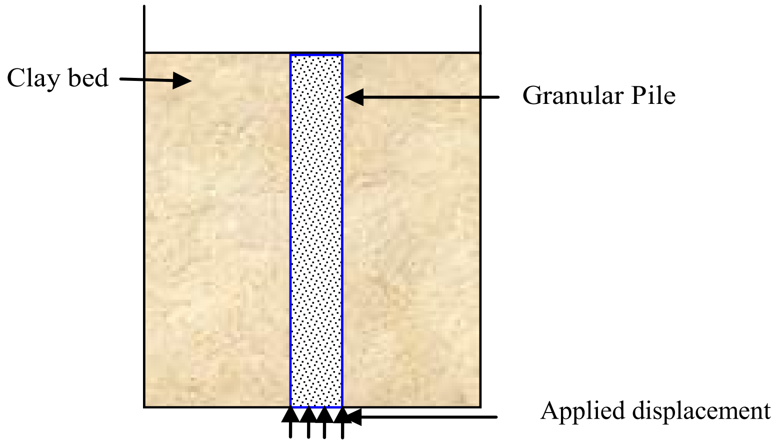

Fig. 1(b) FEM model for present analysis

RESULTS AND DISCUSSION

For verification of input data, compression test analysis by PLAXIS-2D has earlier been done on model GP in clay bed and load-settlement curve has been plotted with model test data of Basu *et al* (2018). Figure 2 shows the load-settlement curve for single GP with different fiber content (Fc). The bearing capacity has been obtained by double tangent methods. Fig. 2 shows that the presence of random fiber in GP increases the load carrying capacity of GP. As compared to unreinforced GP, an improvement of 29% and 44% in load carrying capacity has been observed for 0.5% and 1% (by dry wt. of sand) random fiber in GP respectively. For a loading intensity of 0.5 kN, as compared to unreinforced GP improved soft clay, the settlement has been found to reduce by 25% and 27% due to GP with 0.5% fiber content and 1% fiber content respectively. For a loading intensity 1 kN, as compared to unreinforced GP 60% and 65% reduction in settlement has been observed. So it has been found that higher fiber content in GP shows more efficient behaviour for higher loading intensity than for lower loading intensity. The settlements are found to reduce considerably for the ground treated with random fiber granular piles. Experimental result of physical model studies (Basu et al., 2018) shows similar trend as FEA study.

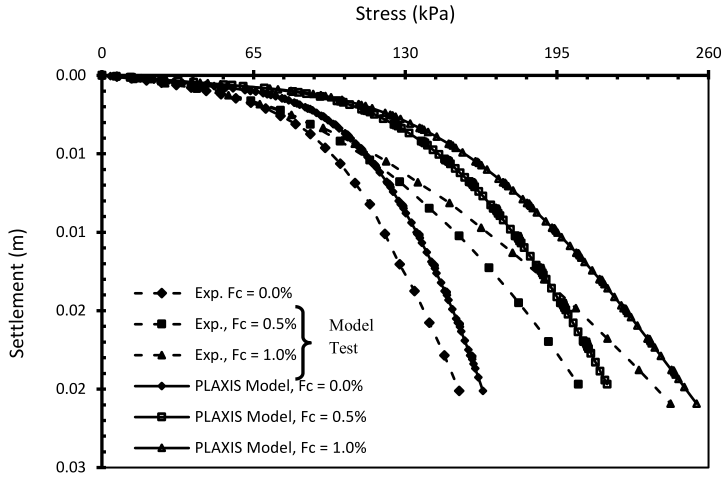

Fig. 2 Load – settlement curve of single GP (in compression)

Effect of fiber content on uplift capacity

The deform mesh after analysis of GAP with F_c 0.5% has been shown in Fig. 3. Figure 4 shows the pullout force versus upward displacement curves for different fiber contents (F_c). The pullout force has been obtained by double tangent method. Figure 4 shows that the presence of random fiber in GAP increases the pullout force capacity of GAP. As compared to unreinforced GAP, an improvement of 58% and 146% in pullout force has been observed for 0.5% and 1% random fiber in GAP respectively. For an upward loading intensity of 0.4 kN, as compared to unreinforced GAP improved soft clay, the upward movement has been found to reduce by 69% and 72% for GAP with 0.5% fiber content and 1% fiber content respectively. For an upward loading intensity 0.8 kN, as compared to unreinforced GAP 61% and 74% reduction in upward movement has been observed for GAP with 0.5% fiber content and 1% fiber content respectively. Thus it has been found that higher fiber content in GAP shows a more efficient behaviour against uplift load.

