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Earthen Dam Siltation: A Review of Various Methods to Calculate Reservoir Sedimentation

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Abstract: ***The shortage of rainfall and its increasing variability leads to moisture stress particularly in dry and rain-fed areas. Reservoirs, created by dams, are constructed to store water for use in non-monsoon months. However, these benefits are not fully explored due to water storage loss due to siltation. The sediment management at dams and reservoirs have given rise to acute complications owing to its impact on water availability, reliability of infrastructure and impact on downstream users. The methods to calculate the volume of siltation trapped by earthen dams play an important role in addressing these issues. The current article also summarizes the various methods that can be adopted to calculate sedimentation in reservoirs of dams.***

I. INTRODUCTION

Siltation (Sedimentation or Silt deposition) is the process by which fine particles (silt, clay and sand) accumulate after settling down in water bodies like rivers, lakes, reservoirs and estuaries, causes being both natural as well as human induced. The suspended sediment particles in water lose their momentum and settle due to gravity. The sediment transport is enhanced by rainfall via watershed runoff, especially in the beginning of rainy season (Mathlouthi and Lebdi). Siltation can lead to various issues like reduction in the benefits from reservoirs in terms of hydropower generation, irrigation, water supply and flood management (Thakkar and Battacharya). The sediment load carried by water depends on various factors including nature of soil, vegetal cover, topography and intensity of rainfall. According to OLIVEIRA et al. (2011) the devastation of vegetation surrounding the rivers brings serious implications to the natural environment. Sedimentation cannot be prevented but may be reduced to some extent (Dr K.R. Arora).

There are several methods to calculate siltation in dam reservoirs, including:

1) *Sediment Transport Models:* Numerical models such as the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Soil and Water Assessment Tool (SWAT), CCHE1D (Consortium of Computational Hydraulics for Engineering 1D Model), HEC-RAS (Hydrologic Engineering Center's River Analysis System)and Hydrodynamic and Morpho-dynamic Modelslike Delft3D, Telemac-Mascaretetccan be used to estimate sediment transport and deposition rates in the watershed feeding the dam. These models take into account various factors such as land use, soil type, topography, and rainfall to predict sediment yield. These models, together with historical records and surveys can provide valuable information on siltation trends over time.
2) *Sediment Sampling and Analysis:* Direct sampling of sediment in the reservoir can provide accurate data on siltation rates. This involves collecting sediment samples from different locations and depths within the reservoir and analyzing their composition and sedimentation rates.

Analysis of siltation of dam is based on following equation

$$T = \frac{Vres}{365\,S} \quad (1)$$

Where, T = Time to siltation (years);

V_{res}= Total volume of the dam (m^3), and

S = Volume of sediment in the dam (m^3 d^{-1})

The total volume of dam can be calculated by Bathymetric survey.

The calculation of the volume of sediment in the dam can be calculated as

$$S = \frac{S\prime}{ds} \quad (2)$$

Where, S= Volume of sediment withheld in the dam (m^3 d^{-1})

S'= mass of sediment withheld in the dam (kg d^{-1})

d_s= Density of solid sediments on the bottom of the dam (kg m^{-3})

The mass of sediment retained on the dam (S') can be determined with the help of following equation

$$S' = DSTe - DSTs \quad (3)$$

Where, S'= Mass of sediment retained in the dam (kg d^{-1})

DST_e= Total sediment discharge entering the dam (kg d^{-1})

DST_s= Total sediment discharge coming out of the dam (kg)

The total solid discharge

DST = DSL DSS (4)

Where, DSS = Suspended solid discharge (kg d^{-1})

DSL = Riverbed Solid discharge (kg d^{-1})

The suspended solid discharges, of input or output of the dam can be determined as

$$DSS = (Cst.Q)0.24 \quad (5)$$

Where, DSS = Suspended solid discharge (kg d^{-1})

CST = Total solids (mg L^{-1})

Q = Stream flow (m^3 h^{-1})

The riverbed solid discharge can be determined by the method of COLBY (1954) as

$$DSL = (39\ V_m^{3.36}\ L.K)\ 10^3 \quad (6)$$

Where, DSL = Solid discharge on the riverbed (kg d^{-1})

V_m = Mean flow velocity (m s^{-1})

L = Linear width of the channel section (m), and

K = Correction factor

The correction factor

$$K = 1.118 \left[\frac{Cst}{Cr}\right]^{0.5} \quad (7)$$

Where, K = Correction factor

C_{st} = total solids concentration (mg L^{-1})

