Calibration of CCHE2D for Sediment Simulation of Tarbela Reservoir

M.Uzair Qamar and Faisal Baig

ABSTRACT_ **The numerical model CCHE2D has been applied to simulate flow field for the Tarbela Reservoir on the Indus River, Pakistan. Initial Water Surface Level, Input and Output Hydrographs, Bed Load Adaptation Length, Porosity, Suspended Sediment Concentration, Bed Load Trasport rate, Sediment Size Classes and Manning's coefficient was identified in the model calibration using measured field data. Whereas, the literature was reviewed for the values of Schmidt number and Suspended Sediment Adaptation Length factor. The calibrated model was then validated using more filed data measured during several Reservoir surveys of Tarbela Reservoir. The results showed that predicted Bed elevations were in a good agreement with the field measurements and imply that the CCHE2D model can simulate, to an extent of satisfaction, an unsteady natural river channel flow with a complicated geometry with sharp bends and wider flood plains.**

Keywords: Simulation, Adaptation Length

I. INTRODUCTION

For the Tarbela Hydropower Reservoir deltaic deposits form a serious threat for the performance of the reservoir. Therefore a systematic approach is very required for the realistic approach towards the prediction of sedimentation. The CCHE2D model is a two-dimensional depth-averaged, unsteady, flow and sediment transport model. The flow model is based on depth-averaged Navier-Stokes equations. The turbulent shear stresses are modeled using Boussineq's approximation, and three different turbulence closure schemes are available for the calculation of the turbulent eddy viscosity. The resulting set of equations is solved implicitly using the control volume approach and efficient element method. The equations for this module include transport equations for bed load and suspended load, the bed change equation, and the bed sorting equation. These equations are discretized using efficient element method or exponential difference scheme.

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II. INITIAL WATER SURFACE LEVEL

The very first variable that will have to be incorporated in the model is the "Initial Water Level". This level is of great importance as model will not do any execution if the initial water level is too low as it will leave too many dry nodes. In the present research the initial water surface level was 472.1409 m as the input bed elevation data was for September 1981 therefore, the input hydrograph will have to be from September 1980 to August 1981.

Table 1
Reservoir Elevation Data for the year 1980-1981.

Year/Month(Ten Daily)	Water Surface Elevation(m) for the first 10 days	Water Surface Elevation(m) for the middle 10 days	Water Surface Elevation(m) for the last 10 days
September, 1980	472.1409	470.9217	468.8256
October	459.0343	452.9383	450.8046
November	449.8902	448.0614	448.0134
December	441.6605	438.0029	438.2596
January, 1981	438.6500	431.9068	429.1636
February	427.9444	426.4203	423.0675
March	418.1906	413.3138	411.7898
April	418.1906	419.7147	421.5435
May	416.3618	410.8753	403.8649
June	398.6832	396.5496	399.9024
July	417.5810	432.5164	458.0719
August	468.7400	470.6169	472.4457

III. MANNING'S ROUGHNESS COEFFICIENT

The value of Manning's n is not of particular importance in the present mode of research as value of n gets ineffective as the area of water containing body gets larger and larger. Anyhow, the value of n for the present research was calculated by Stickler's formula.

$$n = d_{50}^{1/6}/21.6 \quad (1)$$

Or

$$n = d_{50}^{1/6}/26 \quad (2)$$

Where

n= Manning's roughness coefficient

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d_{50}= mean diameter of the bed material as read from figure 4.1 is 0.1 mm

The value of "n" was found to be equal to .032

IV. INPUT/OUTPUT HYDROGRAPH

The input and output hydrographs were used from the period of September 1980 to August 1981. Following table indicates the data used for inflow and stage hydrograph.

Table 2
Input and Output Hydrographic data.

