Estimating the Capability of Shatt Al - Hilla within Hilla City to Carry the Total Bed – Material Load

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Abstract. The case study is Shatt Al – Hilla within Hilla City, where no sediment measurement has been done whatsoever. Data on bed soil and expected hydraulic parameters at Km. 39.000 of Shatt Al – Hilla just at the upstream of Hilla City for the developed design discharge of (303 m³/s) were previously investigated. The main objective of this research is to apply different commonly – used approaches worldwide to estimate the capability of an alluvial channel to carry total bed – material load, taking Shatt Al – Hilla within Hilla City as the case study. Five, somehow different formulas to estimate the bed – material load were used. These are: Lau 1958, Karim & Kennedy 1990, Engelund & Hansen 1967-1962, Ackers & White 1973-1990, and Yang 1973. Considering the results by Yang 1973 of judgment, the research indicated: 1) the expected bed – material load at the considered location is about (200000 m³/Year). 2) Differences of results of predicting sediment load in rivers by different formulas by some folds is not a surprise. 3) Measurement of sediment load at important locations such as those contributing to life and property in an important city (like in the case study) is essential.

Keywords: sediment, Shatt Al-Hilla, bed-load, hydraulic parameters, River.

1. Introduction

Man had faced the dilemma of sediment transport since antiquity. As a local example, due to the continuous process of erosion and sedimentation during centuries, the present course of Shatt Al-Hilla in the district of the Ancient Babylon City is the ancient course of the Euphrates River, whereas the present course of Euphrates is about (15 km) to the west of its ancient course. The golden dream of man in this respect had been and still is the will of having non – silting non – scouring channels. The pioneer work in this regard (commonly denoted as the regime approach) is usually attributed to R. G. Kennedy in the old Punjab area (India and Pakistan) [1].

The registered pioneer theoretical treatment of the subject of channel erosion is that of Du Buat: 1786 [1]. Those followed that work are too many to be named. However, the sediment transport approaches are generally classified into the following, [2]: (1) The regime approach. (2) The regression approach. (3) The probabilistic approach. (4) The deterministic approach. (5) The stream power approach.
The main objective of this research is to apply different commonly used approaches worldwide to estimate the capability of an alluvial channel to carry total bed material load, taking Shatt Al – Hilla within Hilla City as the case study.

2. The case study
Shatt Al – Hilla is the biggest branch of the Euphrates River. It takes its water from the left bank of the Euphrates just upstream of the New Hindiya Barrage. The present design discharge at its head regulator is \( 230 \text{ m}^3/\text{s} \). However, the approved development plan for Shatt Al – Hilla involves increasing the design discharge to \( 303 \text{ m}^3/\text{s} \) \([3, 4]\).

Shatt Al – Hilla crosses Hilla City for the distance \( 32.000 \text{ km} \) to \( 51.500 \text{ km} \) of its length. A stage gage is located at km. 39.000 for which a rating curve is available \([5]\).

Five branch canals take water from Shatt Al – Hilla upstream of Hilla City, with a total design discharge of \( 27.050 \text{ m}^3/\text{s} \) \([4]\).

Consequently, the expected design discharge of Shatt Al – Hilla within Hilla City is \( Q = 275.950 \text{ m}^3/\text{s} \).

According to \([5]\), Shatt Al – Hilla at km. 39.000 would have: \( B = 48.00 \text{ m} \); \( Z = 0 \); \( S = 8 \text{ cm/km} \); \( n = 0.032 \).

According to \([6]\); the bed material of the case study has: \( d_{50} = 0.10 \text{ mm} \); \( d_{35} = 0.03 \text{ mm} \); \( d_{65} = 0.30 \text{ mm} \); \( S_S = 2.72 \).

3. Applications
Too many procedures and equations are available to estimate the sediment carrying capacity of open channels. Considering only those concerned with the total bed material load, the following approaches have been chosen:

A. The empirical approach of \([Larsen: 1958]\).
B. The regression approach of \([Karim and Kennedy: 1990]\).
C. The stream power approach of Engelund and Hansen \([1967; 1972]\).
D. The stream power approach of \([Akers and White: 1973; 1990]\).
E. The dimensionless unit stream power approach of \([Yang: 1973]\).

