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River Behaviour & Control

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OURSELVES

It is happy to be able to bring out this present issue of the journal "River Behaviour and Control" which constitutes its 40^{th} Volume. The total number of papers published so far have crossed 290 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.

Bardhan

Er. M. Bardhan
Director
River Research Institute
West Bengal
Irrigation & Waterways Directorate
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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, rri.wbiwd@gmail.com

(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. (033) 29516733
E-mail: rri.wbiwd@gmail.com

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CONTENTS

Petro Graphic Studies and Probable Inference on River Hooghly at Rathtala, Kalyani, Nadia

Biswanath Ray[1]

Synopsis

Sediments are collected from Hooghly River at Rathtala, Kalyani, and Nadia, to study sedimentological aspects and to use research work in Soil Mechanics. Detailed petrographic studies, both mineralogical as well as textural, are carried out to get glimpses of depositional energy conditions and transport atonal history. The sample is dominated by Quartz (Sio_2) of 70 modal percent. Hardness of this mineral is 7.

The given thin section sample is that of unconsolidated sediments having a bimodality in grain distribution where one is that of sand-sized grains and another of silt-size. The grains are angular to sub-rounded to in most of the cases with larger ones showing better roundness, although in some cases textural inversion can be observed. The sample is dominated by quartz(Sio_2) although prominent amount of feldspar and rock fragments also occur. The grains show prominent overgrowths, sometime broken or even complete overgrowth, having multiple generations in certain cases. The grains are also abraded along the boundaries.

Introduction:-

Petrographic studies of sedimentary rocks as well as sediments are used to extract information regarding the transportational history as well as depositional energy conditions, for decades. Further, such studies are very much useful to determine the probable provenance of the sedimentary rocks/sediments. Variations in textural attributes along or across the course of a river manifest the changes in depositional energy conditions amply. Keeping these basic concepts in mind, loose sediment grains of Hooghly River at Rathtala, Kalyani, Nadia, are studied in this pioneering to generate some insight about the conditions of their deposition as well as probable provenance. Hoogly River is to be carried out in near future to understand the variability in depositional conditions along and across the course of the river. Sedimentary grains are used to prepare thin section with help of a Private Institute. Then the thin section is studied under Leica Microscope at Department of Geological Science, Jadavpur University.

Mineralogical Study:-

The sample is dominated by quartz (70 modal percent) which is a colorless mineral under plane polarized light showing a moderate refractive index and relief. These grains exhibit a considerable roundness and overgrowths, and in some cases are extensively fractured. Under crossed-polars they exhibit undulose extinction and 1st order grey interference color.

The next abundant mineral in the sample is feldspar (5 modal percent). Colorless under plane polarized light and shows one set of prominent cleavage and often two sets too. Compositionally the feldspar varies from plagioclase (showing lamellar and Carlsbad twinning) and microcline (showing cross-hatched/tartan twinning). There are also perthitic variety of feldspar where there are rims of albite around K-feldspar. These grains overall shows

1. Ex. Silt Surveyor, River Research Institute, West Bengal.

low relief and refractive index and low order interference color under cross-polarized light.
There are also flakes of chlorite identified with their green colour pleochroic from light to dark green. They show typical one set of cleavage. Under cross polarised light the grains exhibit second order interference colour with parallel extinction.
Flaky grains of muscovite are also present which are colourless under plane polarised light showing prominent one set of cleavage, moderate relief and moderate refractive index. Under cross-polarised light they exhibit high-order variegated interference colour and parallel extinction.
There are also grains having high refractive index showing yellow to dark green pleochroism and two sets of prominent cleavage. The grains show angular habit and are ubiquitously distributed. They show 2nd order yellow interference colour with oblique extinction at around 22-25 degrees. These are clinopyroxene, especially augite.
There are also grains having high refractive index and relief showing yellow to dark green pleochroism and two sets of prominent cleavage at 60 degrees. The grains show angular habit and are sparsely present. Some grains show incomplete reaction texture of clinopyroxene converting to amphibole. They show 2nd order yellow interference colour with oblique extinction at around 30-35 degrees. Hence, these are hornblende (Amphibole).Pyroxene and Amphibole constitute 5 modal percent.
Rock fragments are also present within the sample.

RF: 5 Modal percent.

Hardness: - Hardness that helps us to identify minerals and their resistance to mechanical action.
Ten minerals have been selected as standards and arranged into a scale in the order of hardness.

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	Name of the minerals	**Chemical formula**	**Mohs hardness**
(1)	Talc	$Mg_3Si_4O_{10}(OH)_2$	1
(2)	Gypsum	$CaSO_4, 2H_2O$	2
(3)	Calcite	$CaCO_3$	3
(4)	Fluorite	CaF_2	4
(5)	Apatite	$Ca_5(PO_4)_3(OH,CL,F)$	5
(6)	Orthoclase	$KALSi_3O_8$	6
(7)	Quartz	SiO_2	7
(8)	Topaz	$AL_2SiO_4(OH,F)_2$	8
(9)	Corrundum	AL_2O_3	9
(10)	Diamond	C	10

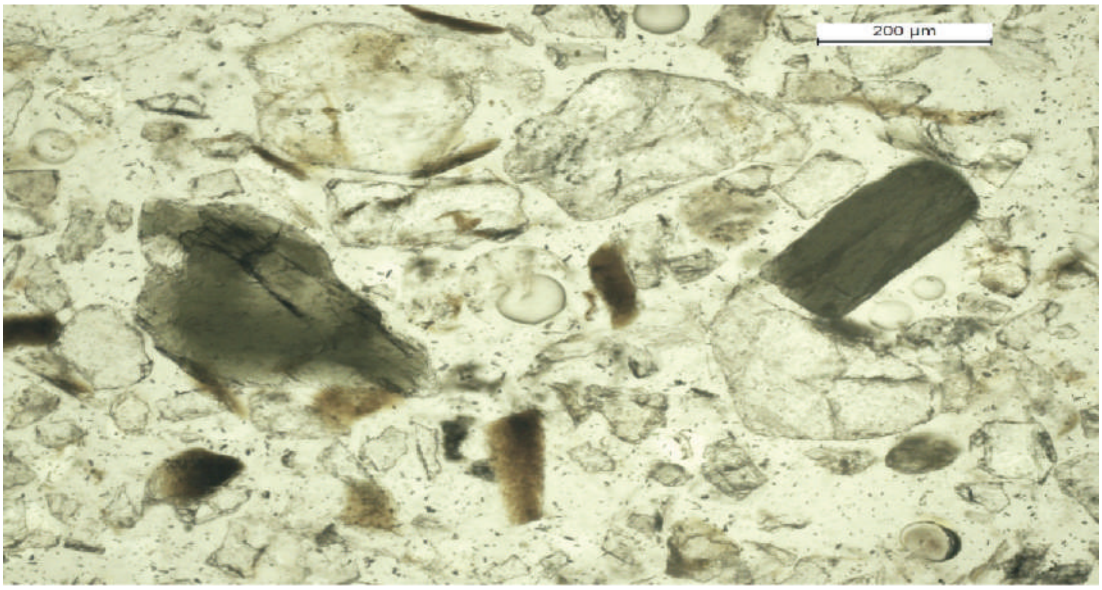

Fig-(1a) A portion of the microscopic view showing muscovite(Mus),chlorite(chl),Quartz(qtz).

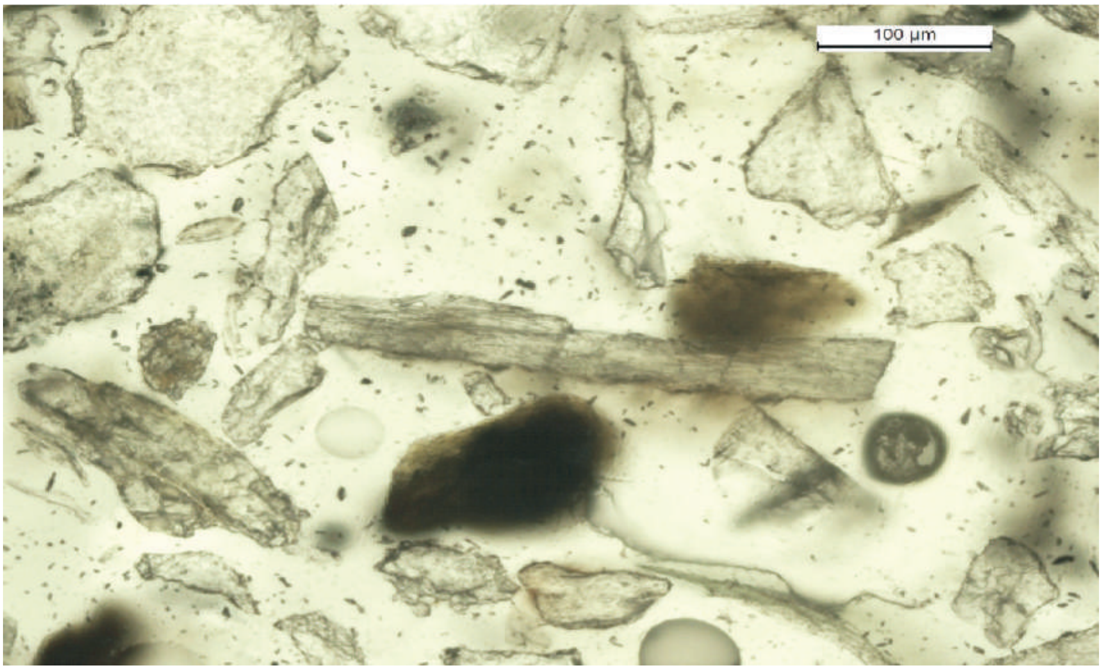

Fig-(1b) A portion of microscopic view showing Feldspar (Felds), Rock fragments (RF)

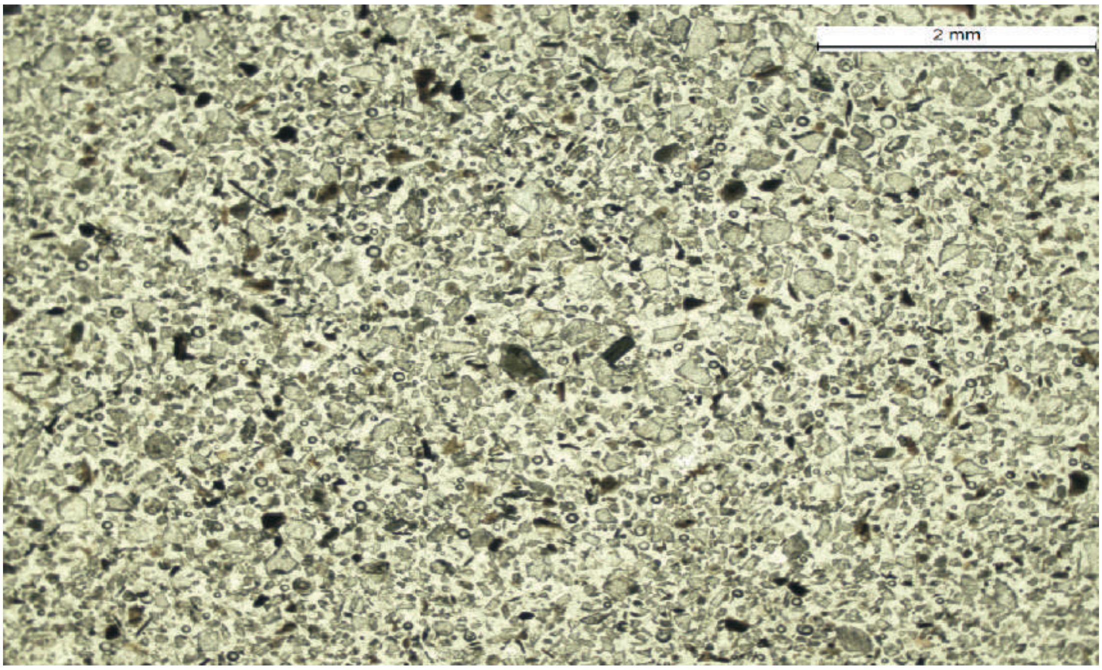

Fig-(2) Microscopic photographs of the prepared thin section (Refracted Light).

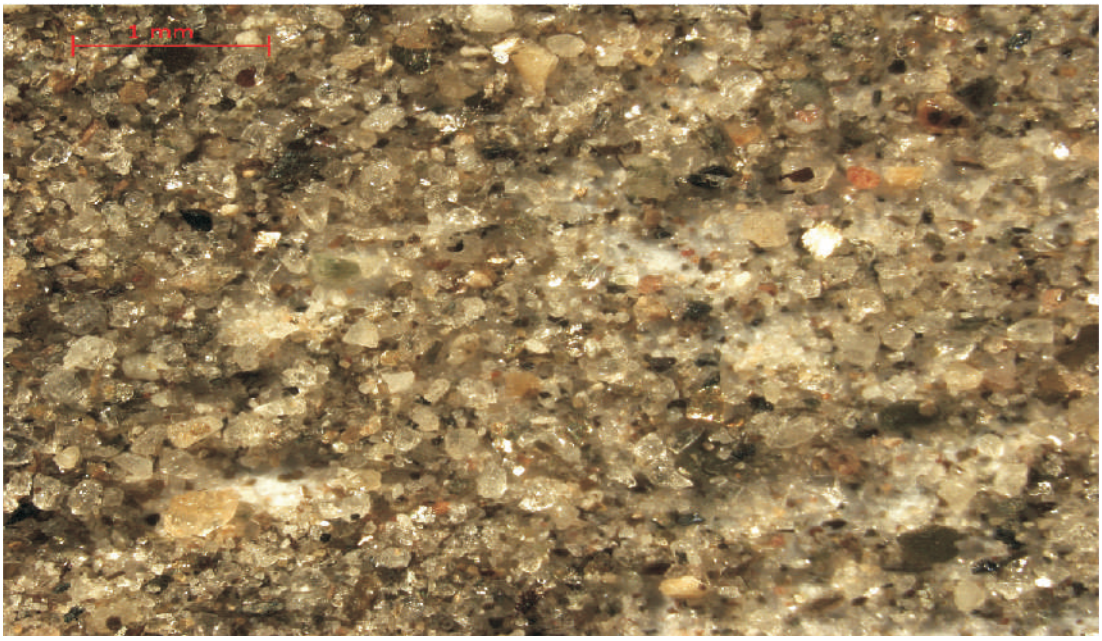

Fig-(3) Microscopic photographs of grains encountered in Hoogly River (Reflected Light).

Hoogly River Basin At Kalyani, Nadia.

CONCLUSION:-

The dominance of quartz within the sample indicate that the sample is mineralogically sorted and have experience a considerable transportation to get sorted. The presence of mafic mineral clasts, mostly of angular habit, indicate a mixing of provenance corroborated by the textural inversion in some micro-domains. The overgrowths and abrasions indicate reworking and recycling of the minerals during transportation. The presence of mostly silt sized grains indicate that the energy condition of the transporting medium was low.

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Continuou guidance of Dr.Shoumik Mukhopadhyay,Asst.Professor,J.U. is deeply acknowledged. Dr. S.S. De Dalal, Dy. Director (SM & CH), RRI, is acknowledged for kindly allowing to pursue this study.
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Sri Sukhendu Chattopadhyay (R.A.), RRI, is also acknowledged for his support during field work.

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Laboratory Investigations on Use of Kolaghat Fly Ash as a Prospective Construction Material

S. Basak[1], D. P. Dolai[2], Souvik Dedalal[3] and Rajarshi Gupta[4]

Synopsis

With rapid urbanization civil engineering construction works have increased considerably. Hence the demand of construction materials is rising, but the natural sources of materials are limited. So, alternative materials are being searched to meet up the demand. Fly Ash is a product of thermal power plants and requires huge space for disposal. Various uses of Fly ash in cement making, land filling, road construction, etc. have successfully been made amounting around 50% till now and disposal and pollution problems remain with the rest amount.

In this paper laboratory investigations on the possibility of using a fly ash collected from the Kolaghat Thermal Power Project have been reported. In one set possible use of fly ash stabilized soil as an embankment material has been reported. In another set some concrete cubes cast with fly ash replacing sand to some percentages have been undergone compressive strength tests. The results have shown some positive trends.

Such practices of using fly ash are expected to help in attenuating problems like disposal, pollution and over exploitation of natural sources of materials.

Key words: - Construction alternatives, CBR, Compressive Strength, Fly Ash.

Introduction: -

In India consumption of cement in various civil engineering constructions has been reported as 328 million tons in 2019 and is going to rise rapidly in near future. Cement is about 10% of concrete while aggregates amount more than 70%. Hence it can be visualized how much Mother Nature, the source of these materials is being exploited. On the other hand, fly ash, a solid waste generated during burning coal for thermal power generation was 213 million tons in 2016 and is expected to rise manifold in the coming decades. Around 50% of it is used in manufacturing of cement and brick, land filling, road construction and other purposes, while the rest is disposed to land causing space problem and pollution (Ref. Sikder et al, 2021).

1. Assistant Research Officer, River Research Institute, West Bengal.
2. Research Officer, River Research Institute, West Bengal.
3. U. G. Student, Amity University, Kolkata.
4. Assistant Professor, Dept. of Civil Engineering, Amity University, Kolkata.

These two problems may be tackled to some extent if fly ash is utilized more in making concrete and in other civil engineering works. Partial replacement of cement by fly ash has shown some positive results. However, the field of partial replacement of sand, that is, fine aggregate by fly ash (FA) is not much investigated. In this matter it may be mentioned that in recent years the Government of W.B. is taking steps to control irregular sand mining to restore the river regime and to generate revenue.

Prospective murrum quarries have recently been unavailable over many parts of the state of W.B. and scarcity is arising for materials for construction and maintenance of the village and embankment roads. Alternative materials have been suggested by high level technical committee in this matter.

In this paper laboratory investigations on the possibility of using fly ash in various construction works has been reported. The fly ash used here was collected from the Kolaghat thermal power plant (KTPP). In one set of investigations, possible use of fly ash stabilized soil as an embankment material has been presented. In another set, some concrete cubes cast with fly ash replacing sand by some percentages have been undergone compressive strength test.