Time(Second)	Inflow(cumecs)	Reservoir Level(m)
0	35738	472
864000	35738	472
1728000	28018	471
2592000	17237	465
3456000	14274	459
4320000	10985	453
5184000	8958	451
6048000	7687	450
6812000	6620	448
7776000	6163	445
8640000	5550	442
9504000	5188	428
10368000	5029	435
11232000	4795	435
12096000	4535	432
12960000	4267	429
13824000	4209	428
14688000	4411	426
15552000	4690	423
16416000	4977	418
17280000	4831	413
18144000	5719	412
19008000	6434	416
19872000	11677	420
20736000	17791	422
21600000	31937	416
22464000	39777	411
23328000	49988	404
24192000	35379	399
25056000	31910	397
25920000	68855	400
26784000	72238	418
2764800	83455	433
28512000	89086	455
29376000	75591	466
30240000	76109	471
31104000	45416	472

V. SCHMIDT NUMBER

Schmidt number is a dimensionless number defined as the ratio of momentum diffusivity (viscosity) and mass diffusivity, and is used to characterize fluid flows in which there are simultaneous momentum and mass diffusion convection processes. It is named after the German engineer Ernst Heinrich Wilhelm Schmidt (1892-1975).

Schmidt number is the ratio of the shear component for diffusivity viscosity/density to the diffusivity for mass transfer *D*. It physically relates the relative thickness of the hydrodynamic layer and mass-transfer boundary layer.

It is defined as:

$$S_c = \frac{v}{D} = \frac{\mu}{\rho D} \qquad (3)$$

- ν is the kinematic viscosity
- *D* is the mass diffusivity.
- μ is the dynamic viscosity
- ρ is the density

The value of mass diffusity was very difficult to calculate. Therefore, the literature was reviewed for the value of Schmidt number. Zhang et al. (1996) used 0.77 value of Schmidt number for different flow and sediment simulation problems and found it quite effective.

VI. ADAPTATION LENGTH

The non-equilibrium adaptation length Ls, which characterizes the distance for sediment to adjust from a non-equilibrium state to an equilibrium state, is a very important parameter in the nonequilibrium transport approach used in NCCHE models. For suspended load, $L_s = Uh/\alpha\omega_{sk}$. The coefficient α is calculated with Armanini and di Silvio's (1988) method. Values of α calculated from this method or other similar methods in the literature are usually larger than 1. However, in practice, α has been given different values by many researchers, most of them being less than 1.

Based on results obtained from validation tests in many reservoirs and rivers, it has been suggested that α = 1 for the case of strong erosion, α = 0.25 for strong deposition, and α = 0.5 for weak erosion and deposition in 1-D and 2-D model (Han, 1980; Wu et al., 2004).

For bed load, the non-equilibrium adaptation length is related to the dimensions of sediment movements, bed forms, and channel geometry. Wu et al. (2004) suggested that it takes the value of the length of the dominant bed forms, such as sand dunes in laboratory cases and alternate bars in field cases. This suggestion has given very promising results in a series of applications. For bed-material load, the non-equilibrium adaptation length is set as the larger of the adaptation lengths computed for bed load and suspended load. For wash load, the adaptation length Ls is assumed to be infinitely long and then no sediment exchange exists near the bed.

A. Suspended Sediment Adaptation Length Factor

For Tarbela reservoir, after going through literature, the value of 0.25 was selected as in Tarbela deposition is a prevailing factor.

B. Bed Load Adaptation Length

The formula for the calculation of bed load adaptation length is

$$L_s = 3d_{50}D_*^{0.6}T^{0.9} \qquad (4)$$

Where,

Ls = Bed Load Adaptation Length

d_{50}= mean diameter of the sediments present at the bed.

$D_* = d_{50}[(\rho_s - \rho)g/\rho v^2]^{1/3}$ (5)

ρ_s = Sediment Density.

ρ = Density of Water.

v = Kinematic Viscosity.

T= Transport Stage or non-dimensional excess shear stress.

$D_* = 0.1((1350\text{-}1000)*9.8/(1000*(1.004*10^{-6})^2))^{1/3}$

$$D_{*=}0.1\left(\frac{0.1*(1350-1000)*9.8}{(1000(1.004*10^{-6})^2)^{1/3}}\right)^{1/3}$$

D_*=1504.1

$T_s = \frac{\tau_b}{\tau_c}$ (6)

$$\tau_b = \rho g h S \quad (7)$$

For the mixed-grain-size bed

$$hS = 0.05 * d_{50} \quad (8)$$

As,

$$d_{50} = 0.1mm$$

$$hs = .05(0.1)$$

$$hs = .005$$

$$\tau_{b=}1000 * 9.8 * 0.005$$

$$\tau_b = 49\frac{Kg}{m^2}$$

Meyer-Peter and Muller' Proposal states

$$\tau_c = 0.047 * (\gamma_s - \gamma) * d_m \quad (9)$$

γ_s = Unit weight of Sediment Particles.($1350 * 9.8 = 13230$)

