MAJOR PROJECT

ON

Bed load transport OF bimodal sediments

Submitted in partial fulfillment

of the requirement for award of the degree of

Master of engineering

In

Civil engineering

(Hydraulics & Flood Control)

Submitted By

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DECLARATION

I here by declare that the work which is embodied in this major project entitled '***BED LOAD TRANSPORT OF BIMODAL SEDIMENTS***' is an authentic record of my own work carried out in partial fulfillment of the requirements for the award of Master of Civil Engineering (Hydraulics & Flood Control) under the guidance of Dr. P.L. Patel, Asst. Professor Dehi College of Engineering, New Delhi. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

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*This is certified that above statement made by ht e student is correct to the best of my knowledge***.**

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LIST OF SYMBOLS

symbol	Meaning
B	Bimodality parameter
C_p	Correction factor
d	Flow depth
d_i	Any size of sediment in a sample
d_{16}	Sediment size in the mixture, such that 16 % material by weight is finer than this size
d_{50}	Sediment size in the mixture, such that 50 % material by weight is finer than this size
d_{84}	Sediment size in the mixture, such that 84 % material by weight is finer than this size
d_a	Arithmetic mean size of sediment mixture
Dc	Grain size of coarse mode
D_F	Grain size of fine mode
d_g	Geometric mean size
d_i	Any size of sediment in a sample
d_σ	Representative size
g	Gravitational acceleration
i_b	Fraction of bed sediment of a given size range
i_B	fraction of bed load in a given size range
M	Kramer's coefficient
Q	Discharge
q_{bi}	Fractional transport rate

R	Hydraulic radius
R'	Hydraulic radius corresponding to grain resistance
R_s	Submerged specific gravity of sediment
S	Energy slope
U	Average velocity of flow
u_*	Shear velocity
u_*'	Shear velocity corresponding to grain roughness
$W*$	Total dimensionless bedload transport rate
X	Correction factor for viscous effect
γ_f	Specific weight of fluid
γ_s	Specific weight of sediment
Δp_i	Percentage of material in a given size range
$\Delta\gamma_s$	Difference of specific weight of sediment and fluid
ξ	Sheltering coefficient
ρ_f	Mass density of fluid
ρ_s	Mass density of sediment
σ_g	Geometric standard deviation of sediment mixture
τ^*_{ci}	Dimensionless CTS of size fraction $d_{i.}$
$\tau^*_{c\sigma}$	Dimensionless CTS of representative size d_σ
τ_o'	Average shear stress corresponding to grain
Φ_b	Dimensionless bed load parameter

Ψ	Einstein's shear parameter
$\sum P_m$	Summation of sediment proportion in coarse and fine mode

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Chapter-1

INTRODUCTION

1.1 GENERAL:

Prediction of sediment transport rates in alluvial channel has been a challenging job for hydraulic engineers since eighteenth century. Knowledge of sediment transport rate in natural river is required for stable channel design, reservoir sedimentation analysis, computation of bed level of alluvial streams and design and maintenance of hydraulic structures.

Increasing construction of hydraulic engineering works on rivers draining needed estimation of bedload transport rates in gravel-bed rivers. As per general accepted hypotheses, the sediments on the river bed start the movement when the bed shear stress on the bed exceeds the critical tractive stress for the bed material. The sediments move in different way in alluvial stream like movement by sliding or rolling along the bed, movement by hopping or bouncing along the bed and the movement in the state of suspension, termed as contact load, saltation load and suspension load respectively. The total of first two contact load and saltation load termed as bed load because the measurement of saltation load is difficult and very low as compare to contact load. Thus in simple way bed load is the material transported on or near the bed. The many rivers include coarse mixed bed-material and may transport significant amount of coarse sediment. The non-uniformity of sediment increases with increase in its average size (Garde and Ranga Raju, 2000). The sediment in nature are invariably non-uniform in the nature, particularly in gravel bed river. Further upper reaches of river are characterized with very fine and coarse sediments, being devoid of intermediate size of sediments. These sediments are classified as bimodal sediments. The bimodal type of sediment distribution is usually represented by two modes, one of sand size and another of gravel size while in unimodal type of sediment distribution consist only one mode. Bimodal sediments are generally found in gravel bed rivers. Bimodal sediments have been found over long reaches of a channel’s course as well as within the transition between gravel and sand beds. Bedload transport in gravel-bed streams highly complicated because of the nonuniformity of the grain size and the layered configuration of channel bed material. The presence of two modes in bimodal sediment makes it more complicated because the movement of one mode becomes influenced by other. A definite solution or method to this complicated problem is still not available.

1.2 BIMODAL SEDIMENT V/S UNIMODAL SEDIMENT

Frequency curve of any sediment sample may be plotted from the data obtained from sieve analysis of sediment. Some frequency curves are found to have one maxima while others may have two maxima. The size distribution of one maxima is defined as unimodal sediment while of two maxima are called bimodal sediment. In exceptional cases one may have more than two maxima called polymodal sediment. There can be several causes for bimodal or polymodal size distribution; one is the possibility that the sample is made up of two or more population corresponding to different modes of transport (by wind, water, glacial etc.) and the second is the tendency of one size grade to be present in larger amounts than other size grade. The impact of human action, such as the increased deposition of fine material following enhanced erosion from deforested catchments or disposal of mining waste, may also make previously gravel beds bimodal.