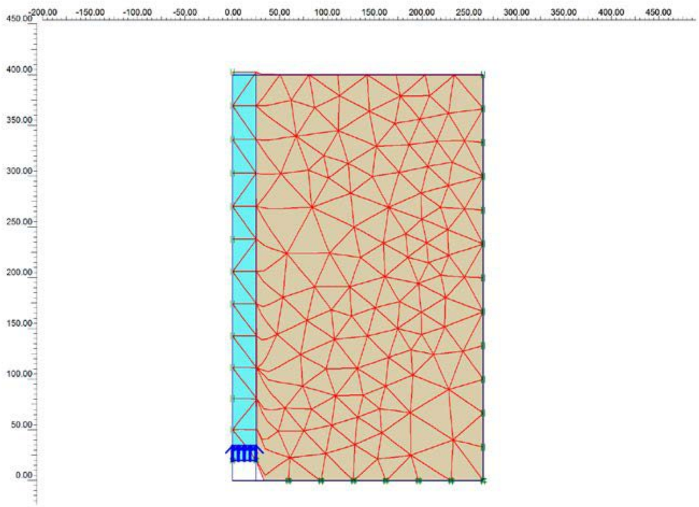

Fig. 3 Deform mesh for GAP with F_c = 0.5%

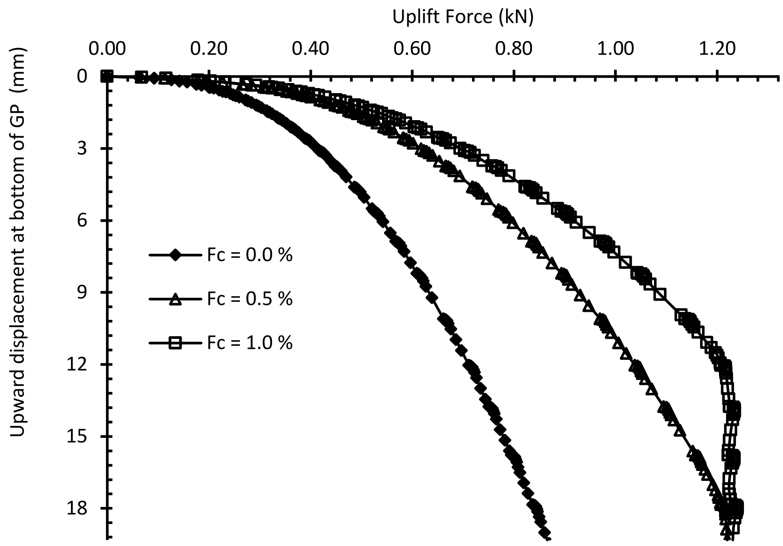

Fig. 4 Pullout force vs upward displacement curves for different fiber content (F_c)

Effect of depth of random fiber mixed sand in GP on uplift capacity

Figure 5 (a) and (b) shows the pullout force versus upward displacement curves for deferent depth of random fiber mixed sand in GAP (F_d) for F_c 0.5% and 1.0% respectively. In this study F_d/d ratio have been varied as 0, 1, 2, 3, 4, 6 and 8 for F_c = 0.5% and 1.0% respectively. For both the cases, it has been found that upto F_d/d ratio 4, the improvement in uplift capacity occurs slightly. After that uplift capacity of GAP increases significantly for both the cases. For example, improvement in uplift capacity value have been found 4%, 11% and 43% for GAP with F_c = 0.5% for F_d = 4d, 6d and 8d respectively w.r.to unreinforced GAP. Similarly, improvement values in uplift capacity have been found 7%, 20% and 152% for GAP with F_c = 1.0% for F_d = 4d, 6d and 8d respectively w.r.to unreinforced GAP. So significant improvement in uplift capacity of GAP has been gained for F_d > 4d for both the cases.