3.1. Given and Basic Data
\( Q = 275.950 \text{ m}^3/\text{s} \); \( B = 48.000 \text{ m} \); \( Z = 0 \); \( S = 0.00008 \); \( n = 0.0320 \); \( d_{50} = 0.1 \text{ mm} \); \( d_{35} = 0.03 \text{ mm} \); \( d_{65} = 0.30 \text{ mm} \); \( S_S = 2.72 \); \( g = 9.8 \text{ m/s}^2 \); \( \rho = 1000 \text{ kg/m}^3 \); \( \nu = 0.000001 \text{ m}^2/\text{s} \).

3.2. Preliminary Calculations
1. Using Manning’s equation with the known \( Q \), \( B \), \( Z \), \( S \), and \( n \), and a trial – and error approach to calculate: \( D = 6.779 \text{ m} \).
2. \( U = Q/A = 0.848 \text{ m/s} \).
3. \( Re = UD/\nu = 5748 592 \); \( Fr = U/(gD)^{0.5} = 0.1 \)
4. \( R = A/\rho = 5.286 \text{ m} \); \( \tau_0 = \gamma RS = 4.144 \text{ pa} \); \( U^* = (T_0/\rho)^{0.5} = 0.0644 \text{ m/s} \).
5. By Rubey [1933]: \([7]\): \( \alpha = 0.0087 \text{ m/s} \).

3.3. Laursen [1958]:
Based on empirical relations, \([8]\) developed the following set of formulas to estimate the bed material load:
1. \[ \tau_0' = \left( \frac{\rho U^2}{S_8} \right) \left( \frac{d}{D} \right)^{3/2} \] (1)
2. \[ Re^* = \frac{U * d}{v} \] (2)

Use Shields’ diagram to find \( F_S \) corresponding to \( (Re^*) \), then:

\[ \tau_{ocr} = F_S (S_S - 1) * \gamma * d \] (3)

3. \[ F = U^*/\omega \); Then from Laursen graph Fig (1), find the corresponding value of \( f[F] \). 

4. \[ C_m = \left( \frac{d}{D} \right)^{-7/6} \left[ \left( \frac{\tau_{ocr}'}{\tau_{ocr}} \right) - 1 \right] * f[F] \] (4)

5. \[ QSTY = \left( \frac{C_m}{100} \right) * \left( \frac{Q}{S_S} \right) * 86400 * 365 \] (5)

For the case study: \( \tau_0' = 0.304 \text{ Pa}; Re^* = 6.44; F_S \) \{calculated for the respective \( (Re^*) \) by the mathematical relationships developed by [3] to represent the Shields’ diagram\} = 0.0338; then: \( \tau_{ocr} = 0.057 \text{ Pa} \)

\( F = 7.4; f[F] = 420; C_m = 0.004205682 \text{ (\%)} \) by weight. Then: \( QSTY = 134 \text{ 556 m}^3/\text{Year.} \)

![Laursen (1958) graph](image)

**Figure 1**: Laursen (1958) graph

3.4. Karim and Kennedy [1990]:

Using nonlinear, multiple regression analyses to a total of (339) sets of river data and (608) sets of flume data, [9] arrived at:

\[
\log \left[ \frac{qST}{(1.65gd^{0.5})^{0.5}} \right] = -2.279 + \log[U/(1.65gd)^{0.5}] + 1.06 \log[U/(1.65gd)^{0.5}] * \\
\log \left[ \frac{U^{*'} - U^{*cr}}{(1.65gd)^{0.5}} \right] + 0.299 \log(D/d) * \log \left[ \frac{U^{*'} - U^{*cr}}{(1.65gd)^{0.5}} \right]
\] (6)

Where:

\[ U^{*cr} = (\tau_{ocr}/\rho)^{0.5} \] (7)

For the case study: \( \tau_{ocr} \) [from Sec. (3.3)] = 0.057 pa; thus \( U^{*cr} = 0.0075 \text{ m/s}; and by Eq. [11]: \( qST = 4.895077 \times 10^{-4} \text{ m}^3/\text{s.m.} \). Consequently:
For equation for dimensionless unit stream power for sand transport, which is: Yang [1973] used (463) sets of laboratory data to determine the values of the coefficients QSTY = qST * B * 86400 * 365

= 740 985 m³/Year.