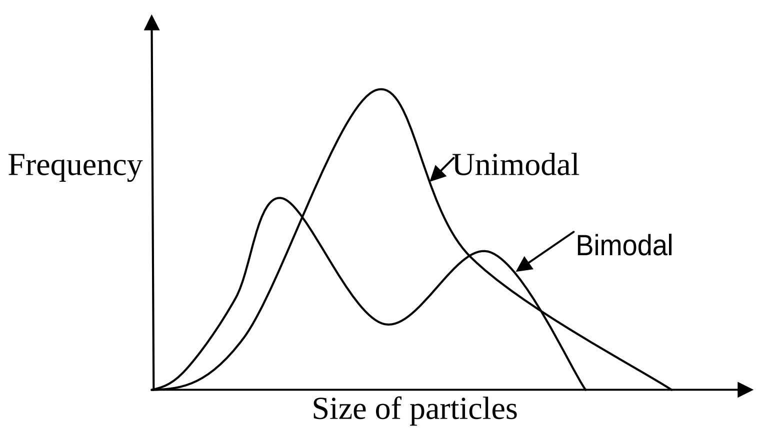

Figure 1.1 Unimodal and bimodal sediments

1.3 EXISTING METHODS FOR CALCULATION OF BEDLOAD:

Many relations and theories have been developed for uniform and non-uniform sediments to relate the bed load transport rate to the hydraulic condition and the sediment characteristics. All these methods are suitable for unimodal sediment only. Their performance for bimodal sediments is far from satisfaction. Some of the existing method of bed load calculation is described in succeeding paragraphs.

1.3.1 EINSTEIN'S APPROACH (1950):

Einstein was the first to attempt a semi-theoretical approach to the bed load transport of non-uniform sediments and developed following relationship for bed load transport

$$i_B q_B = \varphi_* \, i_b \, \rho_s \, g^{1/2} \, d^{3/2} (\rho_s / \rho_f - 1)^{1/2}$$

Where, i_B is the fraction of size d_i in the bed load transport rate q_B (wt/width-time). Hence $i_B q_B$ is the bedload transport rate for the size range d_i. i_b is the fraction of size d_i in bed sediment in the size range *d.* g is gravitational acceleration, ρ_s and ρ_f are mass density of sediment and fluid respectively.

1.3.2 ROORKEE APPROACH (1995):

Misri et al (1984), Samaga et al (1986), developed bed load transport of non-uniform sediments for wide range of flow conditions. Subsequently, Patel et al (1995) extended these relationships for extreme non-uniform sediments with wide range of flow conditions, which is applicable for unimodal non-uniform sediments. The method has been described in detail in chapter 2.

1.3.3 DIPLAS APPROACH (2006):

This approach of estimate bedload transport rates for bimodal sediments consists of dividing the bed material into two unimodal fractions, each with a representative particle diameter. Bagnold (1980) suggested the mode is a suitable choice for the unimodal sediment as a representative size. The basic equation of this approach is

$$q_b = f_s q_s + f_s q_s$$

Where, q_s and q_g are calculated bed load transport rates of sand and gravel, respectively and f_s and f_g are the sand and gravel fractions (%) in the original bed material and q_b is the total bed load transport rate. The detailed description of method is available else where (Diplas, 2006) and described in chapter 2.

1.4 SCOPE OF WORK:

The existing method particularly Roorkee's approach of bedload transport rate calculation are satisfactory for unimodal and weakly bimodal sediments, their accuracy for strongly bimodal sediment is uncertain and hence required to be checked for bimodal sediments.

1. To carry out rigorous review of the work on the bed load transport of non-uniform sediments.

2. To obtain data on bed load transport of bimodal non-uniform sediments from previous investigation.

3. To check Roorkee Approach (Patel et al , 1995) for its adequacy related to bed load transport of non-uniform bimodal sediments.

4. To develop a new relationship for bed load transport of non-uniform bimodal sediments taking into account the critical tractive stress (CTS) of bimodal sediments.

5. To compare the performance of developed relationship with existing relationship on bed load transport of non-uniform sediments.

Chapter-2

LITERATURE REVIEW

2.1 GENERAL

Starting from the contribution of Du Boys in 1879 on bed load calculation, several investigators have been developed the predictors for the prediction of the bed load transport rate by using field and laboratory data. Some of them are completely empirical in nature, while others obtained by either dimensional analysis or based on semi-theoretical approaches. Einstein was the first to attempt a semi-theoretical solution and consider the effect of nonuniformity of sediment. Some approaches for prediction of bed load transport are discussed in succeeding paragraphs.

