Use of Sediments from Dam Reservoir in Construction Industry

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Abstract— Sediments formed by erosion processing the catchment area of stream flow downstream along with the river. When water from the river is in stagenant condition behind the dam, the suspended particles from the water settles along the bed of reservoir. Depending on the topography of the reservoir, intensity of rainfall, type of soil and other conditions the percentage of sedimentation varies. The dam losing its water storing capacity as sediments from dam reservoir starts accumulating and thus the dam fails to serve the purpose for which it was built. Thus periodic removal of dam sediments is necessary to serve the purpose for which dams are built, namely for storage of water. Dredging involves removal of accumulated sediments from bottom of dam reservoir. The aim of this study was to determine the use of the dredged sediments from Tilari Dam reservoir in construction industry. This dam is situated in Dodamarg Taluka, in Maharashtra and is the largest one in Dodamarg Taluka of Kolhapur and has lost its water storing capacity by 11% due to sediment accumulation. To determine the optimum manufacturing procedure to obtain the best product a detailed experimental work was carried out. The main focus of this study was manufacturing bricks from dam sediment and to study the effect of firing temperature and two additives, namely stone dust and bottom ash on the mechanical and physical properties of bricks. A preliminary Environmental Impact Assessment (EIA) was also included in this study highlighting both positive and negative, as well as short term and long term impacts of removal of sediment from Tilari dam reservoir.
Key words: Sediments, Dam Reservoir

I. Introduction

A. Preamble

All rivers contain sediments: a river is considered as a body of flowing sediments. When river water is stilled behind a dam, the sediments it contains settle to the bottom of the reservoir. It is from 5% to 50% of the storage capacity of dams. The percentage of sedimentation is considerably more in case of large dams. Sedimentation depends upon the topography of catchment area, type of soil, intensity of rainfall etc.

As the sediments accumulate in the reservoir, the dam gradually loses its ability to store water for the purposes for which it was built like drinking water storage, hydropower generation. If too much sediment is stored, the natural balance of the dam can be changed.

B. Erosion in catchment

Main parameters, affecting sedimentation in dams:
- Catchment characteristics/shape.
- Type of soil
- Vegetation cover
- Rainfall duration and intensity
- Catchment land use pattern

C. Sediments transport

The following are the main parameters which affect transport:
- Flood discharge/slopes
- Channel geometry, slope and roughness
- Nature of river channel beds and banks

D. Sediments deposition in reservoir

The following are the main parameters, which affect sediment deposition in reservoir:
- Longitudinal and lateral valley slope
- Length and shape of reservoir
- Flow pattern in reservoir
- Nature of incoming floods
- Trap efficiency
- Grain size distribution of sediment
- Water and sediment discharges
- Mode of reservoir operation

E. Dredging of sediments:

To serve the purpose for which the dam was built, the accumulated sediment should be removed periodically. Dredging involves the periodic removal of accumulated bottom sediments. Dredging is an important way of providing sand and gravel for construction and reclamation projects. Dredging can be undertaken to benefit the environment in several ways. Dredged materials are frequently used to create or restore habitats. Another environmental use of dredging has been to remove contaminated sediments, thus improving water quality and restoring the health of aquatic ecosystems. This so- called "remediation" or "clean up" dredging is used in waterways, lakes, reservoirs, ports and harbors in highly industrial or urbanized areas. The removed material may be treated and used afterwards or disposed off under strict environmental controls.

F. Disposal of sediments:

The sediment dredged from reservoir should be disposed off in a proper way. There are many beneficial uses of dredged sediment. The general practice of disposal is dumping of the dredged sediment on the shores. This is not a feasible way of disposal of dredged sediments.

G. Beneficial use of sediments:

Dredged material is increasingly regarded as a resource rather than as a waste. Sediments from dam reservoirs comprise unpolluted, natural, undisturbed sediment which is considered acceptable for a wide range of uses. Beneficial use may be defined as "any use which does not regard the material as a waste". Some of them are as following:
1) Converting infertile land into fertile agricultural land
2) Preparation of bricks
3) Preparation of pavement blocks

4) Preparation of hollow clay blocks
5) Preparation of clay brick aggregates
6) Preparation of clay articles
7) In road construction as filler material
8) Filling discarded quarries
9) Filling borrow pits
10) Land reclamation
11) Creation of artificial island
12) Habitat creation/ enhancement
13) Creation of new facilities and garden for increasing tourism