3.5. Engelund and Hansen [1967; 1972]:
Engelund and Hansen 1967 [2] applied Bangold’s stream power concept and the similarity principle to obtain a set of functional relationships which can be joined into a single formula as:

\[ qST = 0.05U^2 (r_0 / \gamma)^{1.5} / [(S_S - 1)^2 d \sqrt{g}] \]  

(9)

For the case study: \( qST = 3.375 \times 10^{-4} \) m³/s.m.

Then by Eq. [8]: \( QSTY = 511,011 \) m³/Year.

3.6. Ackers and White [1973; 1990]:
Ackers and White [1973] used dimensional analyses to express sediment transport rate in terms of some dimensionless parameters as follows:

1. \( \text{d}_{gr} = d[(S_S - 1)g / \nu^2]^{1/3} \)

(10)

2. \( F_{gr} = U^n [U / \sqrt{32} \log(\alpha D / d)]^{1-n} / [(S_S - 1)g d]^{0.5} \)

where: \( \alpha = 10. \)

3. \( G_{gr} = C [(F_{gr} / A) - 1]^m \)

4. \( X = G_{gr} \times S_S \times d / [D (U_* / U)^n] \)

5. \( QSTY = (X/S_S) Q \times 86400 \times 365 \)

(14)

For \([d > 0.04 \text{ mm}]\) and \((Fr < 0.8)\), and for the transition zone, \([1 < \text{d}_{gr} \leq 60]\) Ackers and White [1973] suggested certain relationships for the values of the involved sub – parameters \((n), (C), (A),\) and \((m)\). Those values have been revised by HR Wallingford [1990] [2] as follows:

6. \( n = 1 - 0.56 \log(d_{gr}) \)

(15)

7. \( \log C = -3.46 + 2.79 \log(d_{gr}) - 0.98[\log(d_{gr})]^2 \)

(16)

8. \( A = 0.14 + 0.23 / \sqrt{d_{gr}} \)

(17)

9. \( m = 1.67 + 6.83 / d_{gr} \)

(18)

For the case study: \( d_{gr} = 2.564; n = 0.771; C = 0.003289; A = 0.2836; m = 4.3338; F_{gr} = 1.2711; G_{gr} = 0.7332; X = 214.6683 \) ppm by weight; and

\( QSTY = 686,809 \) m³/Year.

3.7 Yang [1973]:
Yang [1973] used (463) sets of laboratory data to determine the values of the coefficients in his equation for dimensionless unit stream power for sand transport, which is:

\[ \log C_T = 5.435 - 0.286 \log(\omega d / \nu) - 0.457 \log(U_* / \omega) + \{1.799 - 0.409 \log(\omega d / \nu) - 0.314 \log[U_* / \omega]\} \log[S / \omega](U - U_{cr})] \]

(19)

Where: If \(|U_* d / \nu| < 70|\) then:

\( U_{cr} / \omega = 0.66 + 2.5 / [\log(U, d / \nu) - 0.06] \)  

(20 a)

For \(|U_* d / \nu \geq 70|\) then: \( U_{cr} / \omega = 2.05 \)  

(20 b)
Then: \( QSTY = \left( C_T / 106 \right) \times \left( Q / S_5 \right) \times 86400 \times 365 \)  

For the case study: \( U_r \times d / v = 6.44 \); thus, by Eq. [20 a]: \( U_r / \omega = 4.0 \); then by Eq. [19]: \( \log [C_T] = 1.757743 \); thus \( C_T = 57.24575 \) ppm by weight.

Then by Eq. [21]: \( QSTY = 183.152 \) m\(^3\)/Year.

4. Summary and Conclusion:

Estimating the bed – material carrying capacity of Shatt Al – Hilla just at the upstream of Hilla City by five, apparently different approaches revealed the results summarized in Table (1). Unfortunately, no sediment measurements at the chosen location are available whatsoever. Consequently, there is no direct concrete reference to evaluate the obtained results.