2.2 METHODS FOR PREDICTION OF BED LOAD TRANSPORT:

The sediments in nature are either unimodal or bimodal. Accordingly, the methods for prediction of bed load transport can be grouped as

2.2.1 Computation of Bed Load Transport of Unimodal Sediments:

a) Einstein’s Method

b) Roorkee Approach

2.2.2 Computation of Bed Load Transport of Non-unimodal Sediments:

a) Diplas Approach

a) Einstein's Method (1950):

Einstein proposed a method on the basis of few assumptions, he assumed that

(1) A sediment particle moves if the instantaneous hydrodynamic lift force exceeds the submerged weight of the particle.

(2) Once the particle is in motion, the probability of deposition of particle is assumed equal at all points of the bed where the local flow would not immediately dislodge the particle again.

(3) The average distance travelled by any particle moving as bed load between consecutive points of deposition is assumed to be constant; this value is independent from the flow condition, the rate of transport and the bed condition.

The problem of bed load transport of nonuniform sediment is more complicated than that of a uniform sediment. Because in nonuniform sediments the size distribution of the transported sediments is significantly different from the size distribution of bed material while in the case of uniform sediments, the sediment in motion is not different from the sediment in the bed.

The definition of representative size for a nonuniform material is extremely difficult. Hence Einstein recommends the splitting up of the sediment mixture into various size ranges, determining the transport rate of these size ranges and than obtaining the total transport rate by summation of the individual rates. The bed load can be computed by the above method in following steps:

1. Select a straight reach of the stream under investigation where the flow is uniform. Determine the average energy gradient, bed slope S in the reach. Since the cross section of channel may vary along the reach, an average cross section needs to be obtained. For this purpose all the cross section are slid down along the slope to the last section of the reach ; from this superposition an average cross section can be found. Graph of stage vs area, stage vs hydraulic radius and stage vs wetted perimeter can be prepared for the average cross section. Also from sediment samples in the reach, determine an average size distribution curve for the bed material.

2. By assuming any reasonable value of R' (hydraulic radius corresponding to grain resistance), use the method of Einsteen and Barbarossa to get R (hydraulic radius), stage, U and Q.

3. Find the parameter X as follows:

$$X = 0.77 d_{65}/x \qquad \text{if } d_{65}/(\delta' x) > 1.80$$

$$X = 1.39\,\delta' \qquad \text{if } d_{65}/(\delta' x) < 1.80\ X$$

$$\delta' = 100.6 \nu / u_*'$$

Where, x = correction factor for viscous effects

ν = kinematic viscosity of fluid

u_*' = shear velocity corresponding to grain roughness

4. Find Y from fig (2.1) for the known value of d_{65}/δ'.
5. Find $\beta_x = \log(10.6X\ x/d_{65})$ and $\beta = \log(10.6)$.the calculations up to step 5 from the hydraulic computations and need to be done for different values of R' to cover the expected range of stage in the river.

6. Divide the bed material into convenient fractions, and determine their geometric mean sizes and availability in the bed i_b.

7. Find d/X and read ξ from fig. (2.2).
8. Find ψ and then ψ_* from the following equations:

$$\Psi = (\rho_s - \rho_f) d / \rho_f R'S \quad \text{and} \quad \Psi_* = \xi Y \psi (\beta/\beta_x)$$

9. Read φ_* for the above value of ψ_* from fig (2.3).
10. Compute the bed load rate $i_B q_B = \varphi_* i_b \rho_s g^{3/2} d^{3/2} (\rho_s / \rho_f - 1)^{1/2}$