Literature Review :-

A. Coal ash is the solid residue resulting from combustion of pulverised coal. The residue that settles at the bottom of furnace is bottom ash and that collected by electrostatic precipitators and other ways is fly ash (major constituent). The ash is disposed either by dry system or by wet system. In the dry disposed system bottom ash and fly ash can be stored separately in the ash mound. In the wet system water is mixed with fly ash and bottom ash to form slurry and the mixture is hydraulically transported to the ash pond. The ash particles settle in the ash pond and water is decanted off. Near the inflow zone of the pond, the pond ash is more sand sized and near the outflow zone the ash is mostly silt sized (Dutta, 1998).

   Fly ash contain both the amorphous and crystalline phases. The primary constituents are Silica and Oxides of Aluminium and Iron. The minor elements are Calcium Oxide, Magnesium Oxide etc. Regarding shape, the particles are cenospheres (hollow spheres), plerospheres (solid spheres), needle or flaky (Nayak et al, 2007).

   Several investigators have reported engineering properties or various types of Indian fly ash (Dutta, 1998 and Srinivas, 1999). It has been found that, in general, the values of angle of internal friction of pond ashes range from 25^o to 40^o. Higher values are found with coarser ashes. So, choosing the right type of ash is an important issue.

As the ash possesses good shear strength properties it is a potentially exploitable material in various civil engineering works. De Dalal et al (2007-08) have found a Bandel ash (sand size 40.7%, silt 59.3%, G=2.15) to have angle of internal friction more than 40^{o} at Proctor density.

B. Several numbers of investigation have already been conducted on fly ash as cement substitute in concrete. However, there exist only a few literatures on utilisation of fly ash as partial replacement of sand.

Choure and Chandak (2017) have conducted compressive strength test of M30 concrete, replacing cement by fly ash in varying percentages (0, 5, 10, 15 and 20). Due to pozzolanic action of fly ash, strength has been found to increase with addition of fly ash. Patil et al (2012) have worked on fly ash of Deep Nagar thermal power plant of Jalgaon district, Maharastra. The cement in concrete was replaced by 5% to 25% in steps of 5%. They used M20 grade nominal mix as per IS456-2020 and found that addition of fly ash lowered 28 days compressive strength and delayed hardening. But with 10% fly ash 90 days strength was higher than that of the normal mix. As disposal is a critical problem, they have suggested to use fly ash in minor amount in different construction works.

Sabarish et al (2017) have conducted test on M25 and M40 concrete replacing cement by 10,20,30 and 40% by fly ash. The result was not positive and they have concluded that for use of fly ash in concrete, judicial decisions are needed from the engineers.

Refieiznooz et al (2016) have conducted tests on cubes replacing OPC by 20% fly ash and replacing sand by different amounts (0,20,50,75 and 100%) by bottom ash. No significant improvement was noticed in 28 days strength but after 90 days curing, concrete with coal ash mixtures were found with higher strength.

Mujibur Rahman et al (2020) have conducted experiments in Djakarta, Indonesia replacing sand by fly ash by 0,20,35 and 50%. Their findings were positive and they have concluded that fly ash as replacement of sand would be economical and environment friendly.

Sikder and Ghosh (2021) have conducted tests using nominal mix 1:1:2 with sand replacement by fly ash in different amounts (10,20,25,30,35 and 40%). Workability was affected to some extent by adding fly ash but they have reported positive trend of sand replacement by fly ash in the matter of compressive strength.

Laboratory Tests: -

Some tests reported here has been done in the Quality Control Laboratory of River Research Institute (RRI) at Mohanpur and others have been done in the laboratory of Amity University, Kolkata.

A. The soils and fly ash of Kolaghat thermal power plant (KTPP) were sent to QCL, Mohanpur by the Executive Engineer, East Midnapore Division, I & W Dte. Murrum was collected from a site of Birbhum district. Standard laboratory tests have been done on the soil samples, fly ash, murrum and mixed soils. Initially index properties of the soils and fly ash (FA) have been determined. Sedimentation analysis (using pipette method) and sieving conjointly have been done for getting particle size distribution of the soils having some or considerable amount of fines. Atterberg Limit tests have been done on the clayey soil and specific gravity values of these soil samples have also been determined.

The soil samples have been mixed with FA in some arbitrary proportions. Some engineering properties of these soils and mixed soils have been determined.

Standard Proctor tests has been performed on the original soil samples and the FA mixed soils.

Subsequently California Bearing Ratio (CBR) test in unsoaked condition has been conducted on these samples at or near the Proctor values.

B. The cement samples, sand samples and coarse aggregate samples have been procured from the market. The fly ash, however, is the same, obtained from the KTPP.

Some properties of the ingredients related to Mix Design have been determined at first from the tests with the OPC. However, with the PPC, nominal mix has been used and some properties have been determined.

In Mix Design the target strength was 20 N/mm^2. Following the codal provisions a design mix has been prepared. The cement amounting 330 kg/m^3 of concrete has been chosen.

The mixes are as follows:-

Set	Water(l)	Cement(kg)	Sand(kg)	FA(kg)	Coarse Aggregate(kg)
A (normal)	0.54	1.0	2.17	0	3.84
B (20% sand replacement)	0.54	1.0	1.67	0.42	3,84
C (40% sand replacement)	0.54	1.0	1.19	0.79	3.84

For PPC 1:1.5:3 proportion by wt. has been used for making M20 concrete.

After required curing compressive strength tests have been done in a Compressive Testing Machine (CTM). In one set (using OPC) the cubes were cured in saline water (salt intensity 20 gm/L) to observe the effect of salinity.

Test Results:-

A) Stabilized soils:-

All the test results are given in the Figures and Tables. The clayey silt sample belongs to CL group and the soil mixed with FA has become non plastic. The maximum dry density of the fly ash sample has been found lower than the natural soils due to lower value of G and the OMC is higher.

The CBR values (Unsoaked condition) of the fly ash is more than 12, while the value of the murrum sample is well over 20.

Due to the addition of fly ash the CBR values of these natural soils have improved to certain extent and for the clayey silt soil the improvement is quite noticeable, from 4.3 to 16.8.

Actually, the pozzolanic action of FA is considerable on the clayey sample. While addition of FA the soil has become non-plastic. The permeability values have been improved.

B) Concrete-(Sand Replacement by FA):-

1. OPC- In Mix design the target value of 20 N/mm^2 has not been achieved (Fig. 5) for taking cement in the lower side, 330 kg/m^3 of concrete. A higher value would possibly be required. As the results of the set C are not consistent, these have not been presented here. Curing in saline water affects normal concrete to some extent but fly ash added concrete is not affected.
2. PPC- The results of the nominal mix are shown in (Fig. 6). It is evident that the initial rate of strength gain is low (in the first week). However, gradually the strength improves and ultimate values are more than those of the normal set.

Due to limitations in infrastructure and shortage of time neither any further set of tests nor repeat of tests could be done. However, following conclusion may be drawn in the use of FA as construction material in different fields.

Table-1. Chemical Composition of Kolaghat Thermal Power Plant Fly Ash

Oxides	% by mass
SiO_2	49.5
Al_2O_3	28.3
Fe_2O_3	4.3
CaO	5.3
MgO	1.8
SO_3	1.8
Other Oxides	6.9
Loss on Ignition	2.1

Ref : Sikder *et al*., 2021

Table 2: Results of Laboratory Tests (Natural Soils)

Lab. Sl. No	Location	Nature of Sample	Sp. Gravity (G)	Size Analysis (%)	Atterberg Limits (LL/PL) %	OMC% & MDD (gm/cc)	Permeability Coefficient at 27°C cm/s	CBR %
Q/S-1/22	Kolaghat Thermal Power Project (KTPP)	Fly Ash	2.10	Sand= 30.3 Silt= 62.9 Clay= 6.8	Non-Plastic	OMC= 23.4 MDD =1.265	K_{27}=2.92X10^{-4}	14.02% (2.5mm) Penetration 12.86% (5mm)
Q/S-2/22	Bank of River Rupnarayan, East Midnapur	Sandy Soil	2.68	Sand=44.0 Silt=52.5 Clay=3.5	Non-Plastic	OMC=16.6 MDD=1.61	K_{27}=1.16X10^{-4}	4.98 (2.5mm)
Q/S-3/22	Bank of River New Kansai	Sand	2.64	C Sand to M Sand = 21.27 F Sand = 78.37 (Silt+Clay) = 0.36	Non-Plastic	———	K_{27}=3.57X10^{-4}	7.70 (2.5mm)
Q/S-4/22	Bank of River Chandia	Clayey Soil	2.64	Sand=0.80% Silt=84.2% Clay=15%	LL=34.17 PL=20.79 PI=13.38 (CL)	OMC=18% MDD=1.64	K_{27}=1.15X10^{-6}	4.32 (2.5mm)
Q/S-5/22	Birbhum Site	Murrum, Lateritic Soil	———	Gravel = 6.4 Sand = 54.4 Silt = 21 Clay = 18.2	———	OMC=11.5 MDD=1.99	K_{27}=1X10^{-7}	22.35 (2.5mm)

C = Coarse , M = Medium, F = Fine

Table 3: Results of Laboratory Tests (Mixed Soils)

Lab. Sl. No	Nature of Sample	Sp. Gravity (G)	OMC % & MDD gm/cc	Permeability cm/s	CBR %
A	(Sandy Soil + Fly Ash) = 70 : 30	2.52	OMC = 20.5 MDD = 1.462	$K_{27} = 3.02X10^{-5}$	14.17 (2.5mm)
B	(Sand + Fly Ash) = 70 : 30	2.49	OMC = 15.01 MDD = 1.64	$K_{27} = 5.69X10^{-5}$	8.29 (2.5mm)
C	(Clayey Soil + Fly Ash) = 50 : 50	2.40	OMC = 22.0 MDD = 1.44	$K_{27} = 9.63X10^{-6}$	16.76 (2.5mm)

Table 4: Results of Laboratory Tests on Materials Used in Making Concrete

Materials	Test Results
Cement (a)OPC (43 grade) (b)PPC	Retained on 90 micron-1.4%, G=2.78, initial setting time 47 min and Final setting time 5.5 hrs. Slump for set A, Set B and set C-20mm, 35mm and True. Retained on 90 micron-0.9%, initial setting time 123 min and Final setting time 7.6 hrs. Slump for set A, Set B and set C-65mm, 52mm and 45mm. Set A-Normal, Set B-20% sand replaced by FA, Set C-40% sand replaced by FA.
Sand	Zone II, FM=2.633, G=2.63
Coarse Aggregate	Passing 20 mm and retained on 10 mm. crushed stone chips, G=2.85
Fly Ash	G = 2.10