The beneficial use of dredged material addresses the need for alternatives to conventional dredged material management. Numerous projects have demonstrated that dredged material can be used and/or recycled in a manner that is beneficial from environmental and economic standpoints. Still there are some obstacles in using the dredged material beneficially. The problems may be divided into three general categories:

– State laws and regulation
– Cost
– Physical and Chemical properties of sediment

Following points need to be considered while assessing the beneficial uses-

– Grain size
– Organic content
– Habitat replacement
– Costing of uses

H. Environmental issues:

The environmental issues related to sediment removal from dam reservoir should be taken into account. Direct or indirect environmental and socio-economic effects may be associated with any element of the dredging process- excavation, transport and disposal. The effects may be positive or negative, short term or long term and may include impacts on:

Water quality, for instance, increase of suspended solids, concentration and potential release of contaminants during dredging or disposal; leaching of contaminants from disposal sites.

– Habitats and natural areas
– Local communities: Effects of noise, increased labour opportunities
– Local communities: Effects of noise, increased labour opportunities
– Physical processes: Waves, currents or drainage and hence erosion and deposition

Prior to undertaking dredging and/or disposal projects the Environmental Impact Assessment (EIA) should contain detailed study on

– Beneficial and harmful impacts
– Short term and long term impact
– Reversible and irreversible impact
– Temporary and permanent impact

I. Objective of research

Sedimentation of dams is a serious problem as it reduces water storing capacity of dam and also it may affect the stability of dam depending on percentage of sedimentation. The removal of sediment from dam reservoir causes some impacts on environment. Following are the objectives of this research work:

– Obtain information on the volume of sediment deposited in Tilari dam reservoir.
– Study the environmental impacts (positive-negative, short term- long term) of removal of sediment from dam reservoir .Recommend the beneficial uses of sediment in construction with experimental work.
– Study the influence of firing temperature and additives on the properties of bricks made from Tilari dam reservoir sediment.

II. LITERATURE REVIEW

A. General Review

Over the past decade, some laboratory work has been carried out to study variety of beneficial uses of different types of sediments for the use in construction industry like making bricks, artificial aggregates etc. All the experiments have been performed to use the sediment removed from dams, oceans, lakes as a valuable resource rather than treating it as a waste. In the present study the research work was carried out to use the dam sediment as a raw material for manufacturing bricks. Published literature papers based on the various uses of sediment have been reviewed.

1) The paper by Yang Xu, et al (2014) reported on "Use of Urban River Sediments as Primary Raw Material in the Production of Highly Insulation Bricks" primarily suggests:

– Being moderately organic, river sediments could be used as an organic porous former by increasing its proportion in clay bodies although a resulting reduction in compressive strength must be considered.
– All the samples with 50-70% urban river sediments exhibited typical expansion behavior of porous bodies during firing. At the firing temperature of 1000°C, all the samples expanded approximately 2–3%, most likely due to the decomposition of the gaseous components.
– A highly porous structure was found to be responsible for a reduction of at least40% of the thermal conductivity of the fired bricks.
– Considering the balance of the thermal insulation capacity and the acceptable compressive strength, the bricks containing 50% urban river sediments fired at1050°C were demonstrated to be effective products.. The thermal conductivity values of clay-urban river sediment samples decreased by 40 % after the addition of urban river sediments. The thermal conductivity of the clay-urban river sediment bricks varied from 0.35 to 0.48 W/mK and that for regular burnt clay bricks varies from 0.15 to 0.6 W/mK

2) The paper by Yung-Lung Cheng on "Innovative reservoir sediments reuse and design for sustainability of hydroelectric power plants" focuses on process for design of six sigma where reservoir sediment and the masonry waste from the construction industry were combined with cement and a curing agent (composite of many organic and inorganic materials, a new low-energy, and environmentally friendly construction material. The amount of curing agent depends on the physical and chemical characteristics of the soil being cured).The resulting mixture transformed into a high

strength, non-sintered cured brick after 28 days of natural curing. This product was new walling material that was friendly to environment, fulfill the goal of energy conservation, waste recycle, protect ecosystems and promote sustainable development. Large scale recycling of reservoir sediment solves the problems that reservoir sediment poses, as well as increasing the capacity of reservoirs and the effectiveness of hydroelectric power plants.