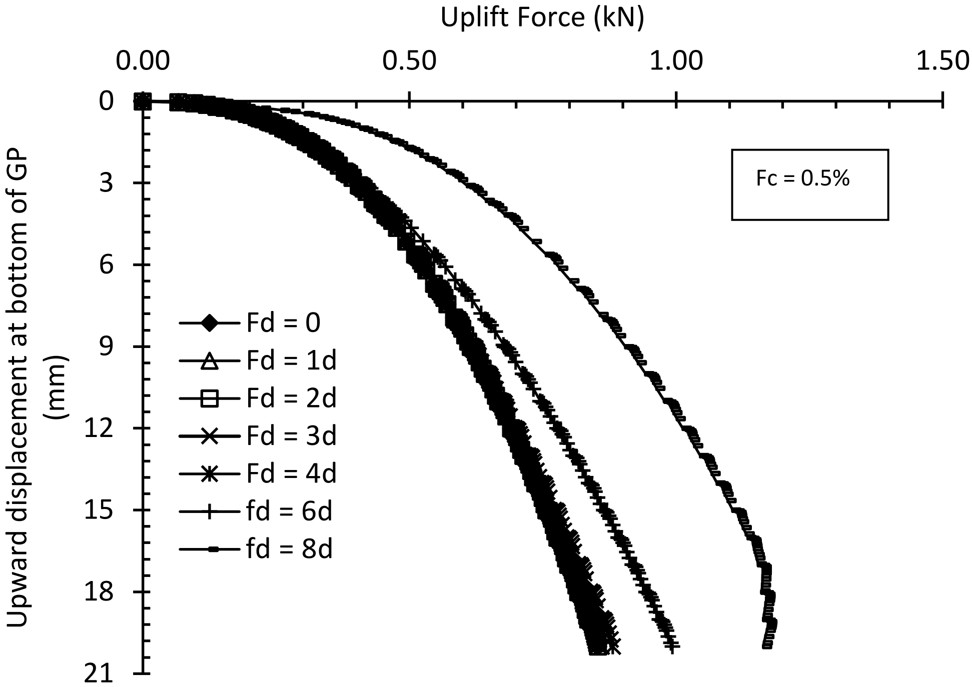

Fig. 4 (a) pullout force versus upward displacement for F_c = 0.5%

Effect of GAP length (L) on uplift capacity

Figure 5(a), 5(b) and 5(c) present the uplift force vs upward displacement behaviour of GAP with length (L) 4d, 6d and 7d respectively. All the cases show that uplift capacity increases with length of the GAP. But with the increase in F_c in GAP, uplift capacity further increases for equal length of GAP. Figure 6 shows that the improvement in uplift capacity of reinforced GAP w.r.to unreinforced GAP for F_c = 0.5% and 1.0%. For F_c = 0.5%, improvement in uplift capacity has found in between 130 to 135% for L = 4d to 7d and for F_c = 1.0%, improvement in uplift capacity has been found in between 140 to 152% for L = 4d to 7d initially. After that improvement decreases with increase in uplift displacement/d ratio. For both the cases (F_c = 0.5% and 1.0%), after a certain ratio the improvement in uplift capacity shows near about the same value. These improvements have been found in percentage as 6%, 18% and 26% for L=4d, 6d and 7d respectively for both the cases F_c = 0.5% and 1.0%.