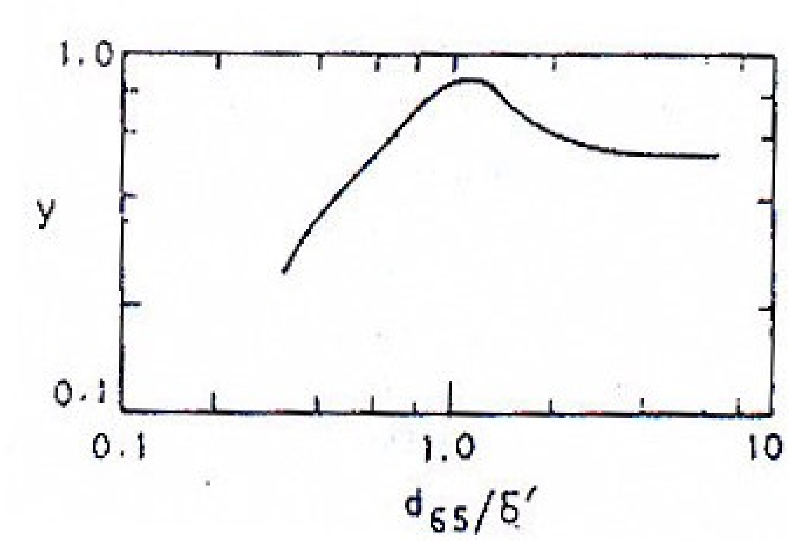

Fig. 2.1 Variation of Y with d_{65}/δ

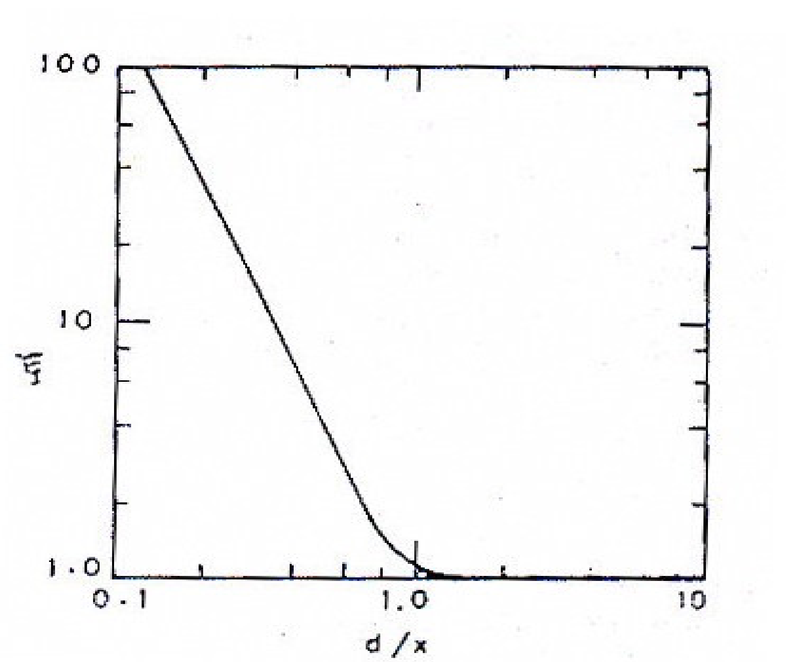

Fig. 2.2 Variation of ξ with d/X

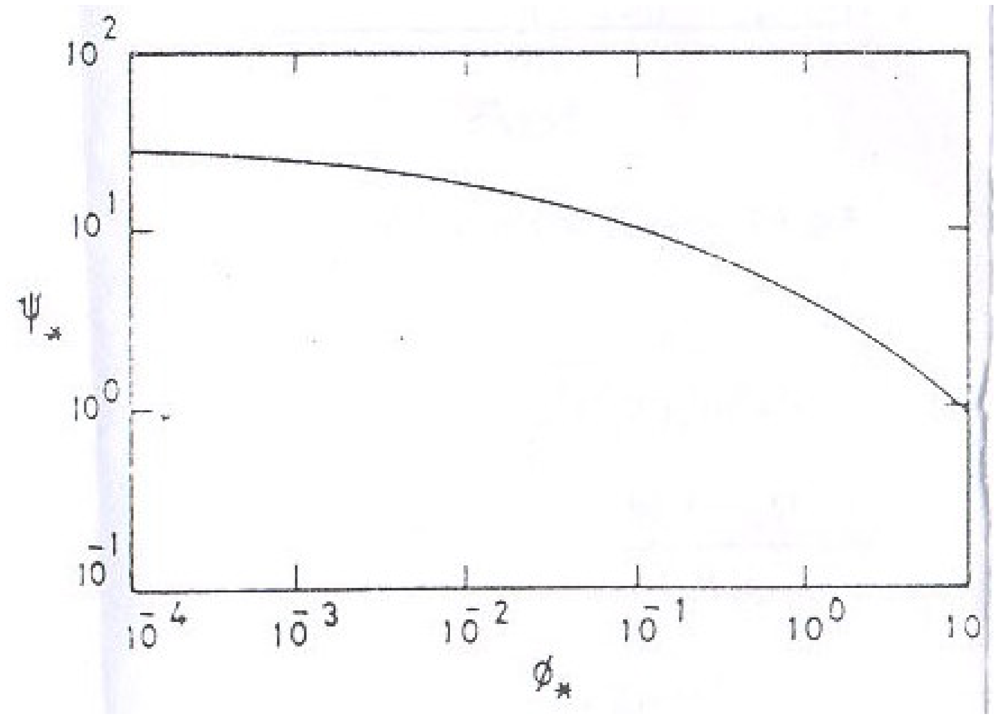

Fig.2.3 Einstein φ_* - ψ_* curve

b) Roorkee Approach:

Misri, Samaga, Patel and Ranga Raju have collected extensive data on partial bed load transport in a laboratory flume using sediment mixtures with size ranging from .07 mm to 40 mm and got the typical graph between $\tau_o'/(\Delta\gamma_s d_i)$ and φ_b based on their measurements (fig. 2.4). From that it can be seen that the transport of fractions coarser than the arithmetic mean size has increased while transport of fractions finer than the mean has decreased due to sheltering, if the relation for uniform sediment is used as the basis of comparison. Misri et al. introduced a parameter ξ_B defined as the factor by which $\tau_o'/(\Delta\gamma_s d_i)$ must be multiplied to get the dimensionless shear stress for use in finding $i_B q_B$. This parameter ξ_B is found to be a function of τ_o'/τ_{oc}', $\tau_o'/(\Delta\gamma_s d_i)$ and Kramer's coefficient *M.*