3) The paper by Chao-Wei Tang on "Production of synthetic lightweight aggregates using reservoir sediment for concrete and masonry" suggests:

- The fine sediments can be used as a primary resource material for lightweight aggregates. Utilizing the source of material and methods of production achieves not only technical benefits but also can result in good social and ecological benefits. This is because it uses a material beneficially which is considered as a waste.
- The particle densities of the sedimentary lightweight aggregates range from 1010 to 1380 kg/m3, significantly lower than normal density aggregates. This can be attributed to the fact the sedimentary LWA particles have a porous core.
- The physical properties and crushing strength of the LWA is better than that of commercially available LWA. This may due to the fact that the sedimentary LWA particles have a hard ceramic shell. These results indicate that sedimentary LWA can serve as an aggregate source for structural concrete.
- The equilibrium density of the concrete made from the sedimentary LWA ranges from 1490 to 1566 kg/m3, or about 29–35% lighter when compared to normal density concrete. This complies with most building code requirements for structural lightweight concrete.
- The 28-day compressive strength of the concrete made from the sedimentary LWA ranges from 19.8 to 34.7 MPa. This satisfies the 17 MPa minimum, 28-day strength requirements for structural lightweight concrete.

4) The paper by Fouad M. Khalaf and Alan S. DeVenny on "Properties of clay brick aggregate for use in concrete" focuses on the physical and mechanical properties of new and recycled crushed clay brick aggregates for use in portland cement concrete (PCC). Various physical and mechanical properties of eight different types of aggregates were determined and compared with the limits set out in the British Standards for aggregate from natural sources used in concrete. The results were also compared with granite aggregate that has20been proved to be a good natural aggregate for producing PCC. The results showed that most of the crushed clay-brick aggregates tested can be used in producing PCC for low-level civil engineering applications.

III. Methodology

A. Dredging process

Sedimentation of the reservoir is natural and ongoing process. The accumulated sediment from the bottom of tilari dam reservoir should be removed periodically to serve the basic purpose for which the dam was built. For this purpose dredging is carried out. Dredging is the relocation of underwater sediments and soils for the construction and maintenance of waterways, dikes, transportation infrastructure, reservoirs and for reclamation and soil improvement. The dredging process consists of the following three elements: Excavation, Transport of excavated material, Utilization or disposal of dredged material.

There are basically two approaches to dredging, mechanical and hydraulic. Mechanical dredging involves removing sediment with machinery usually with a bucket of some type. The most common types are an excavator or clamshell bucket. Hydraulic dredging includes the use of a pump, usually barge mounted, to move material in slurry via a pipeline. Both can be very practical and efficient depending on the material type, depth, and location of its destination.

B. Laboratory study

In present study tests were conducted on sediment of tilari dam reservoir. Full characterization of sediment was carried out by using XRF method from an outside laboratory. Other testing for some geotechnical parameters of sediment was carried out in Collage laboratories. To support the beneficial use of sediment, the experiments such as preparation and testing of burnt clay bricks are carried out. The molding, air drying and heating the bricks with different percentage of additive like stone dust and bottom ash and with different temperatures are carried out. The testing of bricks is done at Collage transportation laboratory.

C. Sediment & additives characterization

1) Sediment characterization:

Full characterization of sediment from tilari dam reservoir was done at an outside laboratory with the use of XRF(X-Ray Fluorescence) method. The sediment was tested to determine the concentration of each trace element of the sediment, oxides such as SiO_2, Al_2O_3, Fe_2O_3, CaO etc., Total Organic Nitrogen, Total Kjeldahl Nitrogen, Nitrate, Nitrite, Total Phosphates, Total Coli, and E-Coli etc.

The purpose of full characterization of sediment is to find whether the sediment contains any radioactive or harmful element which may affect the environment adversely.

2) Additives characterization:

a) Stone dust:

Stone dust is a by-product of crushing stone which is very fine. Because stone dust contains very fine mineral aggregates (grain size 0mm), it forms a hard, load-bearing surface. As of today the stone dust is considered as a waste material which has no further use. But the use of such material which is considered as waste is studied in this work. The hydrometer analysis was carried out to determine the particle size distribution of stone dust.

3) Bottom ash:

Bottom ash is part of the non-combustible residue of combustion in a furnace or incinerator. In an industrial context, it usually refers to coal combustion and comprises traces of combustibles embedded in forming clinkers and sticking to hot side walls of a coal-burning furnace during its operation. The portion of the ash that escapes up the chimney or stack is, however, referred to as fly ash. The clinkers fall by themselves into the bottom hopper of a coal-burning furnace and are cooled. The above portion of the ash is referred to as bottom ash too. Bottom ash may be used as raw alternative material, replacing earth or sand or aggregates. The grain size analysis of bottom ash was carried out.