γ = Unit weight of water. ($1000 * 9.801 = 9810$)

d_m = median grain diameter of sediments. (0.1)

$$\tau_{c=}0.047 * (13230 - 9810) * 0.1 = 16.074\frac{Kg}{m^2}$$

$$T_s = \frac{49}{16.074} = 3.05$$

$$L_s = 3 * 0.1 * 1504.1^{0.6} * 3.05^{0.9} = 66meters$$

VII. POROSITY

Porosity is a measure of the void spaces in a material, and is a fraction of the volume of voids over the total volume, between 0–1, or as a percentage between 0–100%.the porosity of a porous medium (such as rock or sediment) describes the fraction of void space in the material, where the void may contain, for example, air or water. It is defined by the ratio:

$\emptyset = \frac{V_v}{V_t}$ (10)

For Tarbela reservoir the porosity was calculated with the help of Soil Texture Triangle. It was observed that the bed of Tarbela reservoir is made up of 59% sand, 34% silt and 7% clay. By using the following Soil Texture Triangle figure (Fig. 1) the soil at the bed of Tarbela was categorized as Sandy Loam. Afterwards from the table its Porosity was calculated (51%).

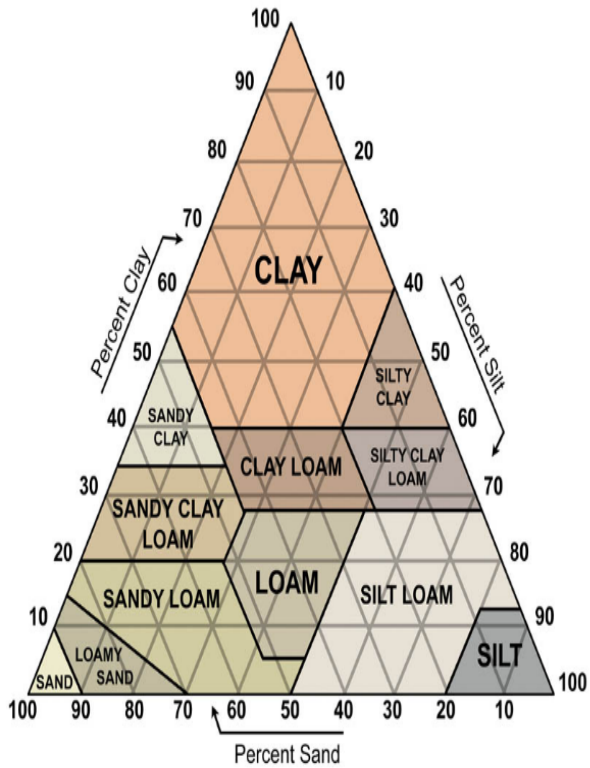

Figure 1 Soil Texture Triangle.

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Table 3
General relationship among texture, bulk density and porosity of soils.

Textural Class	**Bulk Density (Mg/m³)**	**Porosity (%)**
Sand	1.55	42
Sandy loam	1.40	48
Fine sandy loam	1.30	51
Loam	1.20	55
Silt loam	1.15	56
Clay loam	1.10	59
Clay	1.05	60
Aggregated clay	1.00	62

A. Concentration

Concentration was calculated by numerical approach.

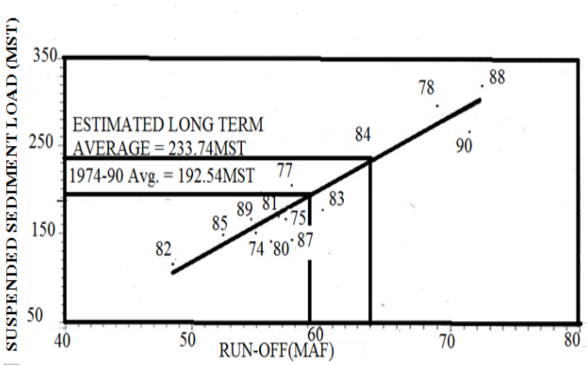

Figure 2 Relation between Suspended Sediment Yield and Runoff into Tarbela Reservoir.