The coefficient C_m is a function of *M* as per the equations

$$C_m = 1 \qquad \text{for } M \geq 0.38$$

$$C_m = 0.7092 \log M + 1.293 \qquad \text{for } 0.05 \leq M < 0.38$$

Patel and Ranga Raju proposed a relationship between $C_m\ \xi_B$ and $C_s\ \tau_o'/(\Delta\gamma_s d_i)$.

$$C_m \xi_B = 0.0713\left(\frac{c_s \tau_o'}{\Delta\gamma_s d_i}\right)^{-0.75144} \qquad \text{……2.1}$$

In which C_s is the function of $\tau_o'/\ \tau_{oc}'$ and can be expressed as

$$\log C_s = -0.1957 - 0.9571\left(log\frac{\tau_o'}{\tau_{oc}}\right) - 0.1949\left(log\frac{\tau_o'}{\tau_{oc}}\right)^2 + 0.0644\left(log\frac{\tau_o'}{\tau_{oc}}\right)^3 \qquad \text{…..2.2}$$

Here τ_{oc} is the critical shear stress for the arithmetic mean size of the mixture as per Shields. Finally Patel and Ranga Raju plot a graph between $\xi_B\ \tau_o'/\ (\Delta\gamma_s d_i\ )$ v/s φ_b for all the available data. Here

$$\emptyset_B = \frac{i_B q_B}{i_b \gamma_s}\sqrt{\left(\frac{\gamma_f}{\Delta\gamma_s g d_i^3}\right)} \qquad \text{………2.3}$$

The bed load can be computed by the above method as described below

1. Divide the bed material into convenient fractions, and determine their geometric mean sizes and availability in the bed i_b.
2. Compute τ_{oc} for size d_a using shield's curve and also find τ_o'.
3. Determine M for the mixture and C_m from above mention equation.
4. Compute C_s for the known values of $\tau_o'/\ \tau_{oc}'$ from Eq.2.2.
5. Compute ξ_B for known size d_i from eq.2.1 and than compute $\xi_B\ \tau_o'/(\Delta\gamma_s d_i)$.
6. Read φ_B from figure 2.1 and determine $i_B q_B$ as

$$i_B q_B = i_b \gamma_s\ \varphi_B (g d_i^3)^{1/2} (\Delta\gamma_s/\gamma_f)^{1/2} \qquad \text{……2.4}$$

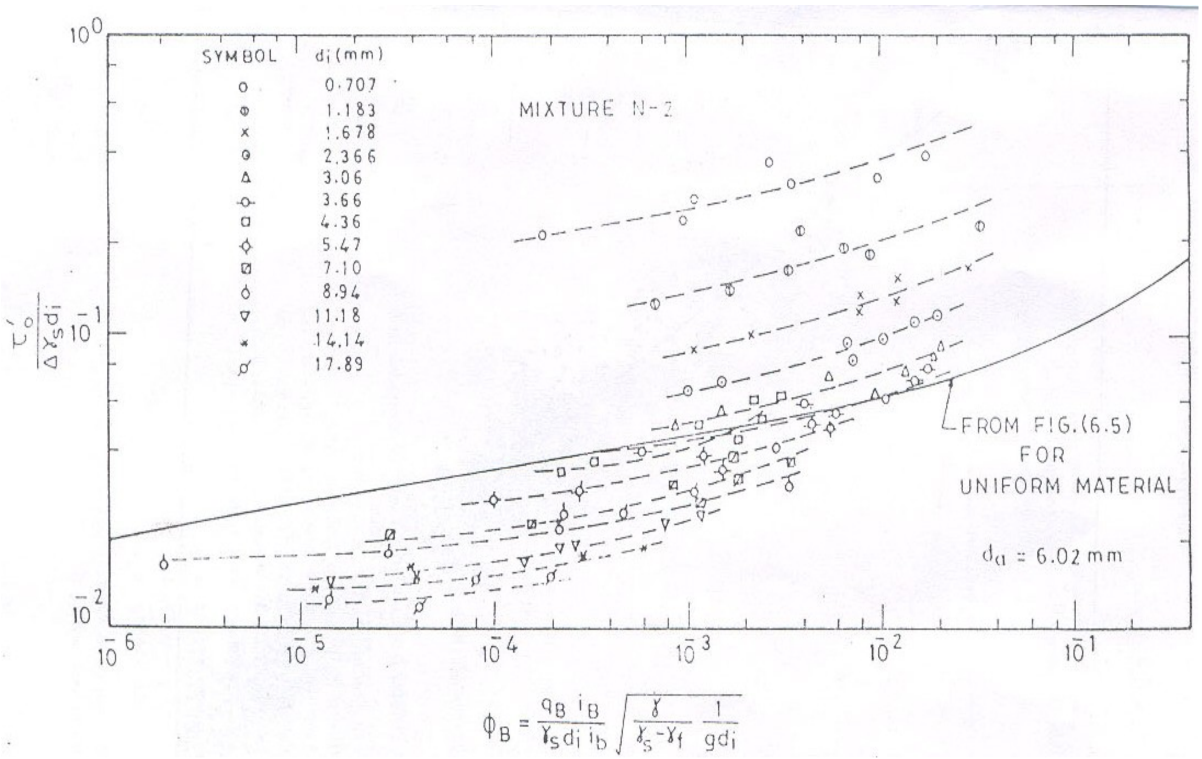

Fig 2.4 Comparison of data on transport of different fractions in a mixture with relationship for uniform material