4) Determination of some physical properties of sediment:

Determination Water content

$$\text{Water content } W = M2-M3/M3-M1*100$$
$$= (67.24-49.38)/(49.38-24.12)*100$$
$$= 70.76\%$$

Determination of liquid limit of sediment

$$\text{Water content } W = M2-M3/M3-M1*100$$
$$=(42.6-37.25)/(37.25-26.74)*100$$
$$=50.90\%$$

At 25 no. of blows the water content is 53.027%.Therefore the liquid limit of sample is 53.027%.

Determination of plastic limit

$$\text{Water content } W = M2-M3/M3-M1*100$$
$$= (33.95-31.73)/ (31.73-26.68)*100$$
$$=43.96\%$$

At 43.14% water content the thread of 3mmdia. Crumbles thus the plastic limit of sample is 43.14%.

Determination of shrinkage limit

$$\text{Volume of wet soil pat (V)} = \text{Volume of shrinkage dish}$$
$$= \text{Weight of mercury}/13.6$$
$$= 297.92 \text{ X } 10\text{-}3/ 13.6$$
$$= 21.905 \text{ X } 10\text{-}3 \text{ m3}$$
$$\text{Volume of dry soil pat (Vd)} = \text{Weight of mercury displaced}/ 13.6$$
$$= 146.94 \text{ X } 10\text{-}3/ 13.6$$
$$= 10.804 \text{ X } 10\text{-}3 \text{ m3}$$
$$\text{Shrinkage limit (ws)} = w - (V - Vd) \text{ X } 100/ Md$$
$$= 73.72 - (21.905 - 10.804) \text{ X } 100/ 18$$
$$= 12.05\%$$

Determination of free swell index of soil

$$\text{Free swell index, percent} =(Vd-Vk)*100/Vk$$
$$=(14-13)*100/13$$
$$=7.9\%$$

5) Experimental work for suggesting beneficial uses of sediment:

For the purpose of recommendations on the beneficial uses of tilari dam sediment for construction purposes, the experimental work to support two beneficial uses was carried out.

6) Preparation of bricks:

The main focus of the study was to use the dam sediment for construction purposes. Brick is not only one of the oldest but also most extensively used building materials in construction work. Conventionally bricks are made from the topsoil which is the raw material for brick making. Taking into account the scarcity of topsoil available for agriculture and other uses, there is a need to search for such material which can be used for brick making which is available in huge quantity and which is regarded as a waste material. The bricks made from dam sediment can be regarded as the beneficial use of dredged material as a resource instead of disposing off it as a waste.

7) Process of brick manufacturing:

a) Air drying, size reduction and sieving of sediment:

The sediment collected from the dam reservoir was in fully submerged condition. It was collected and kept for air drying to remove the moisture. When the sediment dried completely, it was taken for size reduction in a ball mill. Crushed sediment was then sieved through 600µ IS sieve and the sediment passing through 600µ sieve was taken for manufacturing of bricks. The oversized sediment was then returned to the ball mill for further crushing.

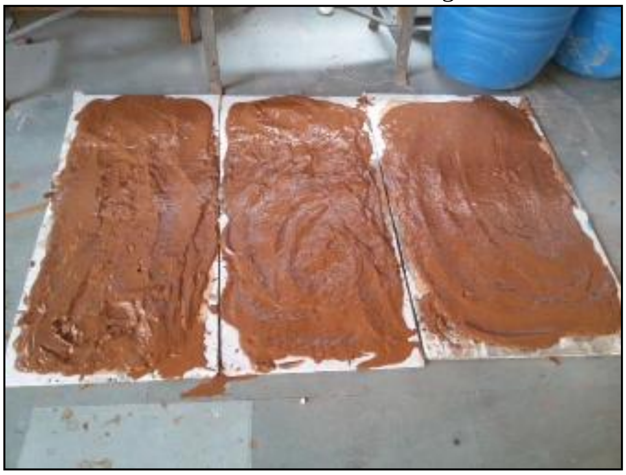

Fig. 1: Air drying of sediment

b) Proportioning and mixing of sediment and additives:

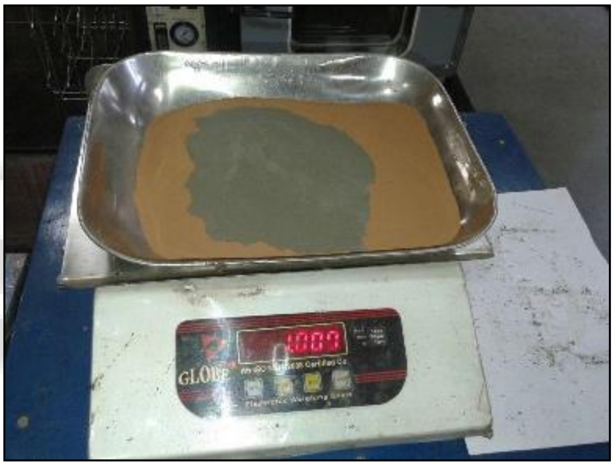

Fig. 2: Proportioning and mixing of sediment and additive

c) Dough preparation:

d) Forming of wedge:

e) Shaping of bricks:

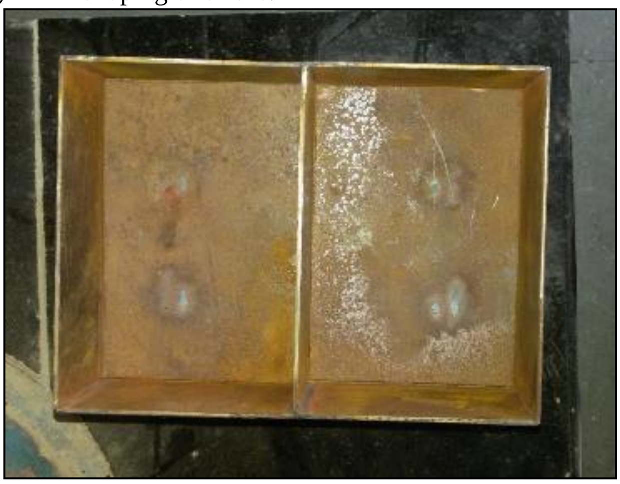

Fig. 4: Mold used for brick making

f) Cutting of excessive dough and leveling:
g) Releasing and leveling:
h) Drying of bricks:

Fig. 5: Air dried bricks

i) Firing of bricks:

Fig. 6: Loading of muffle furnace for firing of bricks

j) Assessing feasibility of sediment for agricultural use:

The purpose of this use was resolving the global problem of scarcity/ degradation of soils and some classical problems in the dams, by turning them into a global resource. The transformation mechanisms inherent to erosion transport and accumulation in the bottom of reservoirs leads to a significant enrichment of nutrients, converting the sediments into a renewable natural resource prone to sustainable use. This study was focused on sediments that accumulate in dam reservoirs, from a point of view of their possible removal and use. Dam reservoir sediments are composed of contributions from two main sources, natural erosion products and agricultural over-erosion products. Their accumulation encompasses a number of problems, technical and environmental, including filling of the reservoir and rendering it useless and changing the properties of the reservoir water. The aim of this study was to define the feasibility of extracting the dam reservoir sediments, using part as fertilizers or artificial soil.

IV. Results & Analysis of Experiments

A. Laboratory Test Results

Physical properties of sediment

Following results were interpreted from the laboratory tests carried out:

1) Water content of sediment = 70.76%
2) Liquid limit (wl) = 53.03 %

(According to IS 2720 Part 5: 1985)

If wl < 35 % - Low compressible soil

wl between 35-50 % - Intermediate compressible soil

wl > 50% - Highly compressible soil

The liquid limit value of Tilari dam reservoir sediment was greater than 50%. Hence it can be interpreted that the sediment was highly compressible soil.

3) Plastic limit (wp)= 43.14 %

Plasticity index (Ip) = Wl – Wp= 9.9

If Plasticity index (Ip) =0 – Non plastic soil

Ip < 7 – Low plastic soil

Ip between 7-17 – Medium plastic soil

Ip > 17 – High plastic soil 100

The plasticity index of sediment was between 7 to17. Hence the sediment was medium plastic soil.

4) Shrinkage limit (ws) = 12.05 %
5) Free swell index of sediment = 7.69 %

V. Conclusions

1) Laboratory analysis has showed that tilari dam sediment does not contain any environmentally harmful substances.
2) Laboratory experiments done at Collage have proved that this sediment can be successfully used for making Class II types of bricks for construction purposes.
3) These bricks can be used for the following:
   – Masonry construction where the faces are to be plastered.
   – Construction of load bearing walls of single storied houses.
   – As brick ballast in RCC work and in lime concrete.
4) Based on the sediment analysis done at the agricultural laboratory it has been certified that the tilari dam sediment is suitable for range of crops under appropriate environmental conditions.
5) Temperature plays a crucial role in improving the quality of bricks. It was found that it is essential to adopt ramp and hold pattern of heating.

A. Future Scope

Testing Of Bricks

1) Compressive strength
2) Water absorption
3) Weight loss on air-drying
4) Loss on ignition
5) Drying shrinkage
6) Firing shrinkage

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