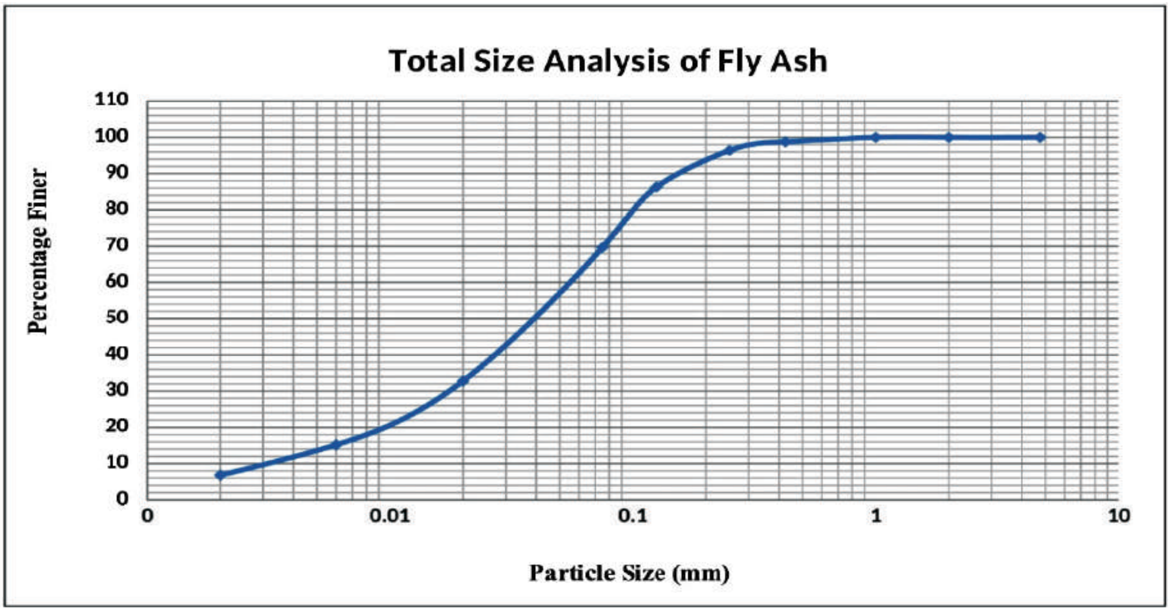

Fig.1: Particle Size Distribution Curve

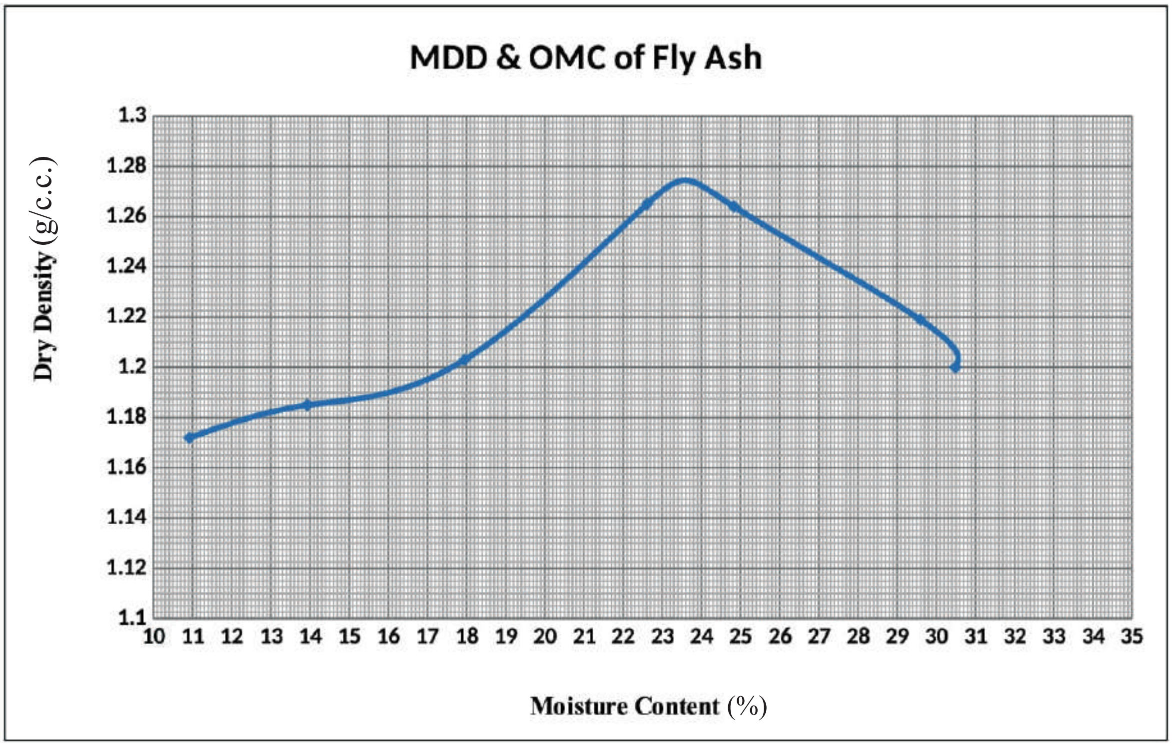

Fig.2: Standard Proctor Test Plot

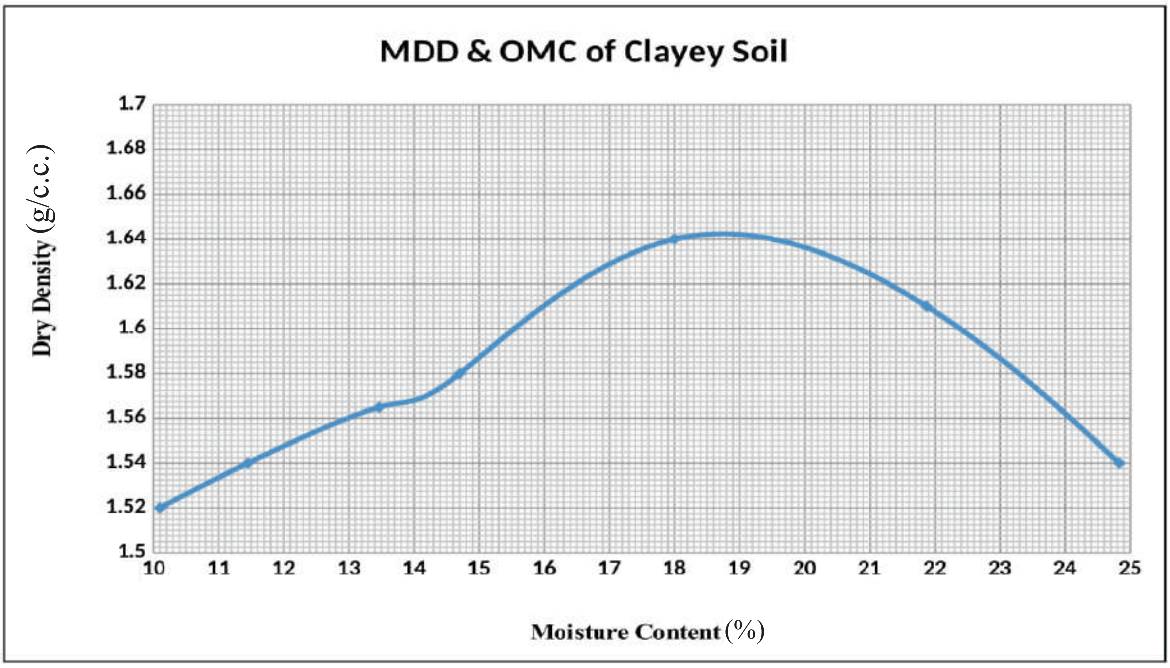

Fig.3: Standard Proctor Test Plot

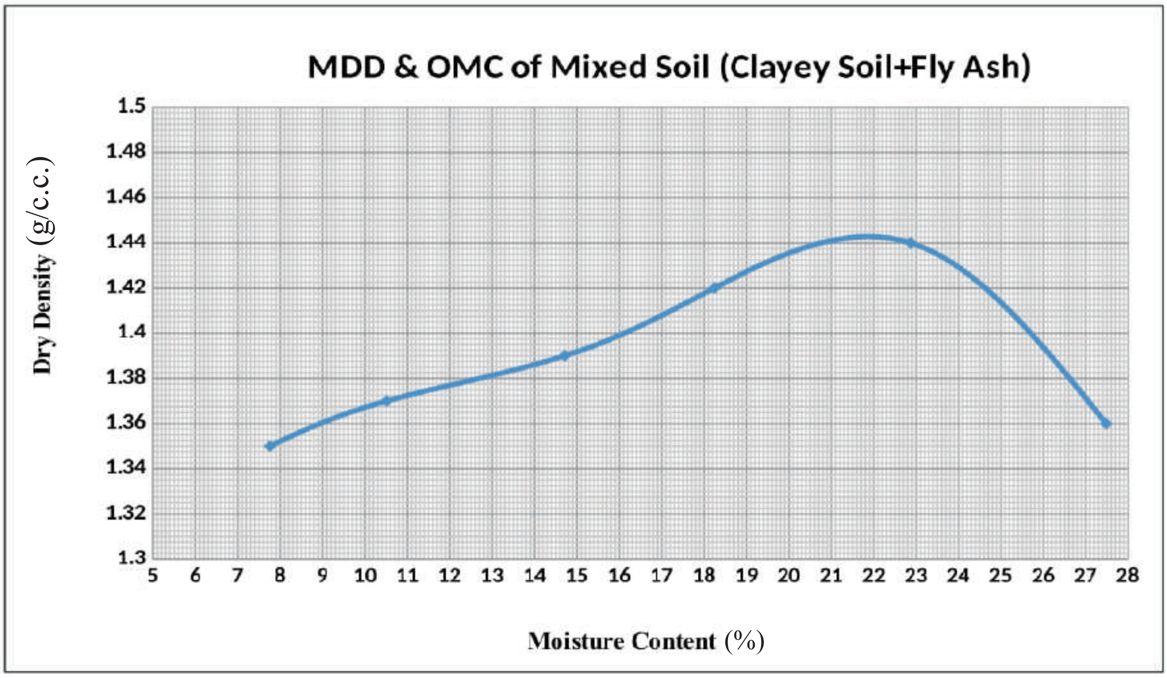

Fig.4: Standard Proctor Test Plot

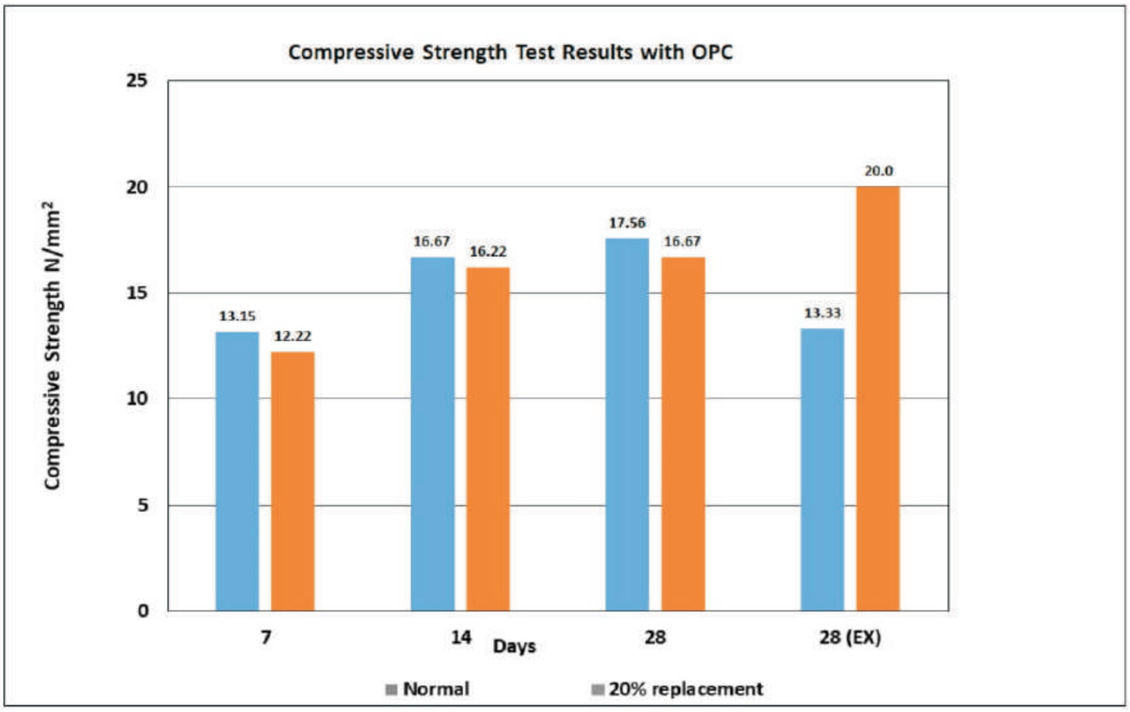

Fig.5: Compressive Strength Values of Different Mixes (OPC & FA)

* 28(EX)-cured in saline water

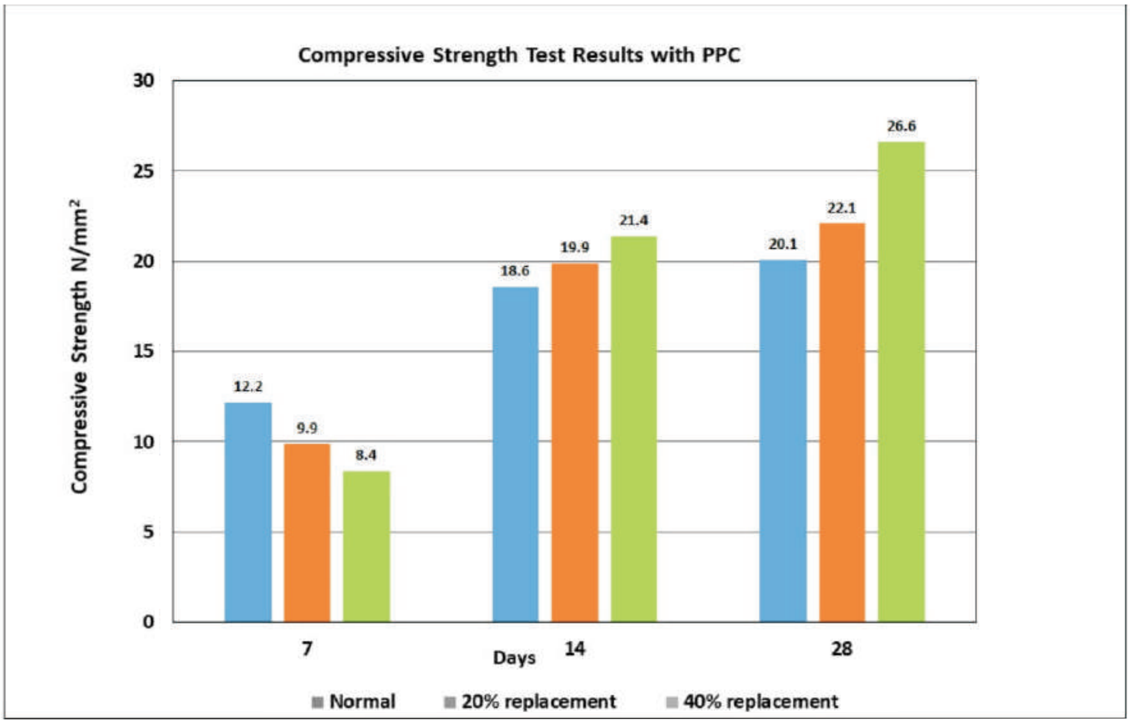

Fig.6: Compressive Strength Values of Different Mixes (PPC & FA)

Conclusion: -

A: Stabilized Soil-

1. As addition of fly ash results in improvement of CBR value of natural soil, the stabilized soil may be used as base course of a road. Clean sand or fat clay (clay higher than 20%) may be avoided, rather sandy loam, loam, clayey silt, etc. may be used. Addition of FA is expected to improve CBR value and cohesion value by pozzolanic action. But as G value is lower and FA itself is susceptible to erosion (rain cuts), the FA mixed soil on embankment should be protected at sides by berms made of clayey soils with vegetal growth on slope.
2. Unlike murrum a FA stabilized sandy or loamy or silty soil cannot be used as surface or wearing course. Actually, such stabilized soil is expected to behave good as base course of a road of average loading. For a finished road wearing course will be needed.
3. Mixing of natural soil and FA is required to be homogeneous so far as practicable.
4. Before applying on large scale such stabilized soil should be used in some stretches on trial basis.

B: Concrete:-

1. The workability of mix (OPC) is improved with 20% replacement of Fly ash but falls with 40% replacement of Fly ash. For PPC the slump is less with addition of fly ash.
2. 87.8% of the target strength of M20 (design mix using OPC) could be achieved possibly due to under estimation of required cement amount. With 20% replacement the results are good. Higher percentage of replacement is not ascertained in this test set, as the results with 40% sand replacement by fly ash are not satisfactory. However, results with tests of nominal mix using PPC are positive. With replacement of sand by fly ash the strength gain is slower in first 7 days but with time strengths are more with addition of fly ash.
3. The rate of strength gain has not been affected by addition of fly ash, but fly ash may help concrete against effect of chemicals in the case of OPC. In the case of PPC, however, strength is lowfor 7 days with fly ash replacing sand, but in due course of time strength gain is considerable.
4. In future research works more tests with nominal mix which is adopted in general construction works may be done. This is due to the fact that huge amount of concrete is used in common households. The long-term curing effect say 90 days may be included in the test programme. Another test set replacing cement (5 – 10%) and sand (20 – 60%) may be done to strengthen the logic of using fly ash in concrete making.

The quality of fly ash varies from plant to plant. Similar experiments may be done with fly ash of other Thermal Power Plants.

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Sediments of Some Rivers in West Bengal – A Study

S. S. De Dalal[1], Sukhendu Chattopadhyay[2] and B. C. Barman[3]

Synopsis

Rivers carry water along with sediment from the catchment coming down with runoff owing to erosion of the either side of bank and along the bed. The present landform of the river path is the result of migration of banks and bar formations on the river bed, occurred due to mechanism of erosion and deposition process. Before going to any river training project, modelling is done as a part of environmental impact assessment and future prediction of the changes in river morphology resulting from the proposed project. In the context, hydrological studies comprising in situ measurements of velocity, discharge, river section, etc. together with sediment load (bed and suspended) are conducted. Running a physical model is time taking and due to scale effect proper representation of sediment load can seldom be incorporated in the model. On the other hand, in a mathematical model (may be 1D, 2D or 3D) such provisions may be included through sophisticated software like MIKE, HEC-HMS, HEC RAS, etc. In this paper bed and suspended loads of some rivers in West Bengal collected during various projects have been assembled and discussed on their variations. Such accumulation of data may help to understand different river regimes in a better way before going to prepare the DPR for new river training projects or rejuvenation of old projects vis-a-vis decaying rivers using mathematical model.

Key words: Bed load, Model, River, Sediment, Suspended Load.

Introduction

A river basin is shaped as a consequence of the erosion and sediment transport of the river. The observation and prediction of the rate of erosion, transportation and deposition on the flood plains, reservoirs, estuaries and elsewhere is one of the tasks of the hydrologists. The sediment moves in the stream as suspended sediment in flowing water and as bed material that slides, rolls or saltates along the stream bed.

The bed load is the material near the bed and formed with coarser fractions. Amount of coarse sediment depends on the sediment transport capacity of the river and well-defined relation is available with flow discharge. The suspended load, often termed as wash load, consists of finer materials washed into the stream that normally travels through the system, redepositing to a little extent only. Unlike bed load, no defined relation is available for suspended / wash load with flow discharge.

1. Ex. Deputy Director (SM & Ch), River Research Institute, West Bengal.
2. Assistant Research Officer (Hydraulics), River Research Institute, West Bengal.
3. Deputy Director (Hydraulics), River Research Institute, West Bengal.

However, high discharges or floods carry much higher sediment concentration than normal flows do, both in the cases of the bed load and wash load. Again, in a turbulent flow gravitational settling of particles is counteracted by upward transport in turbulent eddies. So, in the near bed zone a layer is always having a tendency of settling or getting into suspension. Total sediment load is the sum of the bed load and suspended load and to have a comprehensive idea of a river state, together with the knowledge of river section, bed slope, velocity and discharge, etc. sediment data are also important.

In a large river valley project, there are possibilities of negative impacts on the river regime and so modelling is resorted to in order to visualize, understand and take necessary measure against such consequences. Physical models are time taking and with the development of modern software mathematical modelling is being preferred. In contrast with the physical modelling there are options in mathematical modelling to introduce suspended load data in detail as a parameter. So, nowadays, both the amount and size of bed load and suspended load data are needed for such model studies. Hence, these are included in the hydrological observation programme before any river related project.

In West Bengal (Fig.1 – Map of West Bengal) numerous rivers run through the state with varying landscapes from very steep to gently rolling and very flat. Erosion, flood and drainage congestion at the tracts under tidal influence remain the natural phenomena related to the rivers.

Several river valley projects since the independence and prior to that were executed for irrigation, flood control and other purposes. Nowadays, problems like erosion, deposition, pollution and salinity intrusion are rising. In place of new constructions of dams, barrages or weirs, new projects like river bank protection, dredging to restore river capacity, resectioning of rivers near bifurcation points to achieve suitable share in branches etc. are being undertaken and attended by the authorities. In connection with such projects, modelling is done and for that hydrological information with sediment data are needed.

In the recent years different hydrological surveys have been conducted by River Research Institute (RRI). In these surveys bed, bank materials and river water samples (with suspended load) have been collected and analyzed. In this paper comparative discussion on these sediments have been presented. This will help to have some idea regarding the states of the rivers at the proposed project locations.

In literatures it has been reported that in tropical regions, intensive downpours can cause much more damage than in temperate climates. In general water erosion in the regions between latitude 40^0 North and 40^0 South is the most serious in the world.

Floods carry much higher sediment concentrations than the normal flows. Concentration of fine sediments depends only on the supply of sediment from upstream reaches and no obvious relationship with flow discharge is found.

Wolman and Schick have shown that the sediment yield from urbanized or developing areas ranged from little to very high values annually. Yorke and Herb indicated that annual average sediment yield from cultivated land was 620 t/km^2 and from construction sites the average was 7330 t/km^2.

For rivers flowing over alluvial plains, suspended load predominates and bed load is generally negligible. In such cases the suspended sediment transport capacity is approximately equal to total transport capacity.

Regular measurements of flow discharge and sediment sampling are the routine work of a hydrometric station. With samples at one, two or more depths, total sediment can be calculated in a manner analogous to current meter gauging of flow.

Anderson (1951) analyzed measured data for 29 watersheds in Oregon, US to establish a relationship between suspended load and various regional characteristics of watersheds.

Sediment measurements like current meter measurements give only occasional samples of the sediment discharge. A sediment rating curve relating suspended sediment discharge and water discharge is commonly used to estimate the sediment load on days with no measurement. Such relations are approximate. However, by means of relationship between flow discharge and sediment transport rate and the frequency curve for flow, one can evaluate the total sediment load at a given hydrometric station.

In physical modelling the field values or sections, discharge, velocity, bed slope and gauge are scaled down to laboratory values to run the river stretch and sometimes, silt load is added to duplicate a silt laden river. However, in practice suspended load being considerable in magnitude compared to bed load, cannot be properly represented in model. However, the physical appearance of the model and some other aspects make it popular in the subject.

A study at Arabari near Salboni, West Midnapore was conducted for observing the changes in eroded soil quality with afforestation. Some of the results of the observations have been shown in Fig.2 to 4. As a result of afforestation, runoff and soil erosion were reduced considerably. The eroded soil quality (Fig.4) was also changed.

2. Experiments – Field and Laboratory Works

2.1 *Field Works*

The bed materials were collected either by grab sampler or by Uppal Sampler that has a gate of width 11 cm, which is opened facing the river flow and kept for 30 minutes. The sampler is then lifted and the sediment arrested within the racks is collected and preserved. The depth of the Hooghly, Rupnarayan, Muriganga and Bidya is high. So, lowering the sampler tied with the rope, driving the boat opposite to the flow and keeping balance are tough to maintain. The materials collected are from shallower depth, that is, from toe of the bank.

Attempts were made to collect river water samples from mid-depth of the river. After reaching the required depth the lid of the bottle connected with a thinner rope is drawn to open the mouth and water with sediment fills the bottle. The sample volume is usually one (1) liter.

2.2 *Laboratory Tests*

In laboratory bed materials are dried and undergone grain size analysis. When these are sand, sieving is done. Bed materials of the tidal reaches of the rivers contain considerable amount of fines. These are undergone mechanical analysis following sedimentation analysis (by pipette method) and sieving conjointly.

The suspended load, generally, is of little amount. So, a few samples of the same or nearby section, depth and river state have been assembled to make a specimen amounting 2 to 2.5gm. It is to be mentioned that in practice 25gm of soil is used for sedimentation analysis by pipette method in RRI laboratory.

The results obtained by mechanical analysis are presented in semi log plot of particle size distribution.

2.3 *Case Study*

A field model study was conducted at Arabari near Salboni, West Midnapore during 1948 – 1957. Afforestation was done by the Forest Directorate; Govt. of West Bengal and the model was run by RRI. Rain gauge was installed, flume and silt trap were constructed near the outlet of the model plot of 0.91 Hectare (Total Plot measuring nearly 91 Ha). The place was earlier a denuded land of lateritic soil and at present it is a dense forest. Afforestation was done in 1948 and hydrological observations were taken. Observations were further started in 1951 when the plants were more than 15cm high and the measurements were continued till 1957.

3. Results and Discussions

The results of sediment load of different rivers have been presented in Table-1. Some of the particle size distribution curves have been given in Fig.5 to Fig.10 showing particle size distribution of bed material and suspended load. Rate of bed load movement was studied for the river Karru, Kangsabati and Damodar (Raniganj) using the Uppal Sampler. In respect of sediment load the values of bed load have been found well below 2%. There are limitations in such sampler (Uppal sampler) and the values are expected to be higher.

The bed material of the Karru, Purulia is mostly medium sand with some fine and coarse sand, trace gravel. It is fine to medium sand for the Damodar and Kangsabati. The Hooghly bed sand at Chandannagar is uniform fine sand with mica.