One can clearly see from the figure that the average Suspended Sediment load 198.52 MST. In other words, in one year 192.54 MST sediments have flown into the reservoir. The corresponding inflow for that particular span was 59.20 MAF.

In numerical order it can be written as:

$$Q_w = 59.20\, {}^{MAF}/_{Year}$$

$$Q_s = 192.54\, {}^{MST}/_{Year}$$

$$concentration = \frac{Q_s}{Q_w} \qquad (11)$$

$$= 2.637\, {}^{Kg}/_{m^3}$$

VIII. BED LOAD TRANSPORT RATE

Once again, numerical approach was used for the calculation of Bed Load Transport Rate.

Total Sediment Inflow into the Tarbela Reservoir in 1980-81 = 241.94MST

Out of that Total Suspended Sediment was = 192.54MST

Therefore,

Bed Load= 49.4MST

$$= 1566.46\, \frac{Kg}{sec}$$

Now the average width of the bed of Tarbela reservoir came to be = 1210.4meters

Finally,

$$\frac{Bed\ Load}{Unit\ Width} = 1.29416\ Kg/m/sec\ or\ {}^{Kg}/_{sec}/m$$

IX. DEFINING SEDIMENT CLASSES FOR BED AND SUSPENDED LOAD

Sediment Cumulative distribution curves were used to define the Suspended as well as Bed Load Sediment Classes. The curves are drawn below

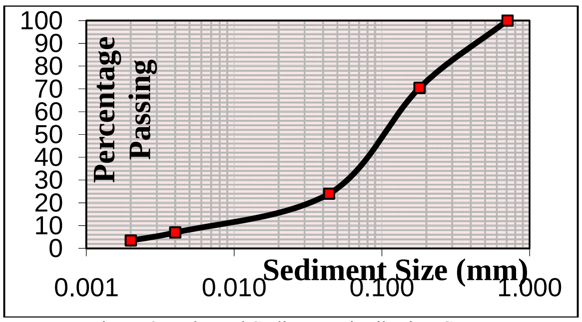

Figure 3 Bed Load Sediment Distribution Curve

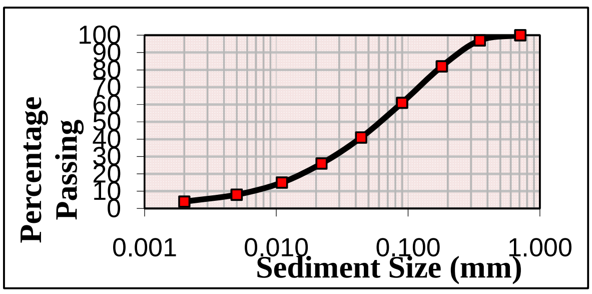

Figure 4 Suspended sediment Distribution Curve.

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X. RESULTS

The model as was calibrated by the using input coordinates given to drew the bed profile shown in the figure below. As these input files were of year 1981 therefore the profile been drawn at the center-line happened to be of that year. Some adjustments with the data were made so that the profile matches to that of the original for the accurate simulation. It should be noted that execution entirely depends on how accurate the input data is. When the model was run for one year time period the model showed the following executed results. It should be noticed that the input variables used in executing everything were found in the way it has been explained in chapter number 4. When model was run for 365 days or 31536000 seconds, it predicted the following shape of the center line.

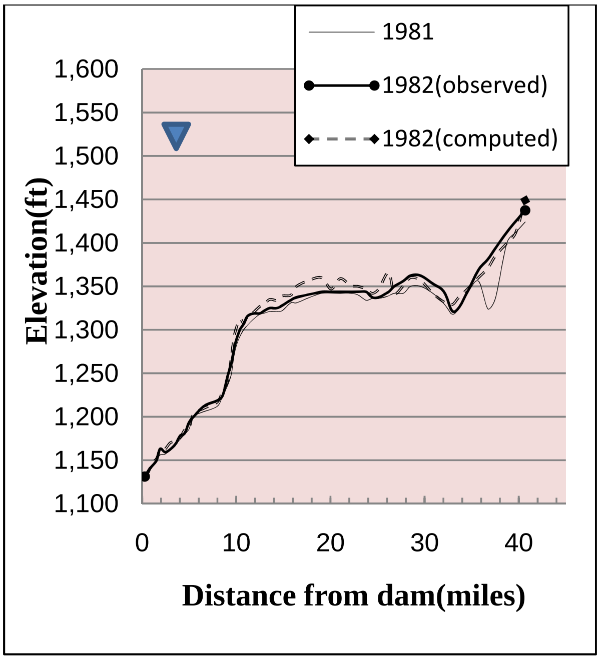

Figure 5 Computed and Observed Bed Elevation Comparison(1982).