Due to the large number of physical, hydraulic, and hydrologic parameters affecting and controlling the sediment transport problem, with their conflicting effects, and in the absence of supporting actual sediment measurements, no single formula can predict the sediment discharge quantitatively ‘accurate’. In fact, accuracy in this regard has no place to be mentioned. Whatever the analytic part in the derivation of a formula for sediment transport is, there is always a significant part to be fulfilled empirically to fit the local conditions, spatially and temporally through using measured data to evaluate the respective coefficients in the mathematical model. This is well recognized in natural streams, particularly the relatively large ones, and especially those with very fine beds (as the case study). Thus, what a sediment – transport formula predicts is only an estimate. How close that estimation to reality depends on how close the actual circumstances of the discussed case to the ideal conditions for which the formula has been derived. Thus, it is practically recognized that computed sediment load from different sediment transport formulas can give vastly different results from each other and from field measurement.

Numerous investigators have evaluated the accuracy of prediction of most of the available, world – wide, sediment transport formulas. One such an evaluation is that of Yang [1996]. He analyzed the sensitivity of the accuracy of (13) formulas including [8, 10, 11] as a function of six basically dimensionless parameters, namely, the dimensionless grain diameter \((d_g)\) [or the mean grain diameter \((d)\)], the relative depth \((D/d)\), Froude number \((Fr)\), dimensionless shear velocity \((U/\omega)\), dimensionless unit stream power \((U S/\omega)\) and the sediment concentration by weight \((C)\).

Using the discrepancy ratio \((R)\), defined as \((\text{Calculated} / \text{observed})\) transport rate, and adopting the acceptance range \([0.5 \leq R \leq 2.0]\) as the guide for comparison, Yang [1996] made detailed analyses in this respect. He used vast amount of measured data in rivers and in flumes in his analyses. He found that the dimensionless stream power of [11] got the first rank of accuracy among the (13) tested formulas.

Considering the cases where the adopted sensitivity parameters cover those of the case study: \(d = 0.0625 - 2 \) mm (or: \(d_g = 1.56 - 50.6\) ); \(D/d = 1000 - 50000\); \(Fr = 0.10 - 0.40\); \(U/\omega = 2.5 - 15.0\); \(U S/\omega = 0.0005 - 0.1\); \(C\) (ppm by weight) = 10 – 100; whereas for the case study: \(d = 0.1 \) mm \((d_g = 2.564)\); \(D/d = 67760\); \(Fr = 0.1\); \(U/\omega = 7.4\); \(U S/\omega = 0.0078\); \(C\) by [11] = 57 ppm by weight. As this research is concerned, the results of the analyses of [2] can be summarized as in Table (2). Consequently, the results of [11] in this research has been considered as the reference of comparison for the other results \(\{\text{as indicated in Column (4) of Table (1)}\}\).

Moreover as stated in [2], because of the tremendous uncertainties involved in estimating sediment discharge at different flow and sediment conditions under different hydrologic, geologic, and climatic constraints, it is extremely difficult, if not impossible, to recommend one formula for engineers and geologists to use in the field under all circumstances.
Table 1: Summary of results

| No. | Formula | QSTY (m³/Year) | % |
|-----|---------|----------------|---|
| 1   | Laursen [1958] | 134 556 | 73.5 |
| 2   | Karim & Kennedy [1990] | 740 985 | 405 |
| 3   | Engelund & Hansen [1967 ; 1972] | 511 011 | 279 |
| 4   | Ackers & White [1990] | 686 809 | 375 |
| 5   | Yang [1973] | 183 152 | 100 |

Table 2: Summarized results of Yang [1996] for the cases that cover the case study of this research

| No. | Formula       | Number of data | R   | % (0.5 ≤ R ≤ 2.0) |
|-----|---------------|----------------|-----|-------------------|
| 1   | Laursen [1958] | 2676           | 1.32| 81                |
| 2   | Engelund & Hansen [1972] | 2731 | 1.17| 93                |
| 3   | Ackers & White [1990] | 2676 | 1.11| 90                |
| 4   | Yang [1973] | 2731           | 1.08| 91                |

From the aforementioned, the following can be abstracted:

1. The estimate of sediment discharge of Shatt Al – Hilla within Hilla City with the new proposed flow of (303 m³/s) is about (200 000 m³/Year).
2. Differences of results of predicting sediment load in rivers by different formulas by some folds is not a surprise.
3. Measurement of sediment load at important locations such as those contributing to the safety and life in an important city (such as the case study) is essential.

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