The suspended load of the Damodar at Durgapur barrage pond contains fines (below 75micron, silt + clay) around 40% and clay 8%. These values are 60% and more than 10% for the Karru and more than 60% and around 10% for the Kangsabati at Kapastikri.

All these samples were collected during monsoon period excepting those of the Hooghly. The suspended load of the Hooghly (winter months) is gap graded, percentage of fines is below 40% and clay is 8%.

The concentration of suspended load is low to very high for the Karru, low for Damodar, medium to high for the Kangsabati and medium for the Hooghly.

On the other hand, the bed materials of the rivers with high tidal influence contain considerable amounts of fines (silt + clay). For the Muriganga and Bidya this is more than 80% and for the Rupnarayan at Dainan it is more than 90%. The suspended load of the Rupnarayan, Muriganga and Bidya contains fines more than 90% and clay more than 35%. Of course, these observations were carried out in non-monsoon months.

In comparison to the western rivers, these rivers contain less suspended load. Actually, river movement gets slackened occasionally due to tide. In addition to this physical reason salt flocculation occurs in tidal reaches. Negatively charged soil particles interact with the saline water and hence depositional environment prevails at these sites.

The suspended load of some North Bengal rivers contains fines 70% – 90% and clay 10% -20% (Fig.10).

An observation was made on different channels at Gadkhali regarding concentration of suspended load over the depth (Table-2). There are fluctuations of silt intensity at each depth, but it is distinct that the intensity is more with greater depth.

Now comparing the type of suspended load (Fines below 60%) of the Karru, Purulia and those of the North Bengal rivers (Fines 70% - 90% and more) it may be said that the forest covering of North Bengal is more compared to Purulia.

The suspended load of the Damodar at Durgapur is much lower than that of the Kangsabati at Kapastikri. The location of Durgapur is nearer to the Dams like Panchet and Maithan, while Kapastikri is rather far from the Kangsabati-Kumari (Mukutmonipur) Dam and only one control structure (Anicut at Mohanpur) exists in between the places. A dam arrests some sediment running down the catchment area and the water released from the dam is with less sediment load.

4. Conclusion

In different rivers of West Bengal, there are so many variations of bed load and suspended load in their quality. Proper knowledge of the total sediment characteristics of the rivers is important to implement any engineering intervention on those rivers, channels or canals. It is also found that the nature of the materials is different in different seasons of a year. So, observations should be conducted for 2 to 3 consecutive years to arrive at suitable values representative of different seasons and discharges and those can be incorporated in the model so that the model can run more rationally.

Following conclusions may be made from this study.

- The grain size analysis of the river bed and suspended load helps to get the average diameter.
- These sediment data are important for formulations to run the mathematical, as well as, physical model using different sediment transport equations in a river or natural channel or adopting any hydrodynamic analysis for determining the morphological changes of the river.
- This will help to calibrate and to validate any mathematical model more precisely and accurately by finding '*n*' value (Manning's co-efficient).
- This will also help to estimate the suspended sediment concentration (SSC) of any river for a particular zone by incorporating physical data into *Visea STAR* software along with the data captured by ADCP from the reflected rays of backscatter while tracking a transect for a particular section of a river during hydrographic observation.