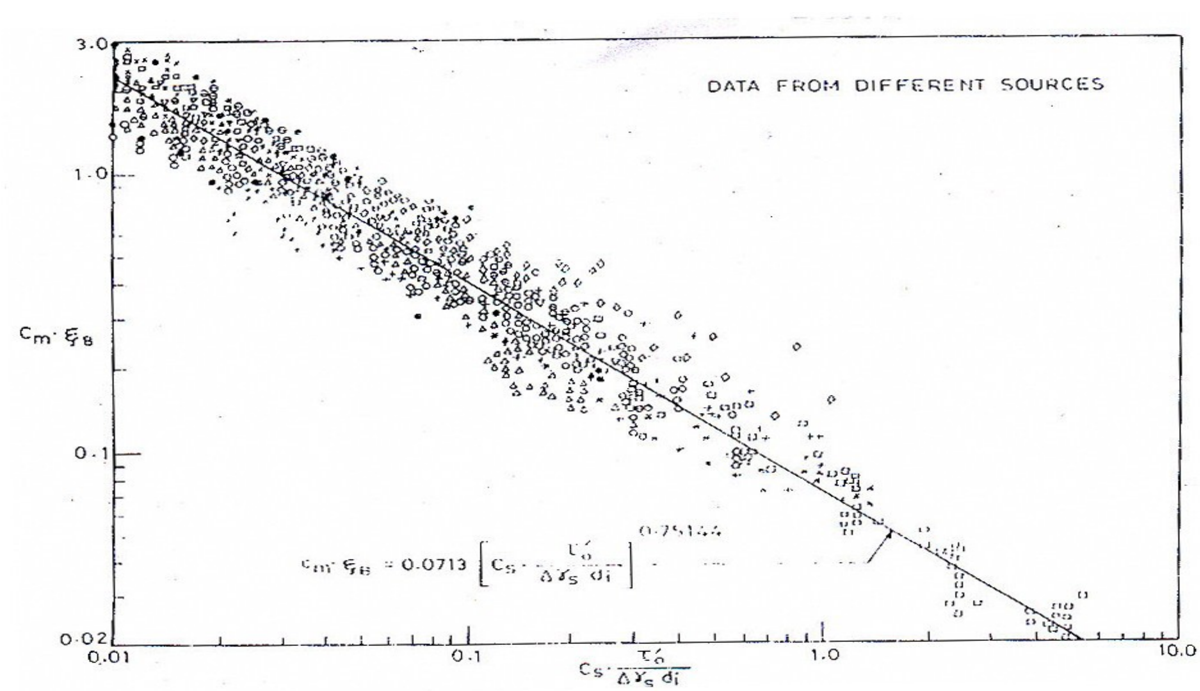

Fig 2.5 Variation of $C_m\xi_b$ with $C_s\, \tau_o'/(\Delta\gamma_s d_i)$

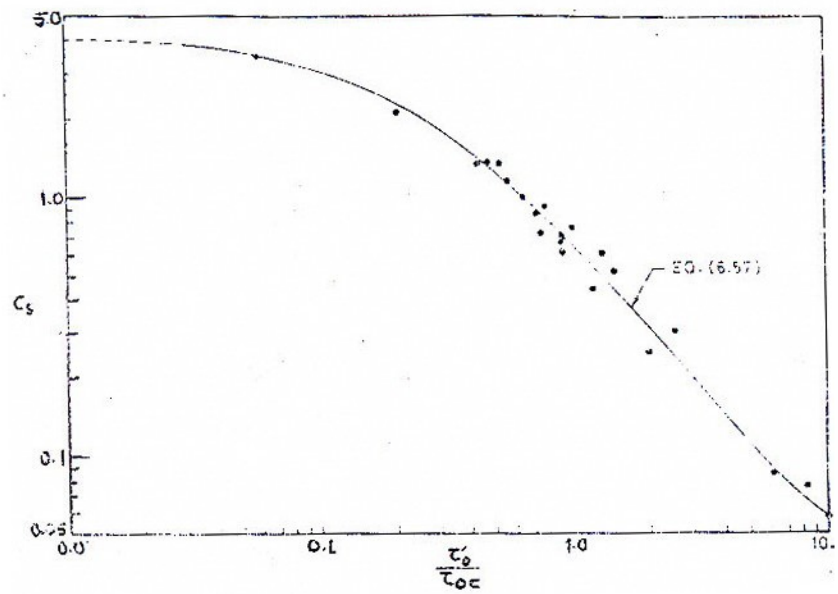

Fig. 2.6 Variation of C_s with τ_o'/τ_{oc}'