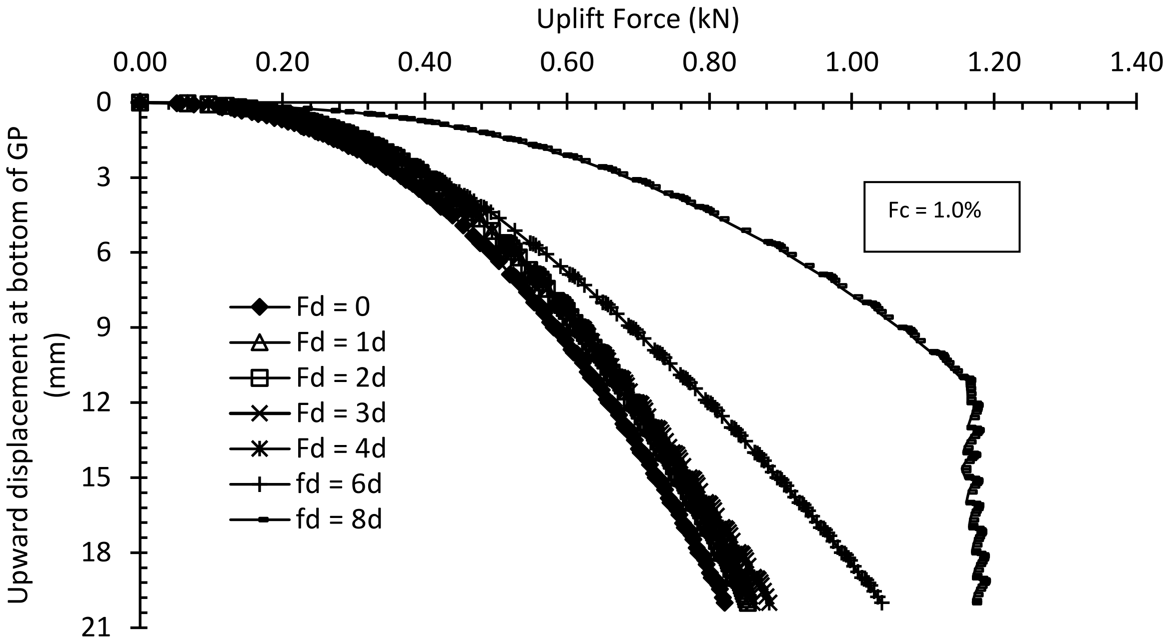

Fig 4 (b) pullout force versus upward displacement for F_c = 1.0%

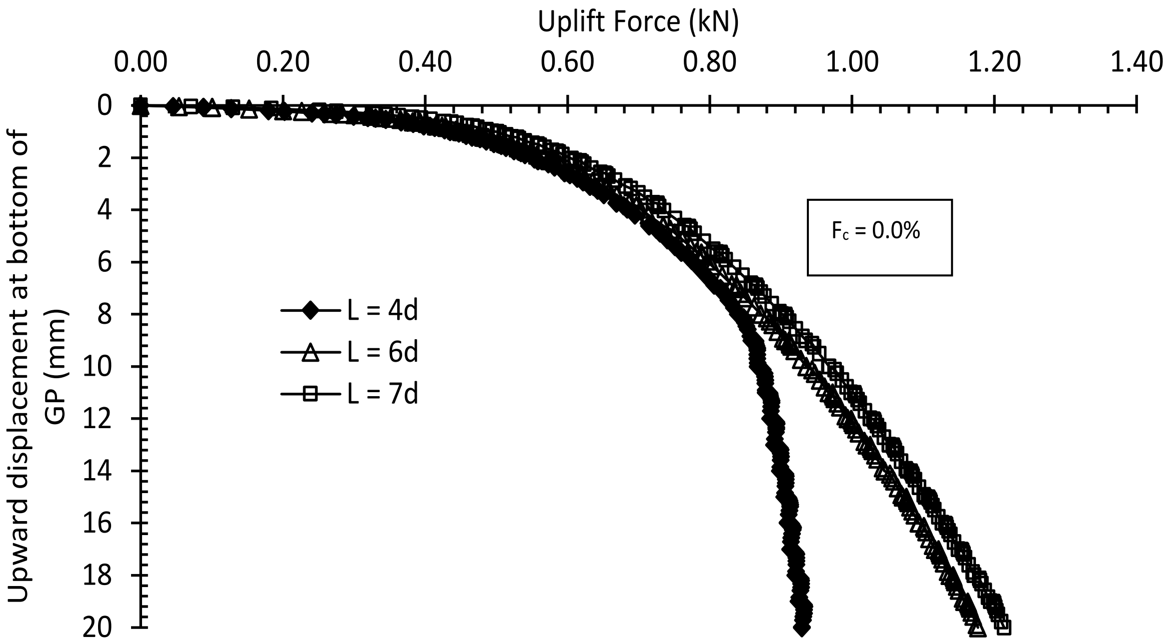

Fig. 5 (a) uplift force vs upward displacement of GAP for F_c = 0.0%

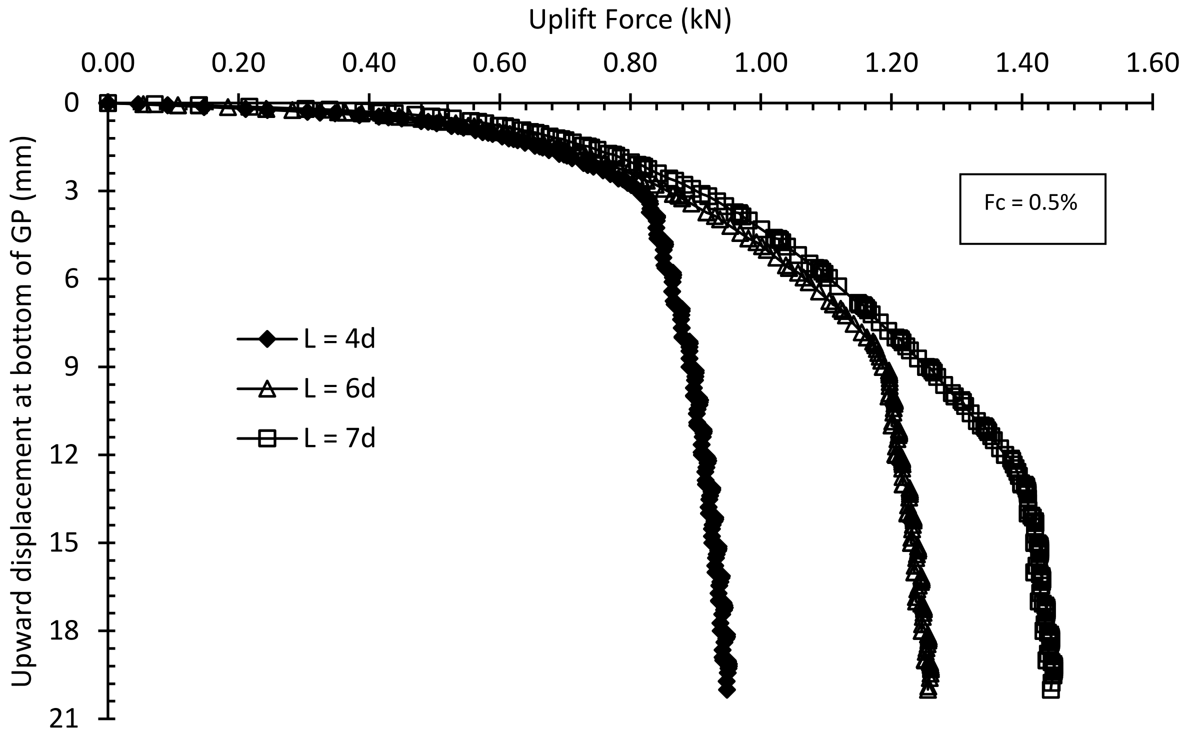

Fig 5(b) uplift force vs upward displacement of GAP for F_c = 0.5%

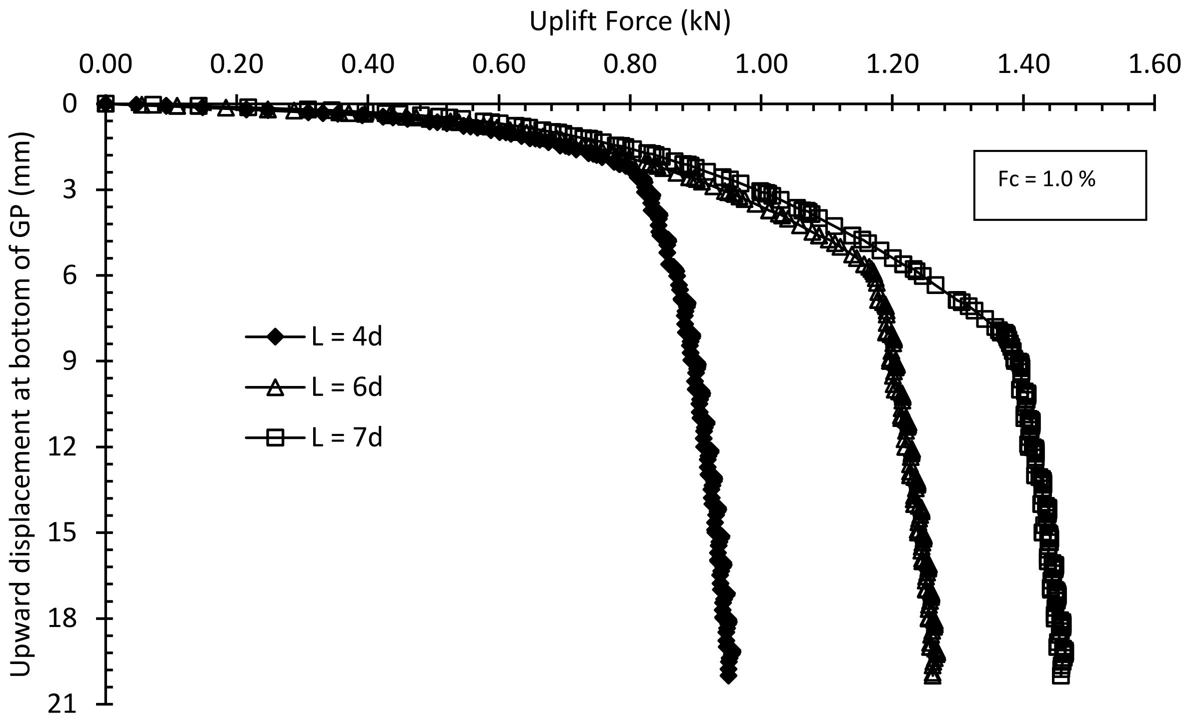

Fig 5(c) uplift force vs upward displacement of GAP for F_c = 1.0%

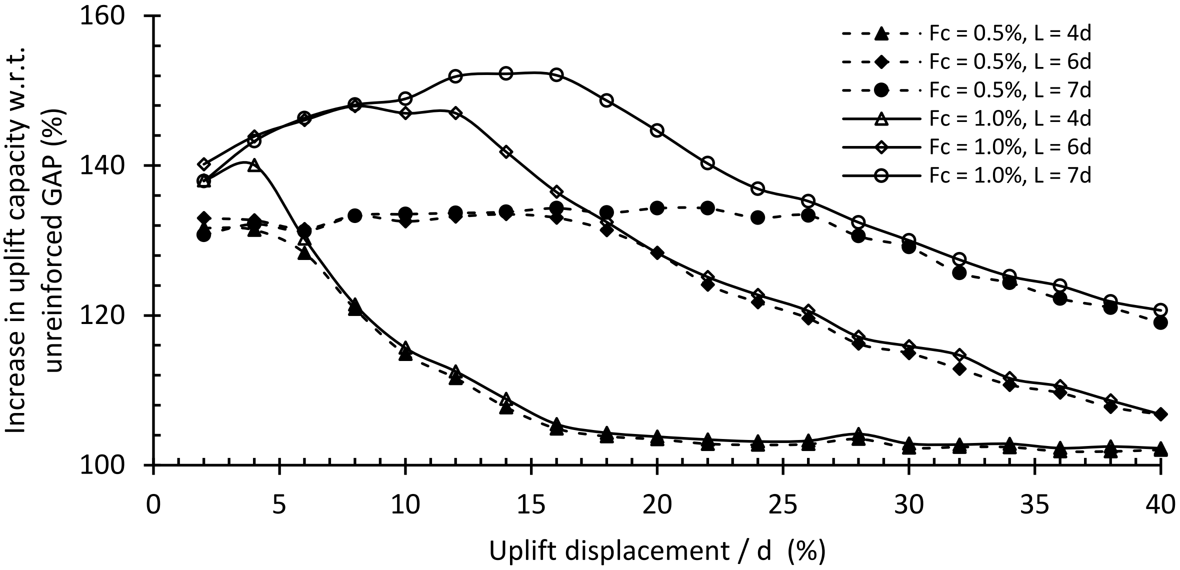

Fig. 6 improvement in uplift capacity of reinforced GAP

Effect of consistency of surrounding clay bed on uplift capacity of GAP

Figure 7 shows the variation of uplift capacity of GAP with consistency of surrounding clay bed. The input data used for this analysis has been shown in Table 2 (Ambily and Gandhi, 2007). The fig.7 shows that uplift capacity of GAP increases with consistency of surrounding clay bed. At low consistency, improvement has been found much less. At c_u = 7 kPa, improvements have been found as 7% and 11% for F_c = 0.5% and 1.0% respectively. Similarly at c_u = 14 kPa, improvements have been found as 57% and 66% for F_c = 0.5% and 1.0% respectively and at c_u = 30 kPa, improvements have been found as 46% and 144% for F_c = 0.5% and 1.0% respectively. It has been found that GAP with F_c = 1.0% shows more improvement rate than GAP with F_c = 0.5% for surrounding clay bed consistency, c_u = 30 kPa than surrounding clay bed consistency c_u = 14 kPa.