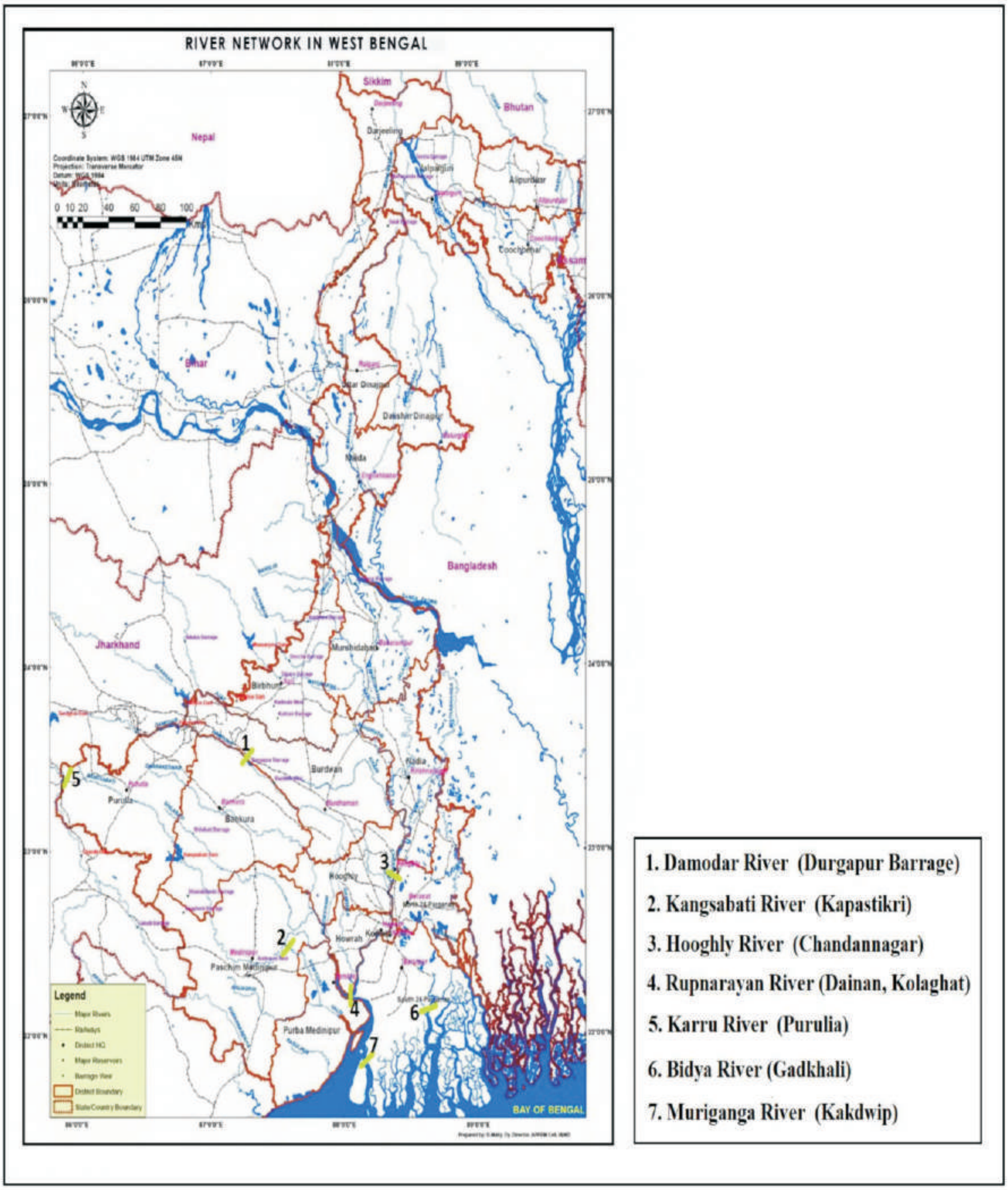

Fig.1. Map of West Bengal showing the Rivers and Places of Interest

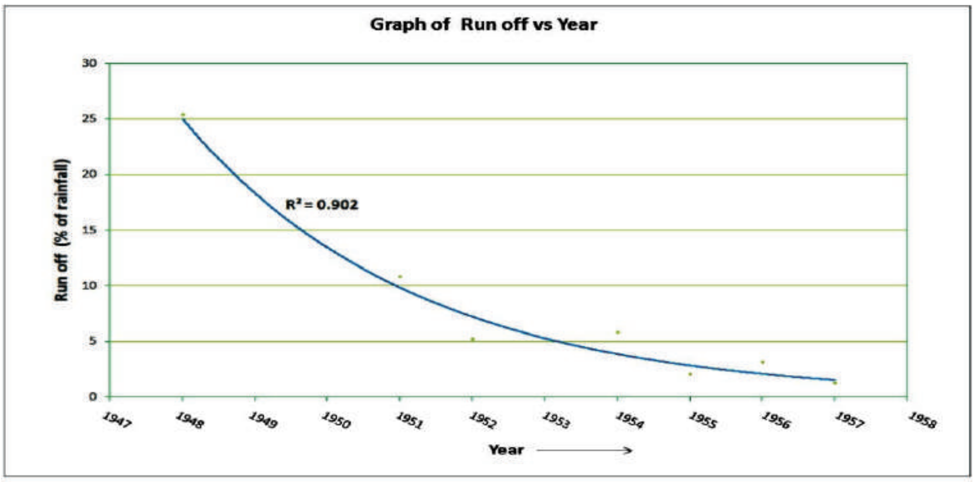

Fig.2. Reduction of Runoff due to Afforestation - Arabari Experiment

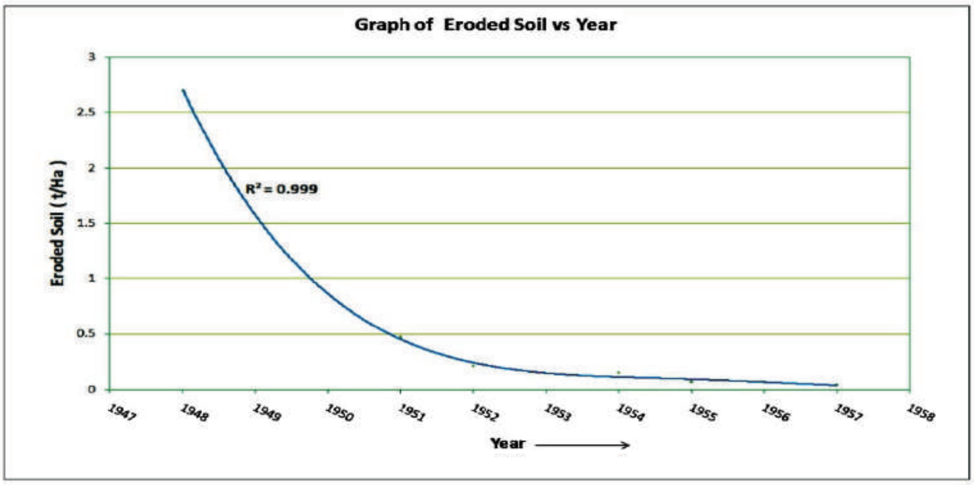

Fig.3. Reduction of Soil Erosion by Afforestation - Arabari Experiment

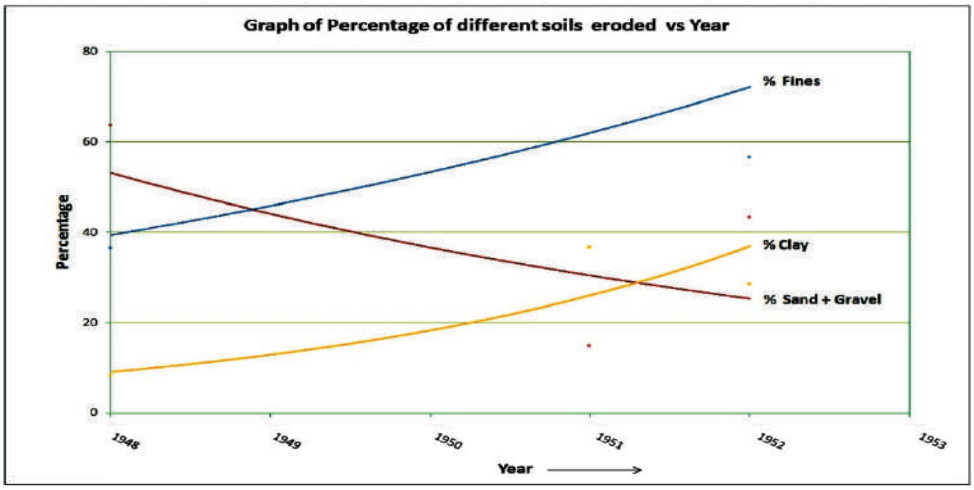

Fig.4. Change in Eroded Soil Quality with Afforestation - Arabari Experiment

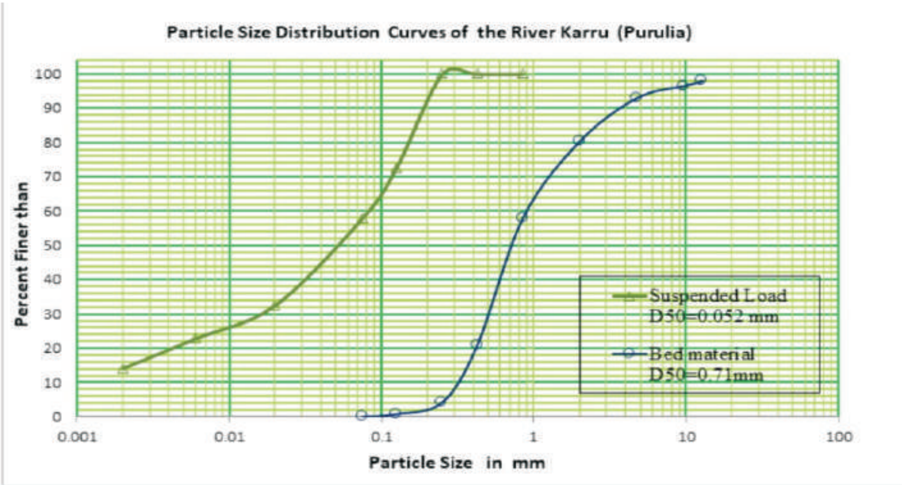

Fig.5. Particle Size Distribution of Sediments of the Karru River

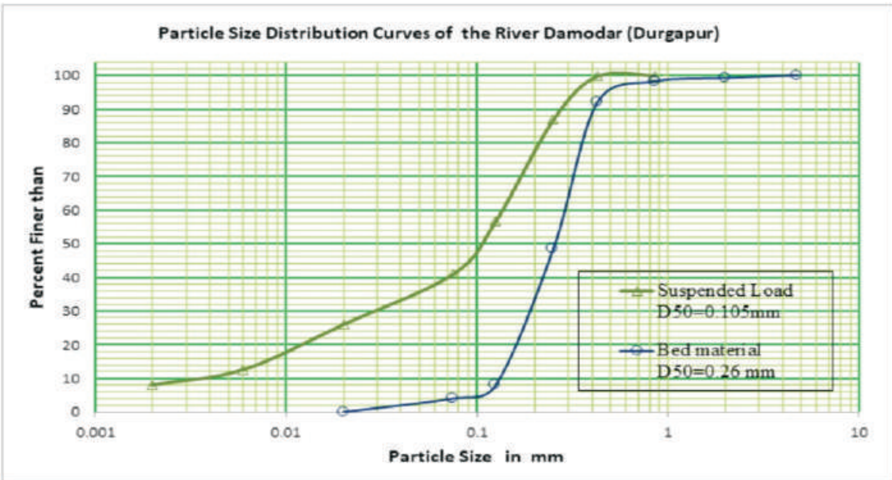

Fig.6. Particle Size Distribution of Sediments of the Damodar River

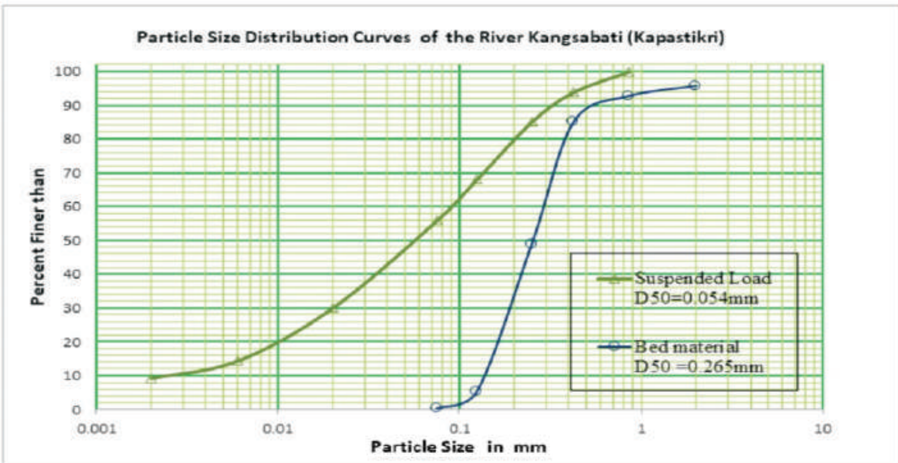

Fig.7. Particle Size Distribution of Sediments of the Kangsabati River

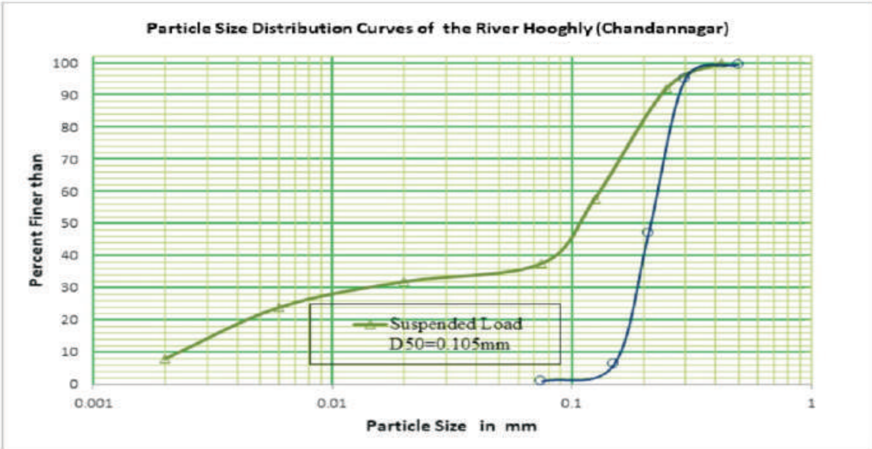

Fig.8. Particle Size Distribution of Sediments of the Hooghly River

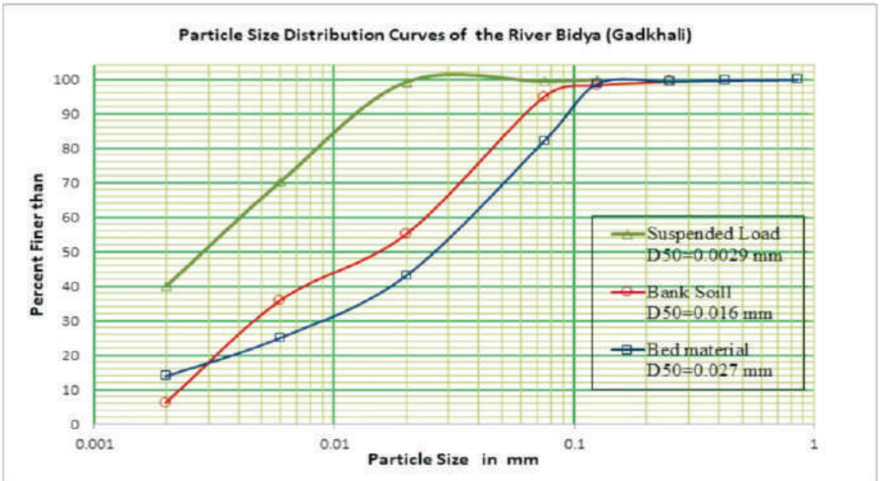

Fig.9. Particle Size Distribution of Sediments of the Bidya River

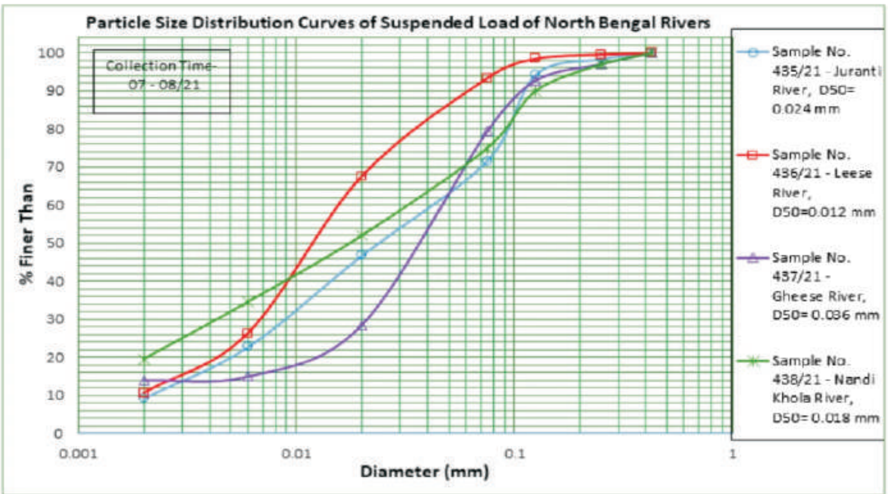

Fig.10. Particle Size Distribution of Suspended Loads of North Bengal Rivers

Table-1. Details of the Bed and Suspended Loads of Different Rivers

River	Site	Bed Load			Suspended Load		
		Rate of movement kg/m/hr	Description	D_{50} mm	Silt intensity mg/L	Description	D_{50} mm
Karru (Monsoon, 2017)	Proposed Dam Site, Bagmundi, Purulia	12.0	Brownish Fine to medium Sand with some coarse Sand and Fine Gravel **(100/0/0)	0.17	20 – 750	Brownish loam to sandy silt with some Clay (42/44/14) TDS: 100 – 200 mg/L	0.052
Damodar (Monsoon, 2016 - 17)	Raniganj,	34.5	Med to Fine sand 100/0/0)	0.43			
	Durgapur Barrage		(96/4/0)	0.26	60 – 100	Brownish loamy Sand (59/33/8) TDS: 120 – 340 mg/L	0.105
Kangsabati (Monsoon, 2012 -16)	Bifurcation Point. Kapastikri, Paschim Medinipur	15.0	Yellowish brown uniform medium to fine sand (100/0/0)	0.265	250 – 500	Yellowish brown loam to sandy Silt with some Clay (44/47/9) TDS: 100 – 200 mg/L	0.054
Hooghly, (Pre-monsoon, 2014, March)	Chandannagar, Hooghly	--	Grey micaceous uniform fine sand (99/1/0)	0.21	120 – 310 (2014)	Grey loamy fine Sand (62/30/8) TDS: 76 – 528 mg/L	0.105
Muriganga (Pre-monsoon, 2021, March)	Jetty Site, Kachuberia, Sagar, South 24 Parganas	--	Grey – Dark Grey Clayey Loam (17.8/70/12.2)	0.038	100 – 120	Grey – Dark Grey Silty Clay (0/55/45) TDS: 24350 mg/L (12900 – 35530)	0.0027
Bidya (Post-monsoon, 2021, January)	Proposed Bridge Site, Gadkhali, South 24 Parganas	--	Grey – Dark Grey Clayey Silt or Loam (17.8/68.2/14)	0.027	100	Grey – Dark Grey Silty Clay (1/59/40) TDS: 15000 mg/L	0.0029
Rupnarayan (Pre-monsoon, 2022, April-May)	Hydrological Study regarding dredging proposal Purba Medinipur		Grey Clayey Silt (4/91/5)	0.035	105	Grey Silty Clay (4/58/38) TDS: Avg. 508 mg/L (123 – 1805)	0.0072

** (sand or gravel and sand / silt / clay)

Table-2. Analysis of Water Samples of the Rivers / Tidal Channels at Gadkhali

River / Channel	Depth	Suspended Load (mg/L)		Total Dissolved Solids (mg/L)
		Avg. Value	Range	
Bidya	0.2D	44.6	34 – 73.6	15306
	0.5D	54.4	31.8 – 106.8	
	0.8D	62.2	35.2 – 113.0	
Karatal	0.2D	78.2	39 – 151.4	13588
	0.5D	87.8	26.8 – 196.4	
	0.8D	89.4	34 – 188.4	
Durgadoyani	--	--	--	16760
	0.5D	57.4	--	
	--	--	--	

D – Depth of the Channel at the point

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MODEL STUDY FOR DETERMINATION OF EFFICIENCY OF A SILT EJECTOR UNDER TEESTA BARRAGE PROJECT

M. Bardhan[1] and S. Chattopadhyay[2]

Synopsis

After construction of a barrage in the main river Teesta in West Bengal, the off taking channel from one of its bank was designed to carry water and augment the discharge of a secondary river Mahananda. The discharge of the main river was heavily laden with silt. To control the quantity of silt, a Silt Ejector was proposed to be constructed in Teesta Mahananda Link Canal for getting silt-free water for irrigation. The design discharge of the canal upstream and downstream of the Silt Ejector was 438.91 cumecs and 382.28 cumecs respectively and the discharge through the Silt-Ejector was 56.63 cumecs. A geometric model of scale 1:36 was constructed in Indoor Hydraulics Laboratory on the basis of design drawings. The model incorporated about 500 m long stretch, about 400 m upstream and about 100 m downstream of the Silt Ejector. In the model, the Silt-Ejector structure was made of thin Perspex sheets. The model was run with the design discharge and with discharges 70%, 50% and 30% of the design discharge. Four nos. of gauges were installed in the model at 360 m upstream, 75 m upstream, 22 m downstream and 100 m downstream of the Silt Ejector. Another gauge was installed in the escape channel. Velocity observations were taken at 324 m upstream, near the upstream face of the Silt Ejector and 80 m downstream point of the Silt Ejector. The observed model data were validated with respect to prototype data. Mustard seeds were used as silt-charge. The entire quantity of mustard seeds passed through the Silt Ejector into the Escape Channel for all discharges, except that of the 30% design discharge. This indicated that the efficiency of the Silt Ejector was good and satisfactory except for low discharge of the order of 30% of design discharge. No undesirable flow features were noticed at the entry of the Ejector.

Keywords : Silt Ejector, Escape Channel, Geometric Model, Mustard Seeds

1. INTRODUCTION

Normally Silt Excluder is used for exclusion of silt. But it was not feasible for Teesta Barrage under prevailing field condition. As such, Silt Ejector was preferred and it was first of its kind in West Bengal. To control the quantity of silt, a silt ejector was proposed to be constructed in the Teesta Mahananda Link Canal. The design discharge of the canal upstream and downstream of the Silt Ejector was 438.91 cumecs and 382.28 cumecs respectively and the discharge through the Silt-Ejector was 56.63 cumecs. The discharge passing through the Silt Ejector was to fall on the main river downstream of the barrage. It was proposed by the authorities to carry out hydraulic model experiments to study the hydraulic performance of the Silt Ejector. The problem was referred to River Research Institute, West Bengal for model study. The model study was performed and necessary report was submitted. After detailed study, it can be said that the above report is still valid today with some modifications.

1. Director, River Research Institute, West Bengal.
2. Assistant Research Officer, River Research Institute, West Bengal.

2. RELATED WORK

Marala Ravi (MR) Link Canal, Sialkot, Pakistan is a big canal which originates from River Chenab at Marala Barrage. It faces severe problem of silt deposition on the bed of canal due to high silts and sediment discharge entering into the canal. The improvement measures were identified separately for Marala Barrage and MR Link canal. Provision of Silt Ejector was studied in a scale model by Irrigation Research Institute (1988). Chohan (1986) carried out a comprehensive review of the problems in MR Link canal. Ahmad et al.(1960) discussed different sediment exclusion methods and devices at the intake of canals. It was established by various experiments that an off take from a straight channel would draw greater proportion in its water than its due share depending on the discharge extraction ratio and the angle of twist. The excluders were tested for full supply discharge in power tunnel and the river discharge equal to 100,000 cusecs. It was envisaged that an excluder of ejector type or vortex excluder would be efficient for exclusion of coarse silt from power tunnel. King (1933) reported that silt carrying capacity of fluid at any point depended on difference in velocity of filaments of flow just above and below the point. A small obstruction over the bed throws up the silt which fall backs and is thrown up again. This motion of silt particle is terms as siltation and depends on the bed roughness, velocity and particle size. Raju and Kothyari (2004) explained the design principles of two kinds of sediment withdrawal methods namely settling basins and vortex chambers. They accomplished that the vortex chamber with high efficiency as compared to settling basin would require small flushing discharge. The negative aspect of vortex chamber is that it is suitable for small channels only. Tiwari et al. (2018) reported that Vortex tube ejector may be used to extract sediments from canal. According to their observation, it is economical method of sediment control by ejecting the sediment loaded bottom layer of flow in the channel Sediment-laden water from the near-bed layer is drawn into vortex tube ejector and taken out through the escape canal which joins the sediment-laden water to the river downstream of diversion head works. Bardhan (2022) discussed about the model study on silt ejector for determination of its efficiency.

3. JUSTIFICATION FOR HYDRAULIC MODEL STUDY

There are many unknown factors in the design of silt ejector such as the capacity of the silting basin in the approach channel, layout of the sub-tunnels and main tunnels, flushing velocity for the particular characteristics of the sediment to be ejected, and flow pattern of the bottom layers of the discharge, etc. As such it is essential that the layout based on the theoretical design be checked by model studies to ascertain the efficiency of the silt ejector.

4. DESIGN DATA OF THE SILT EJECTOR

Lay out plan of the Silt Ejector is shown in Fig 1. Design data of the Silt Ejector and Escape Channel are mentioned in Table 1. Four nos. of main tunnel and twelve nos. of sub-tunnel are there in the Silt Ejector Structure. Each main tunnel consists of three sub-tunnels. Dimension of the main tunnel is 2.1 m x 2.1 m and dimension of the sub-tunnel is 2.80 m x 0.98 m. Length of the Escape Channel is 874 m. Design discharge of the Silt Ejector is 438.91 cumec and design discharge of the Escape Channel is 56.68 cumec.

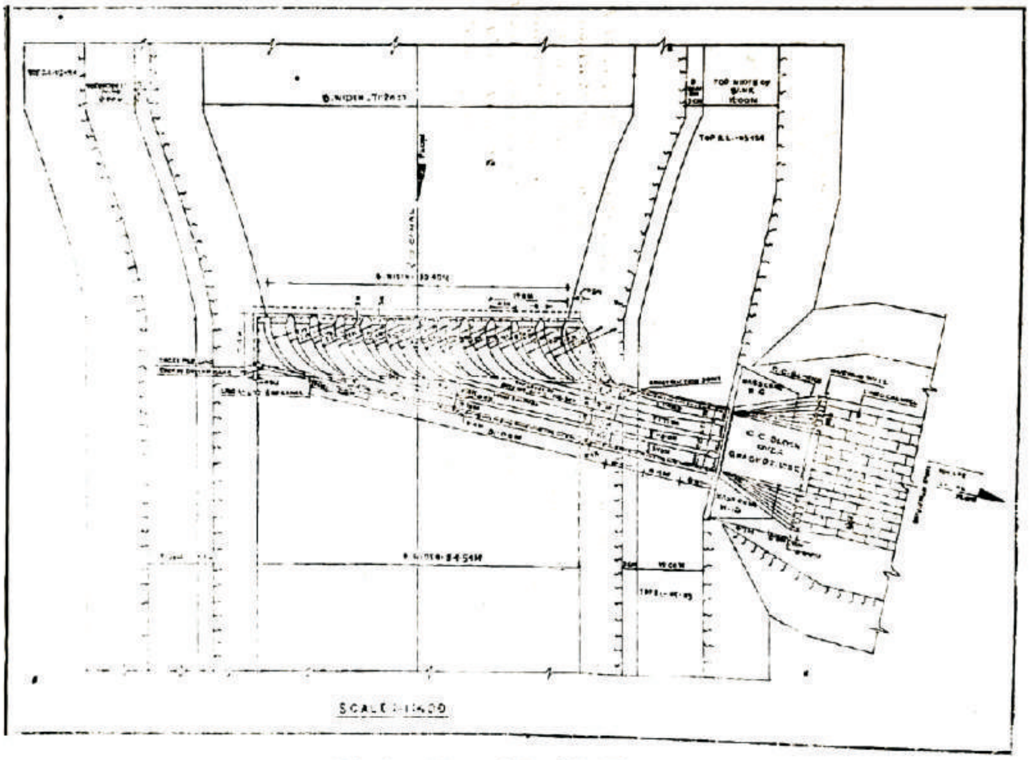

Fig 1 : Plan of the Silt Ejector

Fig 1 : Plan of the Silt Ejector

Table 1 : Design Data of Silt Ejector and Escape Channel of Teesta Mahananda Link Canal under Teesta Barrage Project

Sl. No.	*Details of the Item*
1.	*No. of Main Tunnel = 4*
2.	*No. of Sub-Tunnel =12 (Each main tunnel consists of 03 Sub-Tunnel)*
3.	*Dimension of Main Tunnel = 2.1m x 2.1m*
4.	*Dimension of Sub-Tunnel = 2.80m x 0.98m*
5.	*Off take of Silt Ejector = 0.700 km of T.M.L.C.*
6.	*Length of Escape Channel = 874 m*
7.	*Design Discharge of Escape Channel = 56.68 m^3/sec*
8.	*Bed width of Escape Channel = 9.60 m with 1.5 : 1 side slope*
9.	*Total width of the Silt Ejector at mouth in the T.M.L.C. = 54.54 m*

5. HYDRAULIC MODEL

The model was constructed inside the Indoor Hydraulics Laboratory and the model was constructed on the basis of design drawings. A geometrically similar model of scale 1: 36 was constructed. The model incorporated about 500 metres long stretch of the Link Canal, the reach covered a length of about 400 metres upstream and about 100 metres downstream of the Silt Ejector. Due to shortage of space, the Escape Channel was reproduced for a length of about 30 metres only. The water was supplied to the model through a re-circulating water supply system. The required discharge was measured over a rectangular sharp crested weir and fed into the canal through a stilling basin. Silt traps were provided on the downstream of the canal and also at the downstream ends of the Escape Channel. Four nos. of gauges were installed at 360 m upstream (G_1), 75 m upstream (G_2), 22 m downstream (G_3) and 100 m downstream (G_4) of the proposed Silt Ejector. One gauge G_5 was provided at a place about 12 m from the start of the Escape Channel, about 22 m from the exit of the Silt ejector tunnel. In the model, the Silt Ejector structure was made of thin Perspex sheets.

6. OBSERVATIONS

A discharge equivalent to 438.91 cumecs was passed through the model. The downstream canal gauge G_4 was maintained at the design value of 115.588 m with the help of the downstream control gate. The gauge G_5 of the Escape Channel was maintained at the design value of 112.174 m by controlling the downstream gate of the Escape Channel. Gauge readings of G_1, G_2 and G_3 were observed. Model gauge readings were 113.808, 113.698 and 113.643 metres whereas the computed gauge readings from the design data supplied were 113.731, 113.631 and 113.610 metres respectively. The velocities observed at 324 m upstream of the Silt Ejector are presented in Table 2, 3 and in Fig 2. The average velocity of the whole section near G_1 comes to about 2.088 m / sec whereas the design value is 2.013 m / sec. The velocities observed at 80 m downstream of the Silt Ejector are presented in Table 4, 5 and in Fig 3.. The velocities observed at the face of the sub-tunnels are presented in Table 6, 7, 8, 9 and in Fig 4.. Both surface flow lines and bed flow lines of the canal were taken from about 45 m upstream of Silt Ejector to 22 m downstream of the sub-tunnel entrance. These are presented in Fig 5. No undesirable flow features were noticed at the entry of the Silt Ejector. No eddies or vortices were observed. The flow was tranquil and smooth in all cases. Canal cross-sections at 324 m upstream of the Silt Ejector and 80 m downstream of the Silt Ejector are shown in Fig. 6 and Fig. 7 depicting verticals of velocity observation. Photograph of the Silt Ejector Model is shown in Fig 8.

6.1 Escape Discharge

The discharge passing through the Silt Ejector into the Escape channel was measured volumetrically and they reasonably agreed with the design discharge. The measured model discharge corresponds to about 61.71 cumecs as against the design discharge of 56.63 cumecs. In order to measure the discharges passing through the individual tunnels separately, water was allowed to flow through each tunnel closing the other three tunnels at the end. Due to this closure, there was a rise of water level in the main canal model. However it indicates that with a particular canal water level, the discharge through each of the tunnels was reasonably the same.

6.2. Silt Movement

The bed load transport was simulated in the model by injection of mustard seeds. Mustard seeds were injected at a section 380 metres upstream of the Silt Ejector. The entire quantity of the mustard seeds passed through the Silt Ejector into the Escape Channel. The same experiments were repeated with plastic balls which rolled along the bed and the same result was observed. The mechanism of suspended sediment transport and deposition was not included in the present study.