The cross sections being predicted by the model are below.

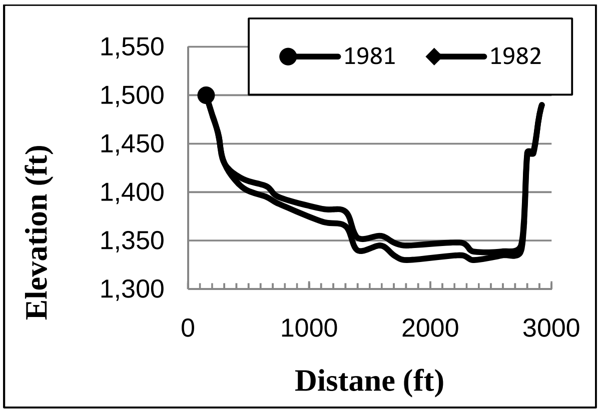

Figure 6 Cross Section at Range Line 39

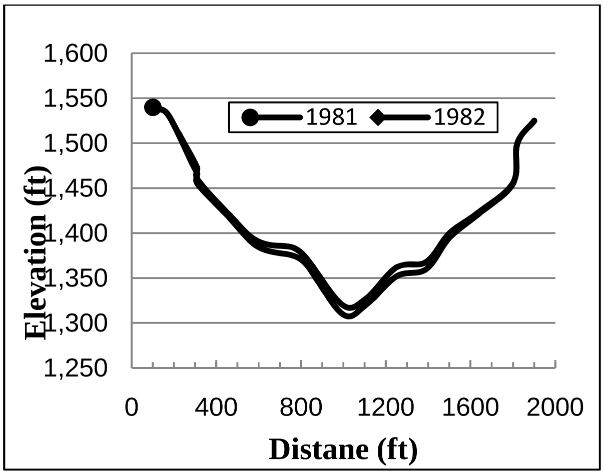

Figure 7 Cross Section at Range Line 45

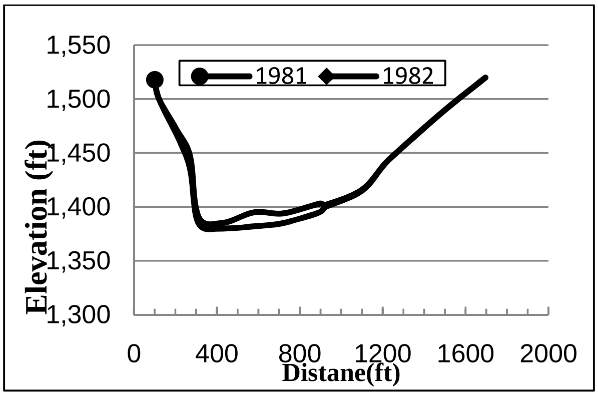

Figure 8 Cross Section at Range Line 50

XI. COEFFICIENT OF MODEL EFFICIENCY

The coefficient of Efficiency of the model as found by the following formula gave a value of 0.98.

$$COE = 1 - \left[\frac{\sum_{i=1}^{n}(B_a - B_m)^2}{\sum_{i-1}^{n}(B_a - B_{av})^2}\right] \tag{12}$$

Where

B_a= Actual Bed Elevation

B_m= Modeled Bed Elevation

B_{av}= Average Actual Bed Elevation

Entering Subsequent value for the each Variable to have the value of COE

$$COE = 1 - \left[\frac{8971.20}{462679.45}\right]$$

$$COE = 1 - 0.0193$$

$$COE = 0.98$$

XII. CONCLUSION

All the variables and constants which were used to calibrate the model gave reasonably good simulated results. The maximum deposition was observed in the range 24 to 36 miles. After 36 mile mark model had shown an extreme level of deviation from the original value. The simulation process might have effected due to the fact that the model is not good for simulating during low flow periods as it will stop or do an unsatisfactory simulation giving unsatisfactory results, as most of the nodes will be dried at that point of the time.

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