C_r = Relative concentration (mg L^{-1}) determined by Colby diagram

3) *Reservoir Bathymetry Surveys:* Regular bathymetric surveys involve measuring the depth and topography of the reservoir. By comparing surveys taken at different times, changes in the reservoir's volume can be calculated, which help to estimate the amount of sediment deposition.
4) *Sediment Rating Curves:* These curves establish a relationship between sediment transport or deposition and flow rates. By monitoring flow rates and sediment concentration in the inflow and outflow of the reservoir,the amount of sediment deposited over time can be estimated.
5) *Remote Sensing and GIS:* Satellite imagery and geographic information systems (GIS) can help monitor land use changes, erosion patterns, and sediment sources in the watershed. This data can be used to estimate sediment input to the reservoir. This method utilizes data of Landsat series and ASTER for mapping of siltation, rock types and minerals.
6) *Sediment Budget Analysis:* A sediment budget is a comprehensive analysis of sediment sources, transport, and deposition in the watershed and reservoir. It integrates various data sources and modelling techniques to estimate sediment accumulation.
7) *Sediment Traps and Basins:* Installing sediment traps or basins in the upstream areas of the reservoir can capture and retain sediment before it reaches the reservoir. The data from these basins can give an idea about the amount of siltation in a particular dam.

II. CONCLUSION

The above methods of sediment calculation are equally reliable and the choice of adoption of a particular method depends on varied factors like scale of project, topography, data availability and the purpose of research.

Moreover, a combination of two or more of these methods can be used to evaluate the amount and extent of siltation in dams.

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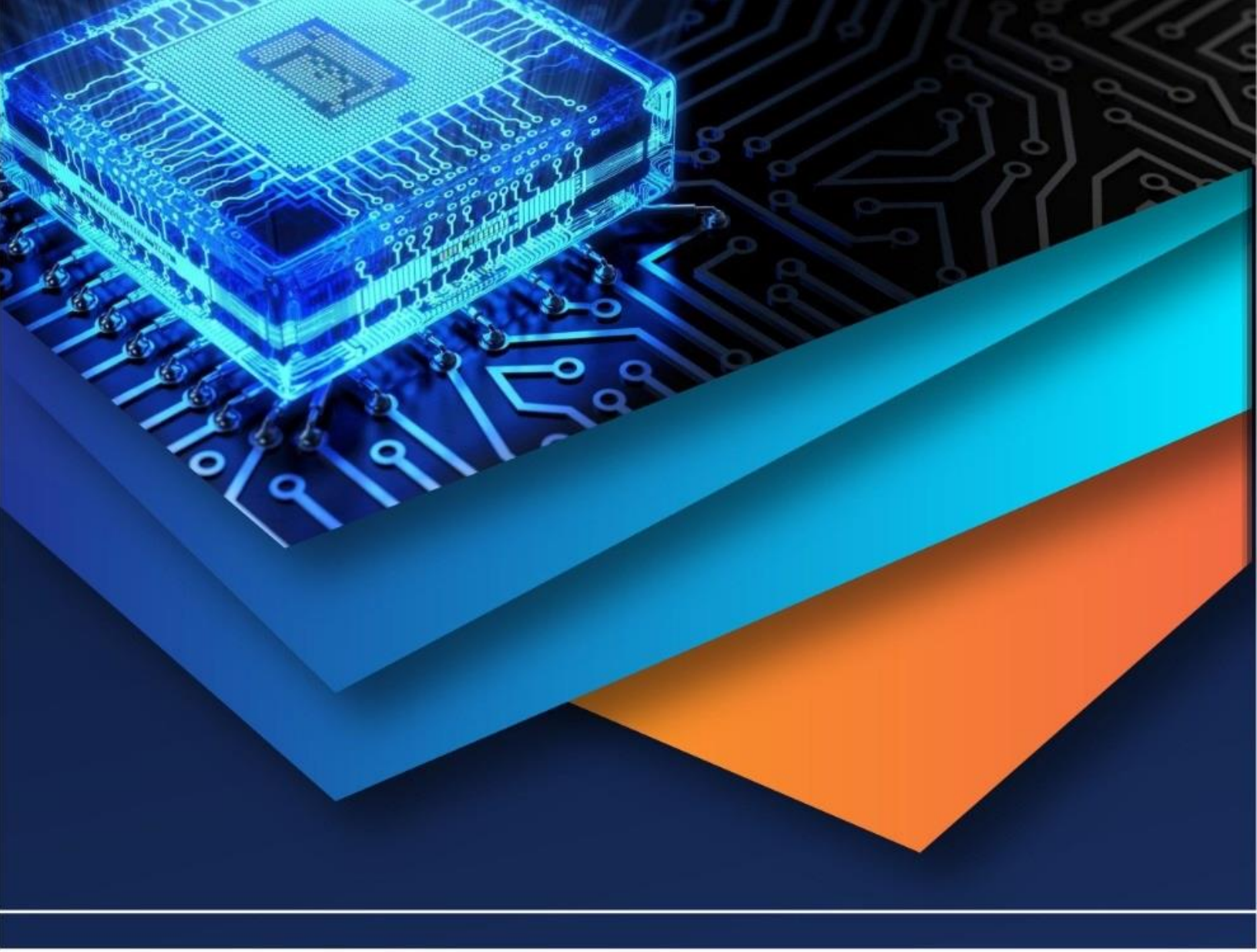

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