7. MODEL RUN WITH DISCHARGES LOWER THAN DESIGN DISCHARGE

Considering the fact that for a part of the year, the canal may have to run with discharges lower than the design discharge, it would be of interest to know the discharge passing through the Silt Ejector and the indication of bed load movement. The model was run with discharges 70%, 50% and 30% of the design discharge (438.91 cumecs) which were discharges of 307.24 cumecs, 219.46 cumecs and 131.67 cumecs respectively. The discharges passing through the Silt Ejector tunnels for discharges 70%, 50% and 30% of the design discharge were about 46.24 cumecs, 33.94 cumecs and 18.54 cumecs respectively. Mustard seeds were injected as bed materials and in all cases except very low discharge of the order of 30% of the design discharge, entire quantity of the injected materials passed out of the Silt Ejector Sub-tunnels. In case of 30% design discharge, the injected materials were observed to get accumulated in front of the Silt Ejector sub-tunnels. Even if they were pushed inside the sub-tunnels, they were not easily moving out. This phenomenon may be attributed to low average bed velocity in front of the sub-tunnels. The flow was smooth in all cases.

8. DISCUSSION

It was seen that the water surface slope in the canal was fairly reproduced in the model. The discharge passing through the tunnels reasonably agreed with the design discharge of 56.63 cumecs. Experiments with mustard seeds and plastic balls as bed load showed that ejection by the Silt Ejector is satisfactory in all cases except for very low discharge of the order of 30% of the design discharge. No undesirable flow features were observed at the entry of the Ejector.

9. CONCLUSIONS

The following conclusions are drawn from the present study.

i. Efficiency of the Silt Ejector is satisfactory in all the cases except for very low discharge of the order of 30% of design discharge. The efficiency of the Silt Ejector is calculated for bed load primarily. It will also be indicative for suspended load.

ii. The difference in water level in the canal upstream of the Silt Ejector and the outfall channel at the exit of the ejector tunnel should be sufficient to extract the desired sediment. A working head of about 1 m is generally considered satisfactory for the purpose.

iii. The quantum of discharge to be run through sediment ejector and frequency of its operation would vary in different periods of the year depending on the sediment load carried in the canal and this may be achieved by operating regulating gates as and when required. It would be desirable to operate the gates fully open or fully closed.

iv. A velocity of 2.43 m / sec (8 ft/sec) to 3.048 m /sec (10 ft/sec) through the tunnel is adequate to move sand size sediments.

v. An escape discharge equal to 10 to 20 percent of the full supply discharge of the canal downstream of the ejector will be sufficient for removal of silt load. The escape channel is given a steeper slope so that the silt is discharged back to the river through the shortest route.

vi. The height of tunnel should be 20 to 25% of the design depth of water in canal.

vii. During the period when sediment ejector is not required to function, it is desirable to operate the regulation gates occasionally for short periods to flush the tunnels consistent with the economy in water requirements for irrigation. Otherwise, the tunnels are likely to get choked and may require manual clearance which may be possible only during closure of the canal.

viii. At times during the normal operation of the sediment ejector, the approach channel and / or tunnels or both may require flushing. This may be done by running the tunnels in rotation to achieve higher velocities.

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Table 2 : Velocity distribution in the canal at 324 m upstream of the Silt Ejector with design discharge 438.91 cumecs

Velocity in m / sec	Vertical numbers from Left to Right (vide Fig. 3) 1	2	3	4	5	Average velocity in m / sec
Bed velocity	1.681	1.879	1.879	1.879	1.879	1.839
Velocity at 0.6 depth	2.059	2.224	2.143	1.783	2.143	2.07
Surface velocity	2.377	2.521	2.45	1.971	2.45	2.354
Mean velocity						2.088

Table 3 : Velocity at 0.6 depth in the canal at 324 m upstream of the Silt Ejector with different canal discharges

Discharge in cumecs	Vertical numbers from Left to Right (vide Fig. 3) 1	2	3	4	5	Average velocity in m / sec
307.24 (70% of design discharge)	1.97	2.057	2.057	2.057	1.97	2.022
219.46 (50% of design discharge)	1.878	1.878	1.97	1.97	1.878	1.915
131.67 (30% of design discharge)	1.97	1.878	1.782	1.782	1.571	1.797

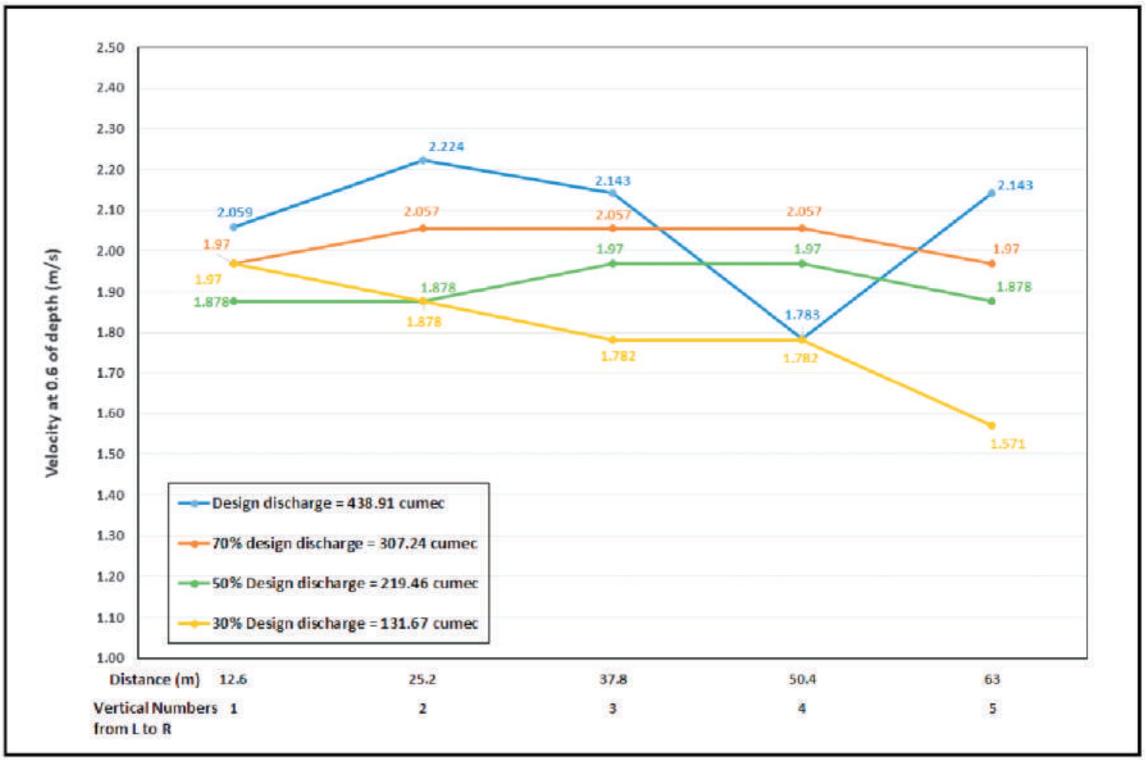

Fig.2. Velocity Distribution at 324 m upstream of the Silt Ejector

Table 4 : Velocity distribution in the canal at 80 m downstream of the Silt Ejector with design discharge 438.91 cumecs

Velocity in m / sec	Vertical numbers from Left to Right (vide Fig. 4)					Average velocity in m / sec
	1	2	3	4	5	
Bed velocity	1.681	1.681	1.681	1.681	1.681	1.681
Velocity at 0.6 depth	1.879	1.971	1.879	1.879	1.879	1.897
Surface velocity	2.224	2.224	2.224	2.143	2.143	2.192
Mean velocity						1.923

Table 5 : Velocity at 0.6 depth in the canal at 80 m downstream of the Silt Ejector with different canal discharges

Discharge in cumecs	Vertical numbers from Left to Right (vide Fig. 4) 1	2	3	4	5	Average velocity in m / sec
307.24 (70% of design discharge)	1.878	2.057	2.057	1.97	1.878	1.968
219.46 (50% of design discharge)	1.878	1.878	1.782	1.782	1.571	1.778
131.67 (30% of design discharge)	1.571	1.571	1.571	1.571	1.571	1.571

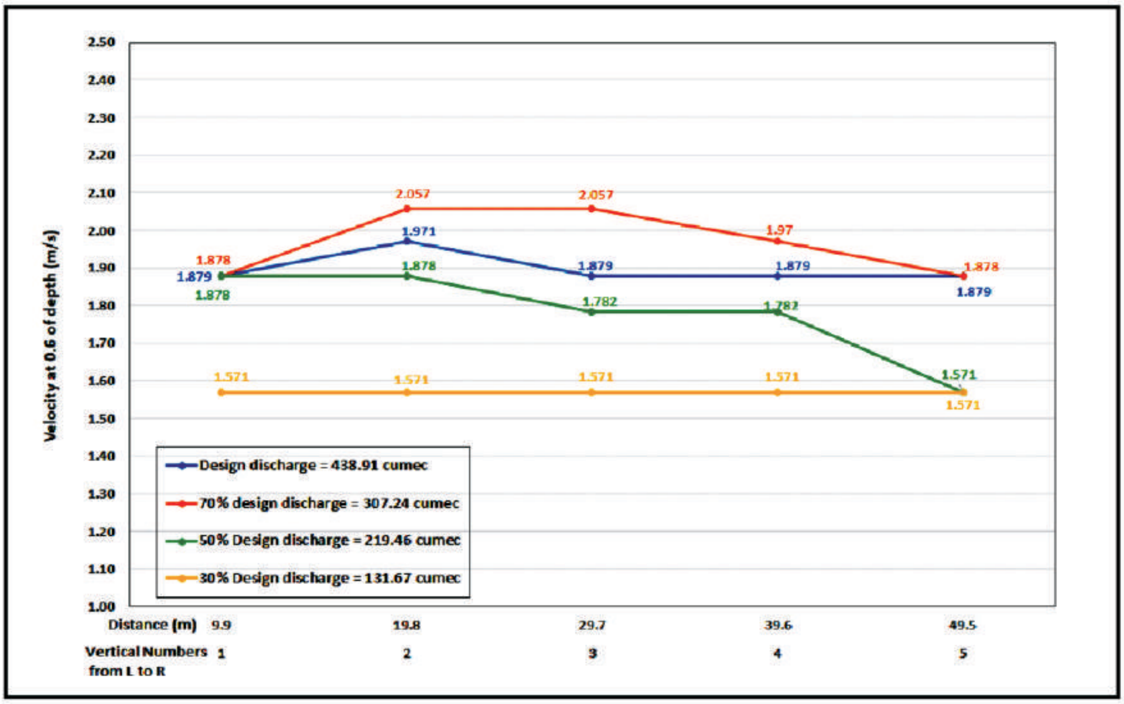

Fig.3. Velocity Distribution at 80 m downstream of the Silt Ejector

Table 6 : Observation of velocities at the upstream face of the Silt Ejector Sub-tunnels with design discharge of 438.91 cumecs in the canal upstream of the Silt Ejector (velocities were observed at 3.6 m upstream of the face of the Silt Ejector)

Velocity in m / sec	Sub-tunnel numbers (from Left to Right)												Average velocity in m/sec
	1	2	3	4	5	6	7	8	9	10	11	12	
Bed velocity	1.57	1.46	1.57	1.46	1.33	1.33	1.46	1.33	1.33	1.33	1.46	1.46	1.424
Velocity at 0.6 depth	1.78	1.78	1.78	1.68	1.68	1.78	1.88	1.78	1.68	1.78	1.68	1.78	1.755
Surface velocity	1.97	1.97	1.97	1.97	1.88	1.97	1.97	1.97	1.88	1.88	1.88	1.97	1.94
Mean velocity													1.706

Table 7 : Velocities at the upstream face of the Silt Ejector Sub-tunnels with discharge 307.24 cumecs (70% of design discharge) in the canal upstream of the Silt Ejector (velocities were observed at 3.6 m upstream of the face of the Silt Ejector)

Velocity in m / sec	Sub-tunnel numbers (from Left to Right)												Average velocity in m/sec
	1	2	3	4	5	6	7	8	9	10	11	12	
Bed velocity	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.11	1.11	1.33	1.33	1.33	1.12
Velocity at 0.6 depth	1.78	1.78	1.78	1.68	1.68	1.78	1.88	1.78	1.68	1.78	1.68	1.78	1.76
Surface velocity	1.97	1.97	1.97	1.97	1.88	1.97	1.97	1.97	1.88	1.88	1.88	1.97	1.94
Mean velocity													1.61

Table 8 : Velocities at the upstream face of the Silt Ejector Sub-tunnels with discharge 219.48 cumecs (50% of design discharge) in the canal upstream of the Silt Ejector (velocities were observed at 3.6 m upstream of the face of the Silt Ejector)

Velocity in m / sec	Sub-tunnel numbers (from Left to Right)												Average velocity in m/sec
	1	2	3	4	5	6	7	8	9	10	11	12	
Bed velocity	1.19	1.03	1.11	1.03	1.03	1.03	1.03	0.94	0.94	0.94	0.94	1.03	1.02
Velocity at 0.6 depth	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.11	1.11	1.11	1.11	1.11	1.16
Surface velocity	1.33	1.33	1.33	1.26	1.33	1.33	1.26	1.26	1.26	1.26	1.26	1.26	1.29
Mean velocity													1.16

Table 9 : Velocities at the upstream face of the Silt Ejector Sub-tunnels with discharge 131.67 cumecs (30% of design discharge) in the canal upstream of the Silt Ejector (velocities were observed at 3.6 m upstream of the face of the Silt Ejector)

Velocity in m / sec	Sub-tunnel numbers (from Left to Right)												Average velocity in m/sec
	1	2	3	4	5	6	7	8	9	10	11	12	
Bed velocity	1.11	1.03	1.03	1.03	1.03	1.03	1.03	0.94	0.94	0.94	0.94	0.94	1.00
Velocity at 0.6 depth	1.19	1.19	1.19	1.19	1.19	1.19	1.11	1.03	1.11	1.11	1.19	1.11	1.15
Surface velocity	1.19	1.26	1.26	1.33	1.33	1.26	1.19	1.19	1.19	1.26	1.26	1.19	1.24
Mean velocity													1.13

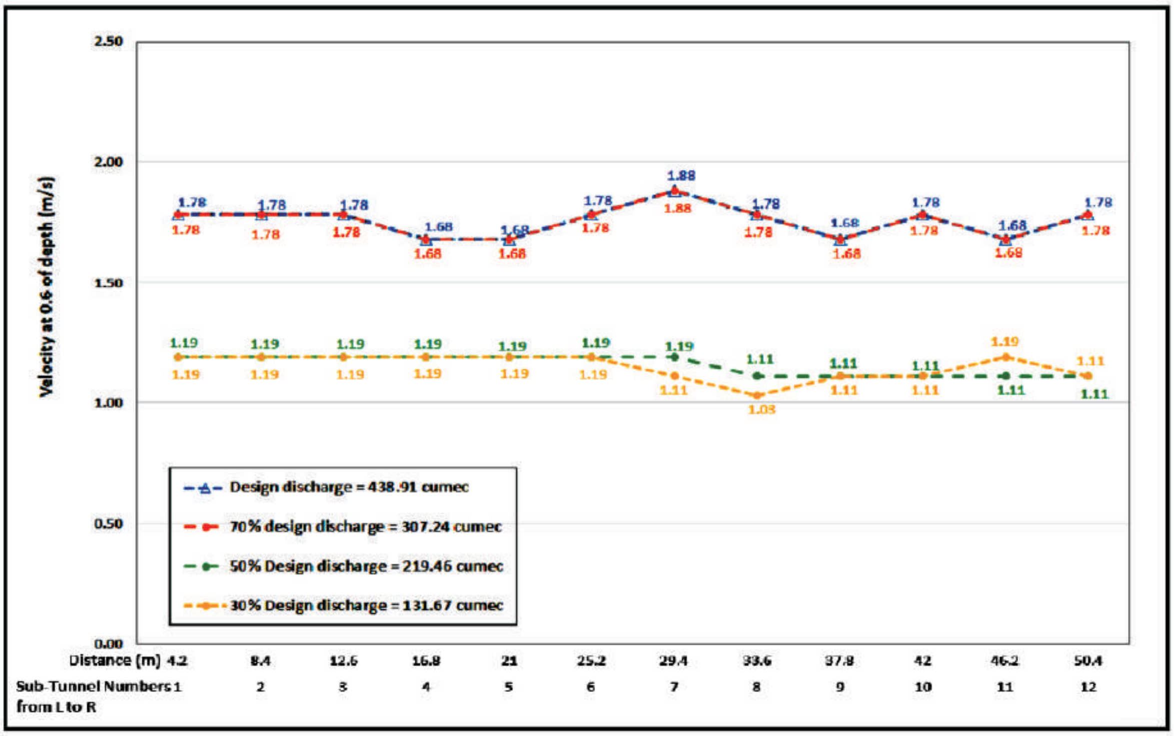

Fig.4. Velocity Distribution in Sub-Tunnel at 3.6 m upstream of face of the Silt Ejector