Table 2 input data for analysis effect of consistency of surrounding clay bed on uplift capacity [Ambily and Gandhi (2007)]

w (%)	E (kPa)	Poisson's ratio	c_u (kPa)	γ_{dry} (kN/m^3)	γ_{sat} (kN/m^3)
25	5500	0.42	30	15.57	19.46
30	3100	0.45	14	14.6	18.88
35	2150	0.47	7	13.6	18.36

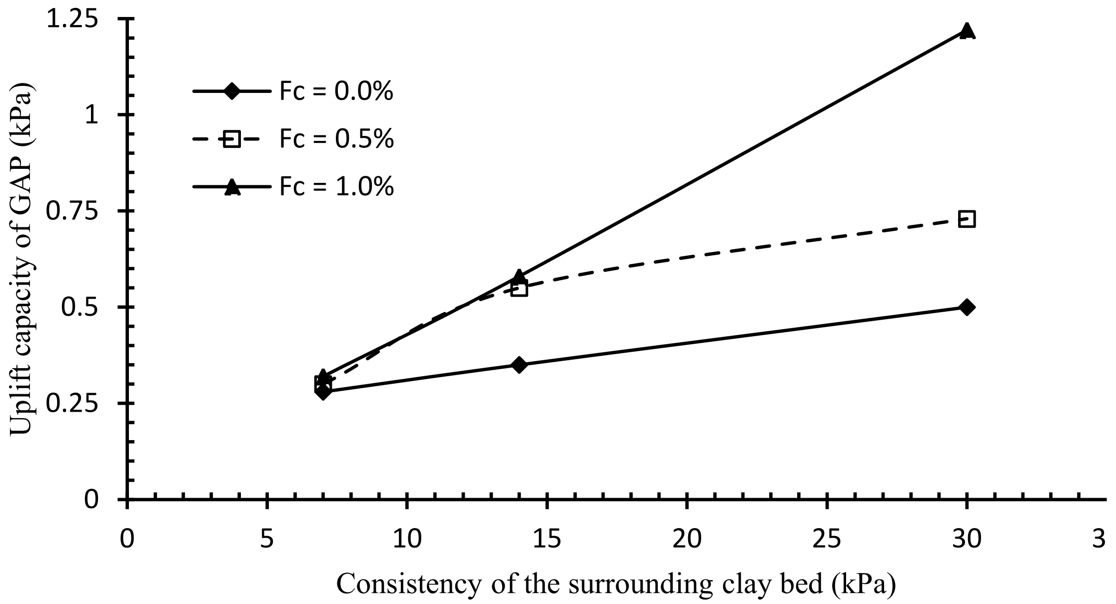

Fig. 7 Uplift capacity of GAP with consistency of surrounding clay bed

CONCLUSION

Foundations of structures are required to transmit compressive forces safely to the subsoil. Sometimes these may be escorted with moments in addition to the lateral forces causing uplifting of foundations due to expansive soils, frost heave, wind, and hydrostatic force. The granular anchor pile (GAP) a ground improvement technique is capable of providing resistances against compressive and pullout loads.

In the present study, numerical analysis has been executed using finite element software PLAXIS-2D on uplift capacity of randomly oriented fiber mixed granular anchor pile (GAP). The analysis examines the influence of factors such as fiber content (F_c), depth of random fiber mixed sand in GP (F_d), length to diameter ratio of GP and consistency of surrounding clay bed on the uplift capacity of randomly oriented fiber mixed granular anchor pile (GAP). Based on the study following conclusions are made:

- The presence of random fiber in GAP increases the pullout force capacity of GAP as compared to unreinforced GAP.
- Up to F_d/d ratio 4, the improvement in uplift capacity is little. After that uplift capacity of GAP increases significantly for both the cases F_c = 0.5% and 1.0%.
- Uplift capacity increases with the length (L) of the plain GAP. Again with the increase in F_c in GAP, significant improvement in uplift capacity has been observed.
- Uplift capacity of GAP increases with consistency value of surrounding clay bed. At low consistency value (very soft), improvement has been found very less for both Fc = 0.5% and 1.0%. So, GAP seems to be effective in soft to medium stiff clay deposit.

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5. PLAXIS 2D (Version 8) Finite Element Package

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