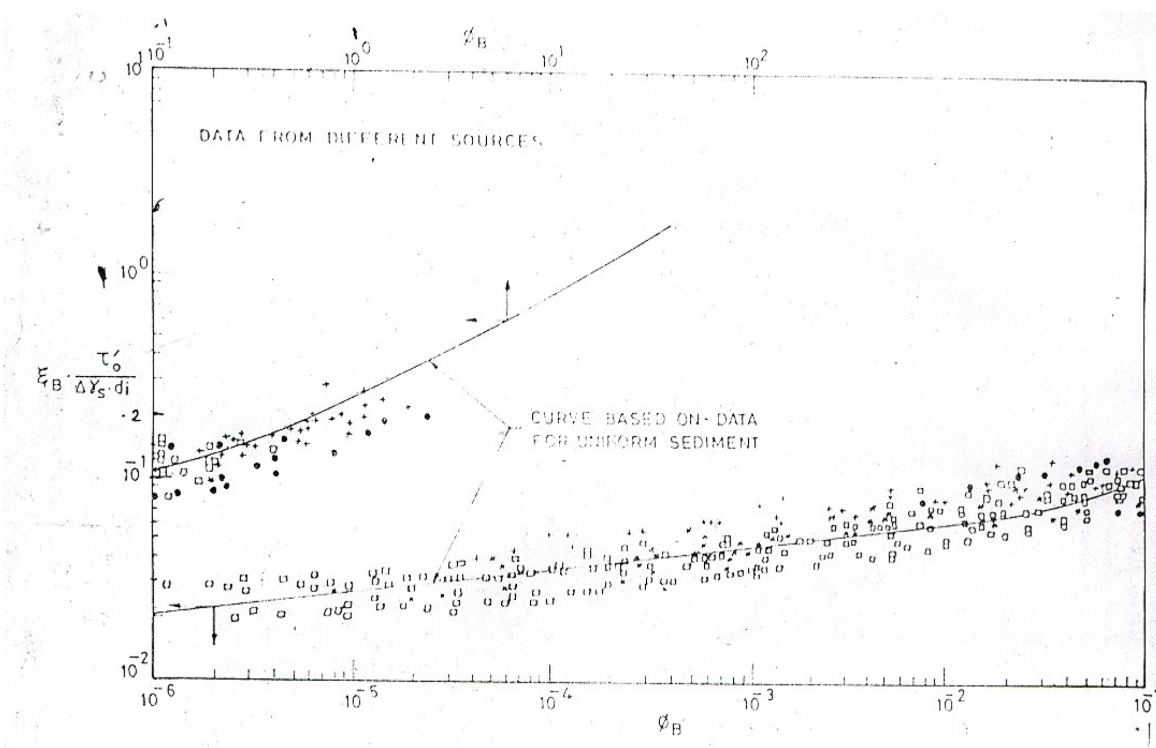

Figure 2.7 Field data plotted on bed load transport law for nonuniform sediments

c) Diplas approach:

Diplas's approach to estimate the bed load transport rate for bimodal sediment consists of dividing the bed material into two unimodal fractions, each with a representative particle diameter (mode is a suitable choice for unimodal sediment). By assuming two independent unimodal components of sand and gravel, the total bed load transport rate q_b can be expressed as

$$q_b = f_s q_s + f_s q_s \qquad \text{...........2.5}$$

Where, q_s and q_g are calculated bed load transport rates of sand and gravel, respectively and f_s and f_g are the sand and gravel fractions (%) in the original bed material. dimensionless form of this equation is

$$W^* = f_s W_s^* + f_g W_g^* \qquad \text{.........2.6}$$

Where, $W^* = \frac{R_s q_B}{\sqrt{g}(dS)^{1.5}}$

In which W*= Total dimensionless bedload transport rate

R_s = Submerged specific gravity of sediment

g = Gravitational acceleration, d = Flow depth, S= Energy slope and

$$W_s^* = \frac{1}{0.132\tau_s^{*-0.35} + 10^{-9.59}\tau_s^{*-7.95}} \qquad W_g^* = \frac{1}{0.132\tau_g^{*-0.35} + 10^{-9.59}\tau_g^{*-7.95}}$$

are dimensionless bed load transport rates of sand and gravel respectively. Where τ_s* and τ_g*= shield stresses based on the mode of sand and gravel respectively. The shield stress parameter is expressed as $\tau_s^* = dS/R_sD_s$ and $\tau_g^*=dS/R_sD_g$. Diplas plot the graph (fig.2.2) between the observed total bedload transport rate and calculated bedload transport rate and found that decreasing the amount of sand in bimodal materials increase the error in the bed load transport rate using this approach.