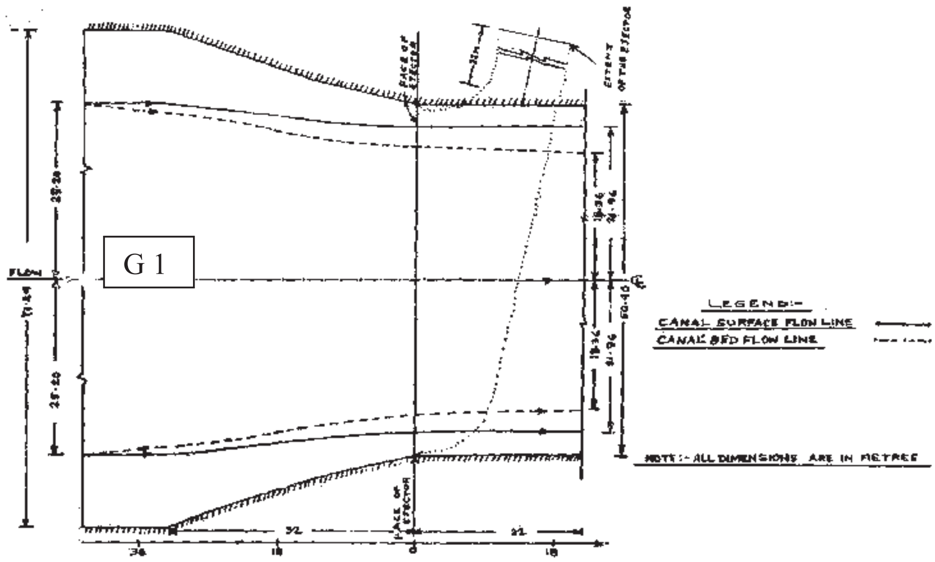

Fig 5 : Canal surface and bed flow-lines for canal discharge 438.91 cumecs

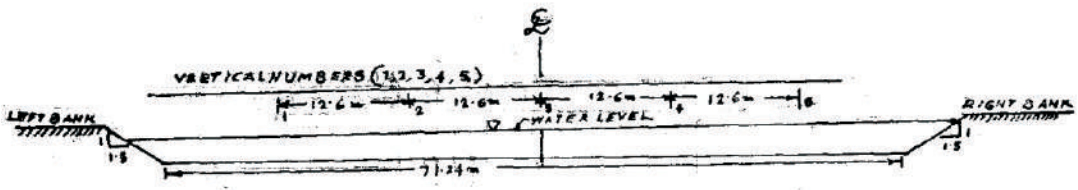

Fig 6 : Canal cross-section at 324 metre upstream of Silt Ejector

Fig 7 : Canal cross-section at 80 metre downstream of the Silt Ejector

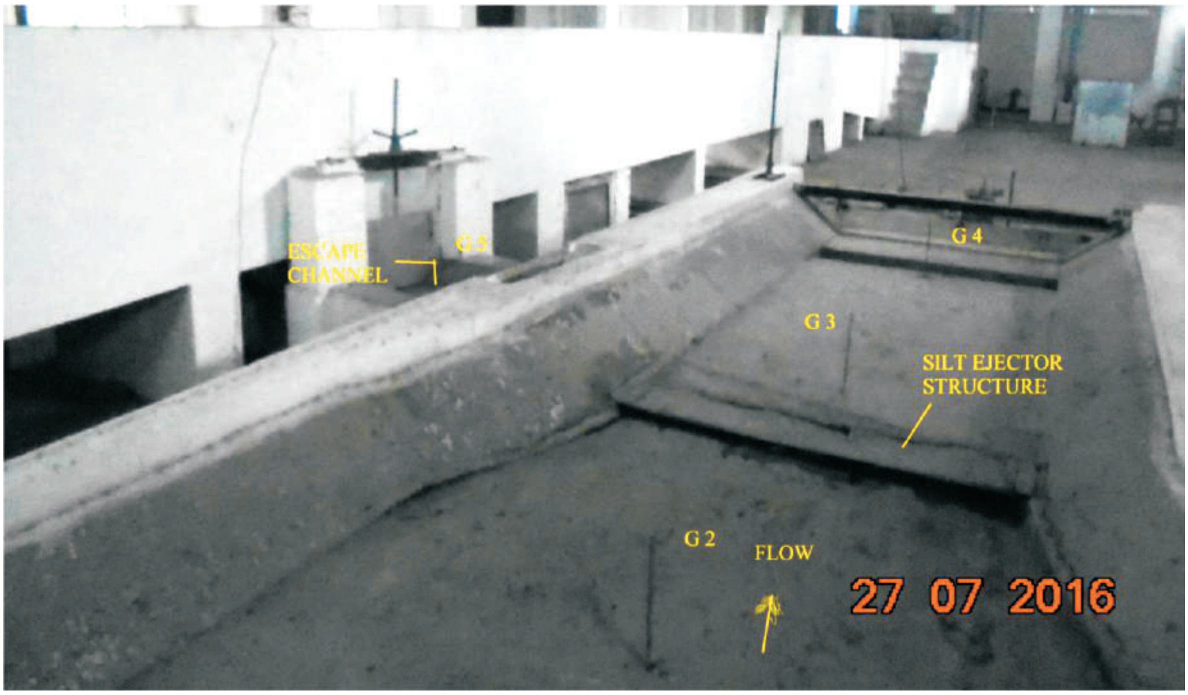

Fig 8 : Photograph of Silt Ejector Model

A Revisit to Indian Ocean Tsunami 2004

M. Bardhan[1]

Synopsis

On 26th December 2004, the South Asian countries along the Indian Ocean were hit by giant tsunami, the deadliest in modern history. It was triggered by a massive undersea earthquake, measuring 9.0 on the Richter scale, with its epicentre off the coast of Sumatra, Indonesia. The devastating earthquake occurred as thrust faulting on the interface of the Indian Plate and Burma Plate. In a period of minutes, the faulting released elastic strain that had accumulated for centuries from ongoing subduction of the Indian plate beneath the overriding Burma micro plate. In India, the Andaman and Nicobar islands were the worst hit though the coastal morphology of eastern peninsular India also changed. The brunt of the attack was borne by the coral reef eco-system, which in most cases helped reduce the impact on land. Most of the coral reefs in the Great Nicobar Island have been reduced to rubbles. Sand and silt are deposited on the reefs choking them. Many reef dependent species have lost their habitat and their breeding cycles have been disrupted. The massive sea ingress and their submergence of Nicobar's coastal flat lands have uprooted several corals, increased water turbidity and destroyed habitats. In tsunami warning system, Data based Tsunameter plays an important role in disaster management and crisis prevention. The effective application of this equipment is influenced by factors such as data collection, processing, distribution, capacity building, institutional development and information sharing. Present paper reports about the formation and characteristics of the tsunami that occurred on December 26, 2004 in Indonesia. Some important information regarding the above tsunami is presented here.

Keywords: Tsunami, Coastal Morphology, Tsunami Warning System, Tsunami Run-up

1. Introduction

The word Tsunami is from Japanese. Tsu means harbour and nami means waves. The phenomenon of tsunami is a series of large sea waves of extremely long wavelength that are generated by a violent, impulsive under-sea disturbance or activity near the coast or in the ocean. During sudden displacement of sea floors, the relative movement produces large tremors resulting in the generation of Tsunamis. Tsunamis can be generated due to other non-seismic disturbances such as violent volcanic eruptions or underwater landslides. Gravity will also have an impact on the generated waves. Tsunamis characterised as distant and local depends on distance they travel, period required, amplitude and frequency of waves and the extent of damages they can cause. The velocity of the generated waves is found to be proportional to the depth of water and gravitational acceleration. Fig. 1 depicts a tsunami hitting the coastline. Fig. 2 depicts fourteen countries affected due to Indian Ocean Tsunami 2004.

1. Director, River Research Institute, West Bengal.

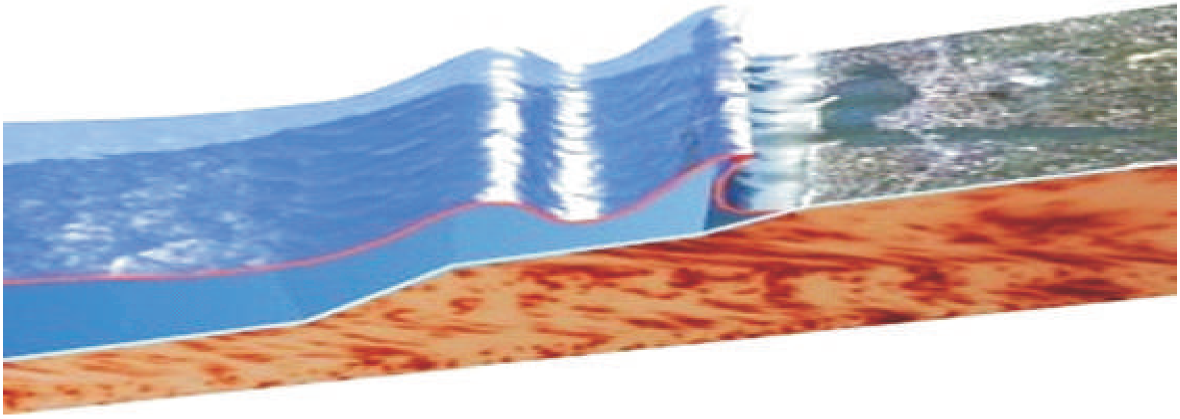

Fig 1 : A tsunami hitting the coastline

Fig 2 : Countries affected due to Indian Ocean Tsunami December 2004.

1. Literature Study

Mohd. Athar (2005) discussed about the formation and characteristics of the Indian Ocean Tsunami that occurred on December 26, 2004. He suggested some preventive and precautionary measures also. V. Sundar (2005) reported regarding generation, propagation and effects of tsunami. He suggested steps for effective management after tsunami with particular reference to coastal erosion. Basavarajappa and Prakash (2005) discussed regarding origin, characteristics and damages of tsunamis. Jagadeesh, Kumar and Nagesh (2005) discussed regarding cause, effect and preparedness of tsunami. They discussed necessity of early warning system for prediction of tsunami. Kurian and Prakash (2005) discussed the impact of Indian Ocean Tsunami 2004 on the Kerala Coast. Kudale (2005) discussed regarding the interaction of tsunami with coastline. He reported behaviour of coastline and performance of the existing seawalls / breakwaters along the Indian Coast during the Indian Ocean Tsunami December 2004.

2. Origin of a Tsunami

When two plates come into contact at the plate boundary and collide, heavier plate can slip under a lighter one known as subduction. Later it leaves enormous hand print in the form of a deep oceanic trench along the sea floor. Sometimes this subduction zone of the sea floor connected to the lighter plate may snap-up suddenly due to pressure from the sinking plates which results in the generation of earthquakes. When some of the pieces of the plates snaps up and shoots rocks upwards with tremendous forces, the energy of those forces is transferred to the water. This energy pushes the water upward above normal sea level resulting in the birth of tsunamis.

The main causes of tsunamis are : -

i) **Earthquake** : The most destructive tsunamis that are generated from large shallow earthquakes with an epi-centre or fault line near or on the ocean floor is usually occur in regions of the earth characterized by large tectonic subduction zones along the tectonic boundaries. When the two major tectonic plates collide against each other, the rocks break which displace large areas of the ocean floors from a few kilometres to thousand kilometres or more. The sudden vertical displacement over such large areas disturbs the ocean floor and displaces water generating destructive tsunamis.

ii) **Volcanic eruptions** : The volcanic eruptions which are relatively uncommon also represent impulsive disturbances that can displace a great volume of water and generate gigantic waves in the immediate vicinity.

iii) **Submarine landslides, rock fall and underwater slumps** : The tsunami waves can be generated from displacement of water resulting from rock fall, ice fall and sudden submarine landslides or slumps. Such events may be triggered impulsively from the instability and sudden failure of submarine slopes, which are sometimes caused by ground motions of strong earthquakes.

4. Tsunami Characteristics

Tsunamis are characterized as shallow-water waves. These shallow-water waves are different from wind-generated waves. Wind-generated waves usually have period of five to twenty seconds and a wavelength of about 100 to 200 meters. A tsunami can have a period in the range of ten minutes to two hours and a wavelength in excess of 500 km. It is because of their long wavelengths that tsunamis behave as shallow-water waves. A wave is characterized as a shallow-water wave when the ratio between the water depth (d) and its wavelength (L) gets very small ($d/L < 0.5$). The speed (C) of a shallow-water wave is equal to the square root of the product of the acceleration of gravity (g) and the depth of the water.

$$C = \sqrt{gd}$$

One can note that the speed of a tsunami wave thus does not depend on the wave length or its energy level. The rate at which a wave loses its energy is inversely related to its wavelength. Since a tsunami has a very large wavelength, it will lose little energy as it propagates. Hence in very deep water, a tsunami will travel at high speeds and travel great transoceanic distances with minimum energy loss.

5. Movement of Tectonic Plates in the context of December 2004 Tsunami

The 2004 Indian Ocean earthquake was unusually large in geographical and geological extent. An estimated 1,600 km of fault surface slipped about 15 m (50 ft) along the subduction zone where the Indian Plate slides or sub-ducts under the overriding Burma Plate. The slip did not happen instantaneously but took place in two phases over several minutes. The Indian Plate is part of the great Indo-Australian Plate, which underlies the Indian Ocean and Bay of Bengal, and was moving north-east at an average of 60 mm/annum. The India Plate meets the Burma Plate, which is considered a portion of the great Eurasian Plate, at the Sunda Trench. At this point, the India Plate sub-ducted beneath the Burma Plate, which carried the Nicobar Islands, the Andaman Islands, and northern Sumatra. Due to sideways movement between the plates, the 2004 Indian Ocean earthquake resulted in a rise of the seafloor by several metres, displacing an estimated 30 km^3 of water and triggering devastating tsunami waves. The raising of the seafloor significantly produced a permanent rise in the global sea level by an estimated 0.1 mm (Roger Bilham 2005).

Some of the major tsunamis in the past are presented in Table – 1.

Table 1 : Major Tsunamis of the World

SL No.	Year	Location	Causes	Causalities
1.	1755	Lisbon, Portugal	An earthquake, the subsequent tsunami and fires	Wiped out more than one third of Lisbon population
2.	1883	Indonesia	Eruption of Island volcano of Krakatoa, caused a series of large tsunamis waves rising up to 40 m above sea level	
3.	1908	Italy	A tidal wave created by a major earthquake	Totally washed away Messina, Reggio, Calabria and dozens of nearby towns
4.	1946	Pacific Ocean	The Aleutian Island earthquake tsunami	About 165 people were killed in Hawaii and Alaska
5.	1960	Chile	The largest ever Great Chilean Earthquake at a magnitude of 9.5 off the coast of Chile, generated waves measuring up to 25 m high across the entire Pacific Ocean	
6.	1964	Alaska (USA)	Good Friday Earthquake of Magnitude 9.2	Struck Alaska, British, Columbia, California and coastal Pacific Northwest towns
7.	2004	Indonesia	Earthquake of Magnitude 9.0	The 2004 Indian Ocean earthquake triggered a series of tsunamis on 26 December 2004 that devastated coastlines surrounding the Indian Ocean killing an estimated 227,898 people.
8.	2011	Pacific coast of Japan	Earthquake of Magnitude 9.1	On 11 March, 2011, an earthquake of magnitude 9.1 produced (10 m) high tsunami.

6. Indian Ocean Tsunami of 26 December 2004

On 26th December 2004, the South Asian countries along the Indian Ocean were hit by giant tsunami, the deadliest in modern history. It was triggered by a massive undersea earthquake, measuring 9.0 on the Richter scale, with its epicentre off the coast of Sumatra, Indonesia. This greatest earthquake was the 4th largest one since 1900 and largest since 1964 Alaska earthquake. The devastating earthquake occurred as thrust faulting on the interface of the Indian Plate and Burma Plate. In a period of minutes, the faulting released elastic strain that had accumulated for centuries from ongoing subduction of the Indian plate beneath the overriding Burma micro plate. The epicentre of this earthquake was near the triple junction of three tectonic plates where major earthquakes and tsunamis occurred in the past. An estimated 1200 km of faultline slipped 15 m (50 ft) along the subduction zone where the Indian Plate dives under the Burma Plate. This formed a shock wave in the Indian Ocean, creating tsunamis that travelled at up to 800 km/hour. Tens of thousands were killed by the resulting tsunamis, which were as high as 10 m and struck between 15 minutes and 3 hours after the quake, causing one of the most cataclysmic disasters in modern history. The multiple tsunamis struck and ravaged coastal regions all over the Indian Ocean, devastating regions including the Indonesian province of Aceh, the coast of Sri Lanka, coastal areas of the Indian state of Tamil Nadu, the resort island of Phuket, Thailand and even as far away as Somalia and several other countries in Africa, 4500 km or more west of the epicentre as depicted in Fig 3, Fig 4, Fig 5, Fig 6 and Fig 7.

Fig 3 : An aerial view of a destroyed and flooded village after waves hit following an earthquake near the provincial capital of Banda Aceh, Aceh province, Indonesia, on December 28, 2004. (Source : Google Search)

Fig 4 : Waves wash through houses at Maddampegama, about 60 kilometers (38 miles) south of Colombo, Sri Lanka, on December 26, 2004. Tsunami waves triggered by earthquakes crashed into villages along a wide stretch of Sri Lankan coast, killing more than 35,300 people and displacing millions. (Source : Google Search)

Fig 5 : Waves crash through houses at Maddampegama, Sri Lanka, on December 26, 2004. (Source : Google Search)

Fig 6 : A natural color satellite image shows the coastline of the southwestern city of Kalutara, Sri Lanka on December 26, 2004 slightly less than four hours earthquake and shortly after the moment of tsunami impact. (Source : Google Search)

Fig 7 : Photograph of Phuket, Thailand moments after the Indian Ocean Tsunami ravaged Southern Asia on December 26, 2004. (Source : Google Search)

6.1 Impact of December 2004 Tsunami on India

The tsunami reached the states of Andhra Pradesh and Tamil Nadu along the southeastern coastline of the Indian mainland about 2 hours after the earthquake. At the same time, it arrived in the state of Kerala, on the south-western coast.

Along the coast of Tamil Nadu, the 13 km Marina Beach in Chennai was battered by the tsunami which swept across the beach taking morning walkers unaware. At Marina beach in Chennai, the beach slope is flat. As such, the tsunami surge entered the large area of the city without any resistance. These are depicted in Fig. 8 and Fig. 9. A 10 m black muddy tsunami ravaged the city of Karaikal, Puducherry district, where 492 lives were lost. This is depicted in Fig 10. The city of Pondicherry, protected by seawalls was relatively unscathed. The rubble-mound seawall fronting the Pondicherry city provided protection against the tsunami waves. The seawall took the major impact of the tsunami. The water flow of the order of half a meter height overtopped the seawall, but did not cause any significant damage in the thickly populated area of Pondicherry city . Also there was no significant damage to the seawall structure during the tsunami. At the coastal town of Kanyakumari, the seabed was exposed briefly before a large wall of water can be seen on the horizon and subsequently flooding the town. The worst affected area in Tamil Nadu was Nagapattinam district, with 6,051 fatalities caused by a 5 m tsunami, followed by Cuddalore district, with many villages destroyed. This is depicted in Fig 11. Most of the people killed were members of the fishing community. Velankanni a sea shore town with a Catholic Basilica and a popular pilgrimage destination was also one of the worst hit by this tsunami that struck at around 9.30 am on that Sunday, when pilgrims who were mostly from Kerala among others were inside the church attending the Malayalam Mass. The rising sea water did not enter the shrine, but the receding waters swept away hundreds of pilgrims who were on the beach. The shrine's compound, nearby villages, hundreds of shops, homes and pilgrims were washed away into the sea. About 600 pilgrims died. The tsunami run-up was only 1.6 m (5.2 ft) in areas in the state of Tamil Nadu shielded by the island of Sri Lanka but was 4–5 m (13–16 ft) in coastal districts such as Nagapattinam in Tamil Nadu directly across from Sumatra. On the western coast, the run-up elevations were

4.5 m (15 ft) at Kanyakumari District in Tamil Nadu. The rubble-mound seawalls along with groynes were constructed at various stretches between Chennai and Ennore for protecting the national highway and the land area from erosion. This sea wall offered protection against the tsunami. However, the tsunami run-up reached far inside the land and caused damage in the stretches where the seawall did not exist (Kudale 2005). At Kalpakkam township, a small sand dune is followed by landward slope. The gravity added to the tsunami flow and caused devastating damage to lives and property in this area.

The state of Kerala experienced tsunami-related damage in three southern densely populated districts, Ernakulam, Alappuzha, and Kollam, due to diffraction of the waves around Sri Lanka. This is depicted in Fig 12. The southernmost district of Thiruvananthapuram, however, escaped damage, possibly due to the wide turn of the diffracted waves at the peninsular tip. Major damage occurred in two narrow strips of land bound on the west by the Arabian Sea and on the east by the Kerala backwaters. The waves receded before the first tsunami with the highest fatality reported from the densely populated Alappad panchayat (including the villages of Cheriya Azhikkal and Azhikkal) at Kollam district, caused by a 4 m (13 ft) tsunami. The tsunami run-up was 3.4 m each at Kollam and Ernakulam districts in Kerala. The time between the waves ranged from about 15 minutes to 90 minutes.

Many villages in the state of Andhra Pradesh were destroyed. In the Krishna district, the tsunami created havoc in Manginapudi and on Machalipattanam Beach. The most affected was Prakasham District, recording 35 deaths, with maximum damage at Singraikonda. Given the enormous power of the tsunami, the fishing industry suffered the greatest. Moreover, the cost of damage in the transport sector was reported in the tens of thousands. The tsunami run-up was 2.2 m at Andra Pradesh, inundation distance of about 1 km and 985 km of coastline affected.

Fig 8 : An aerial view of Marina beach after a tsunami triggered by an earthquake in the Indian Ocean hit the area in the southern Indian city of Madras on December 26, 2004. (Source : Google Search)

Fig 9 : Marina Beach after the Tsunami on 26.12.2004. (Source : Google Search)

Fig 10 : Tree stumps and debris remain on Karaikal Beach several years after the 2004 tsunami. The tsunami travelled 2.5 km at its maximum inland at Karaikal, Puducherry

Fig 11 : Indian men stand exhausetd after searching for missing relatives at Silver Beach in Cuddalore, some 185 kms south of Madras, 27 December 2004, after tidal waves hit the region. (Source : Google Search)

Fig 12 : Tidal waves devastated the south Indian coastline 26 December 2004 killing 1000 people. (Source : Google Search)

6.1.1 Impact on Andaman and Nicobar Islands

The 26 December 2004 tsunami had a major impact on Andaman and Nicobar group of Islands. The Andaman Islands were moderately affected while the island of Little Andaman and the Nicobar Islands were severely affected by the tsunami (S.R. Gandhi 2005). The landmass of the Islands subsided due to earthquake / tsunami causing relative rise in the water level. The sea level rise caused inundation of large areas in most of the Islands. The high tide line receded which aggravated the erosion problem in many Islands. The vegetation in the coastal belt was destroyed due to inundation. Flooding occurred at the coast and low-lying areas inland, which were connected to open sea through creeks. Inundation was observed, along the east coast of South Andaman Island, restricted to Chidiyatapu, Burmanallah, Kodiaghat, Beadnabad, Corbyn's cove and Marina Park/Aberdeen Jetty areas. Along the west coast, the inundation was observed around Guptapara, Manjeri, Wandoor, Collinpur and Tirur regions. Several near-shore establishments and numerous infrastructures such as seawalls and a 20 MW diesel-generated power plant at Bamboo Flat were destroyed. In Malacca, located on the island of Car Nicobar, there were high tsunami waves with a maximum tsunami wave height of 11 m. Waves nearly three stories high devastated the Indian Air Force base, located just south of Malacca. Inundation limit was found to be up to 1.25 km inland. The impact of the waves was so severe that four oil tankers were thrown almost 800 m from the seashore near Malacca to the Air force colony main gate. In Campbell Bay of Great Nicobar Island, the tsunami waves hit the area three times with an inundation limit of 250–500 m (820–1,640 ft). A rise in sea level was observed. The tsunami waves wreaked havoc in the densely populated Jogindar Nagar area, situated 13 km south of Campbell Bay. The worst affected island in the Andaman & Nicobar chain is Katchall Island. The significant shielding of Port Blair and Campbell Bay by steep mountainous outcrops contributed to the relatively low wave heights at these locations, whereas the open terrain along the eastern coast at Malacca and Hut Bay contributed to the great height of the tsunami waves. The tsunami waves were 3 m high at Port Blair on South Andaman Island, 8 m high at Campbell Bay on Great Nicobar Island and 10–12 m high at Malacca (in Car Nicobar Island) and at Hut Bay on Little Andaman Island.

7. TSUNAMI WARNING SYSTEM

Tsunami warning system uses the velocity difference between seismic waves (several kilometers per second) and tsunami waves (up to 0.2 km/s for the deepocean). These waves are generated from the same source, but the larger the distance, the longer the arrival time difference. For trans-oceanic tsunamis, such as those in the Pacific or Indian Oceans, hours may elapse between an earthquake and the tsunami arrival. The earthquake location and size can be quickly and accurately estimated by seismological observations and the actual tsunami generation and propagation can be confirmed by an off shore sea level monitoring system such as bottom pressure gauges if the data are transmitted and monitored in real time. Numerical computation of tsunamis can be also utilized.

In the case of the 2004 Sumatra-Andaman earthquake, the Pacific Tsunami Warning Center (PTWC) in Hawaii issued the first information bulletin approximately 15 min after the earthquake. This bulletin gave the correct epicentre but vastly underestimated the magnitude as 8.0. PTWC upgraded the magnitude estimate to 8.5, 69 minutes after the earthquake and warned of the possibility of a tsunami. This warning came approximately an hour before the tsunami reached the coasts of Thailand, Sri Lanka, and India. For a tsunami of nearby origin, the parent earthquake provides the most effective warning to coastal residents. In Japan, a tsunami warning based on seismology is issued 2 to 5 min after the earthquake and is immediately relayed to coastal residents by the media or other methods (K. Satake and Atwater 2007). Such instrumental warnings to be effective depend on infrastructure to disseminate warning information prior assessment of tsunami hazards by means of tsunami-inundation mapping and relentless education of coastal residents. On Maikhao Beach in north Phuket City, Thailand, a 10-year-old British tourist named Tilly Smith had studied tsunamis in geography at school and recognised the warning signs of the receding ocean and frothing bubbles. She and her parents warned others on the beach, which was evacuated safely (Telegraph London 1 Jan 2005). John Chroston, a biology teacher from Scotland, also recognized the signs at Kamala Bay north of Phuket, taking a busload of vacationers and locals to safety on higher ground. Anthropologists had initially expected the aboriginal population of the Andaman Islands to be badly affected by the tsunami and even feared the already depopulated Onge tribe could have been wiped out. Many of the aboriginal tribes evacuated and suffered fewer casualties, however. Oral traditions developed from previous earthquakes helped the aboriginal tribes escape the tsunami (Manu Gupta and Anshu Sharma 2006).

7.1 Prediction of Tsunami by Tsunameter

Tsunameter is an instrument that measures temporal variation of amplitude of tsunami wave in deep ocean (1000 m depth). In tsunameter, a direct deep ocean measurement of tsunami is possible as they propagate from shore to coastal communities.

Tsunamater

The tsunameter as shown in Fig 13 consists of four basic components.

i) A Bottom Pressure Recorder (BPR)
ii) An Acoustic Link
iii) A surface buoy equipment
iv) A satellite telecommunication capability

Bottom Pressure Recording System

The bottom pressure recorder (BPR) as shown in Fig (14) is a important component of the tsunameter system and includes a Digiquartz broad band depth sensor, a computer, data logger and acoustic transducer to communicate with the surface buoy. The Digiquartz broad band depth sensor is the primary sensing element in the bottom pressure recorder. This sensor monitors pressure continuously and if the pressure reading changes above a set threshold, then the tsunameter automatically transmits data to a surface buoy. The surface buoy makes a satellite connection to Tsunami Warning Centres that evaluate the threat and issue a tsunami warning. The most important sensing requirement is the detection of a very small pressure changes at water depths up to 6000 meters. The change in pressure in terms of water depth due to tsunami in the open ocean is generally less than one centimetre. The resolution capability of Digiquartz broad band depth sensors make it possible for tsunameters to detect water level changes of less than one millimetre at the deployed depth of 6000 meters. The setup is shown in the Fig 15.

Surface Mooring System

The surface mooring uses a 2.5 diameter fiberglass over foam disk buoy with a gross displacement of 4000 kg (shown in Fig. 16). The mooring line is 19 mm 8- strand plaited nylon line with a rated breaking strength of 7100 kg and is deployed with a scope of 0.985. This maintains a tight watch circle to keep the buoy positioned within the narrow cone of the acoustic transmission. Two downward looking transducers are mounted on the buoy bridle at a depth of 1.5 m below the sea surface. A multi layered baffle system of steel, lead and syntactic foam shields the transducers and cushions them with rubber pads for a soft mount.

7.1.1 Working principle of Tsunami Detection Mechanism

A Tsunameter system consists of a seafloor Bottom Pressure Recording (BPR) system capable of detecting tsunamis of pressure as small as 1 cm depth and a moored surface buoy for real-time communications. An acoustic link is used to transmit data from the BPR on the seafloor to the surface buoy. The data are then relayed via a satellite link to ground stations which demodulate the signals for immediate dissemination to Tsunami Warning Centres.

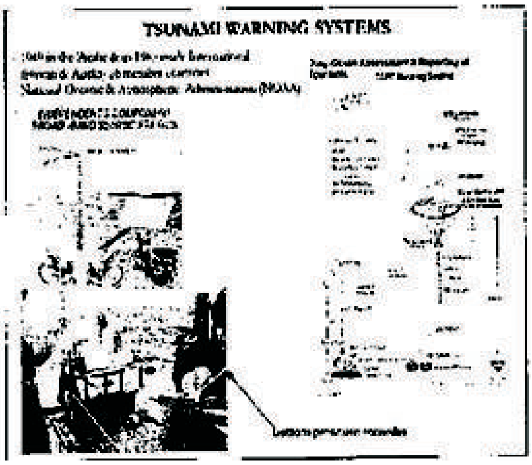

Fig 13 : Tsunameter
(Source : Google Search)

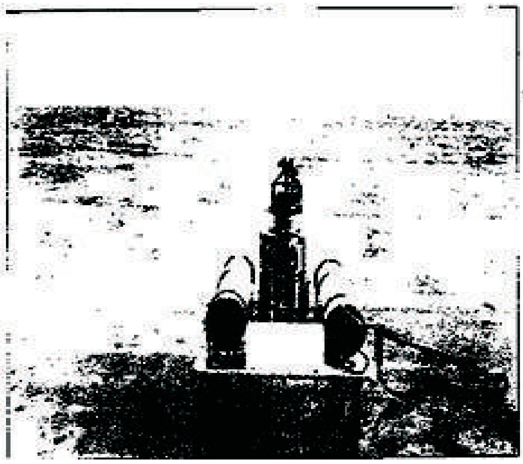

Fig 14 : Tsunameter Bottom Pressure Recorder (Source : Google Search)

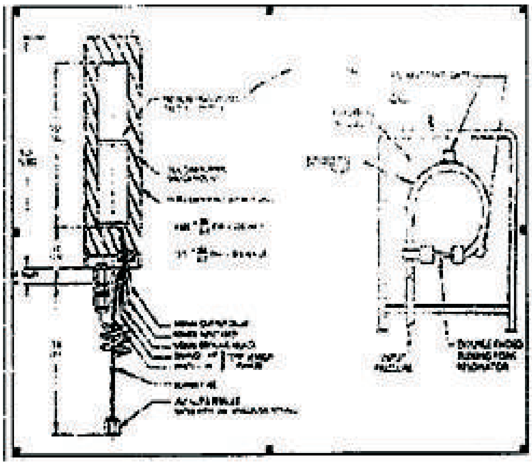

Fig 15 : Digiquartz Bourdon Tube Broadband Depth Sensor (after Jagadeesh 2005)

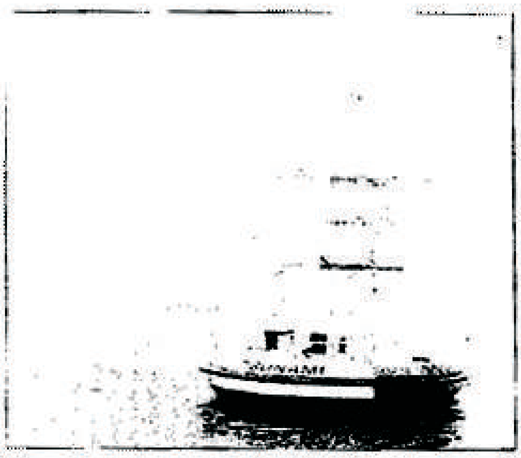

Fig 16 : Surface Mooring System (after Jagadeesh 2005)

8. Conclusions

The following conclusions are derived from the above study:-

i) A noticeable rapid rise or fall in coastal water is a sign that a tsunami may be approaching. In some cases, the sea may recede up to 800 m from the coast. The people may be advised not to venture into this temporarily dry area. It is not possible to prevent a tsunami but being educated about a tsunami can help in reducing the destruction and loss of lives.

ii) Tsunami Warning Systems should be installed in high risk areas. Several countries in the world have developed Tsunami Warning System. These are mostly fitted in high risk regions in and around the Pacific Ocean. Occurrence of Tsunamis cannot be prevented but adopting precautionary measures in the form of Tsunami Warning System provide information regarding the characteristics of tsunami waves such as time of travel, height, magnitude, etc.

These information may be communicated to the various centre to aware the people living in nearby the coastal areas.

iii) Building of tsunami walls of up to 4.5 m height in front of populated coastal areas and floodgates and channels to redirect the water from incoming tsunamis are helpful. The feasibility of constructing protective structures merely for tsunami needs to be critically examined considering the environmental impact, socio-economic aspects, etc. For the important establishments like Nuclear Power Plants, safe grade elevations need to be designed considering the tsunami run-up levels. Japan has built tsunami walls about 5 m high in front of the thickly populated and developed coastal areas.

iv) The sand dunes and vegetation along the coastline offered partial protection against the tsunami surge. As such, the eco-friendly protective measures like sand dunes and vegetation along the coast may also be kept in mind while working out plan for coastal protection against tsunami.

v) Training programmes on management of earthquakes, workshops on community participation in disaster management and allied topics should be periodically organized by the local government and NGOs to educate the people living in nearby coastal areas.

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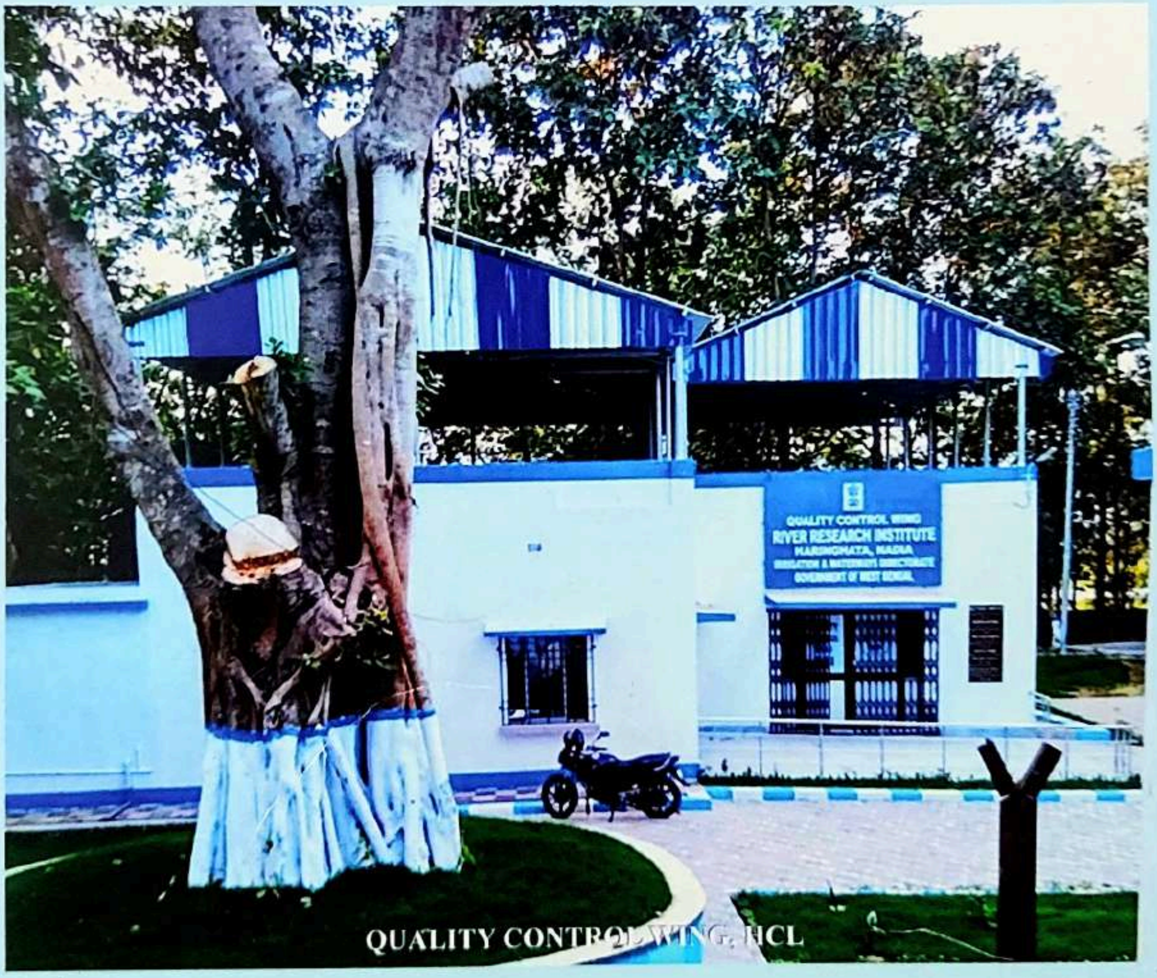

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