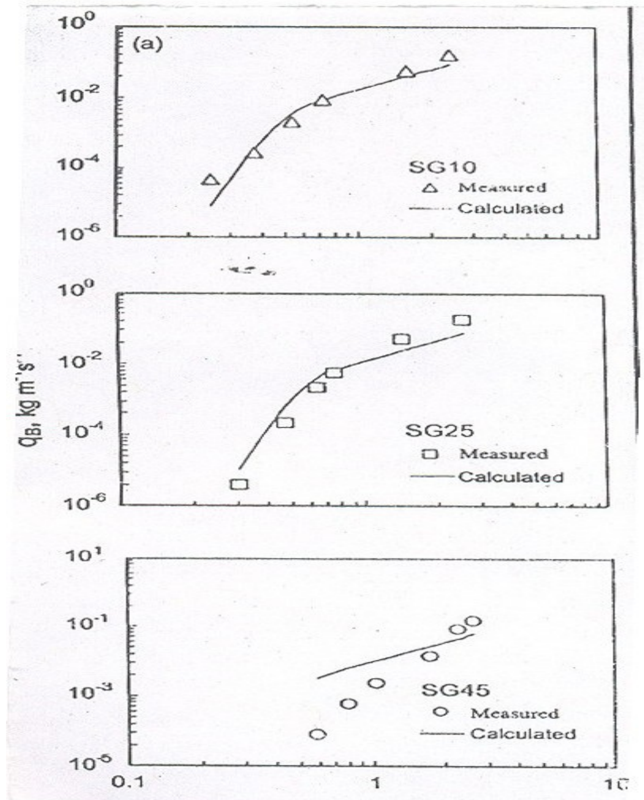

Figure 2.8 Measured bedload transport v/s bed shear stress for SG data

Chapter-3

SOURCE OF DATA

3.1 General:

The data related to sediment mixture are collected from the previous investigations related to bimodal sediments. These data have been used to check the accuracy of the existing method of Patel and Ranga Raju (1995) for bed load transport and develop new relationship based on critical tractive stress approach of bimodal sediment.

3.2 Characteristics of Sediment Mixtures:

The characteristics of different bimodal sediment used in the present study are summarized in Table 3.1 along with their data source.

Table 3.1 Characteristics of Sediment Mixtures

Mixture	B	M	σ_g	d_σ	d_a	$\tau^*_{c\sigma}$	Data Source
SG10	2.49	0.21	1.83	1.11	1.05	.01762	Kunhle (1994)
SG25	2.6	0.116	3.8	3.56	1.89	.01263	Kunhle (1994)
SG45	2.73	0.084	4.1	6.01	2.85	.01170	Kunhle (1994)
J27	2.49	0.105	5.49	33.30	12.72	.01131	Wilcock (2001)
BMC	2.63	0.061	6.73	39.86	10.57	.00880	Wilcock (2001)

The size distribution of selected bimodal sediment are given in tabular form below

Table 3.2 Grain size distribution of Sediment Mixtures

Mixture Name → / Size (in mm) ↓	SG10	SG25	SG45	J-27	BMC
0.2102	2.5	2.1	2	0.1	0

0.25	**7**	3.5	3	2.9	1.7
0.2973	9.6	8.5	6.8	3.5	3.3
0.3536	18.5	14	9.8	2.1	1.3
0.4204	20.5	11	8.8	3.4	2.6
0.5	9.6	14.4	9.7	2.1	1.5
0.5946	6.5	7.6	5.2	1.9	0.9
0.7071	6.5	3.6	2.5	1.8	0.8
0.8409	1.2	3	2.6	1.4	0.6
1	3	2	1.4	1.7	1
1.1892	1.5	1.6	1	3.3	1.6
1.4142	1	1.4	1.2	3.2	1.3
1.6818	1	0.8	.8	1.6	1.1
2	0	0.2	.2	1.3	1.5
2.3784	0	0	0	3.5	3.1
2.8284	0.2	0.5	.8	3	2.9
3.3636	0.5	1.4	2	5	4.1
4	1.4	5.4	8.2	4.4	4.5
4.7658	3.5	6.6	10.8	3.8	3.5
5.6569	1.8	6.7	11	3.8	3.4
6.7272	1.4	4.5	9.6	3.5	3.1
8	0.5	1	2	3	2.8
9.51				3.7	3.3
11.31				3.4	3.2

13.45				5.6	5.2
16				5.6	5
19.02				5.4	5
22.63				5.5	4.9
26.90				3.5	2.9
32				3.1	2.4
38.05				1.9	1.6
45.26				1.9	2.2

Chapter-4

ANALYSIS OF DATA

4.1 GENERAL:

The data obtained from previous investigations are analyzed to calculate the bed load transport rate of the sediment mixtures by Patel et al. (1995) method and the same is compared from observed transport rates. A new relationship is developed based on critical tractive stress from approach of nonuniform sediments. The performance of new relationship is compared with existing relationship, i.e. Patel et al. (1995).

4.2 BIMODALITY PARAMETER (B):

The degree of bimodality and its effect on transport should depend on the separation in grain size between the two modes and the proportion of sediment contained in the modes (Wilcock, 1993). Wilcock expressed a relation for bimodality parameter as

$$B = (Dc / D_F)^{1/2} \sum P_m \qquad \text{……….4.1}$$

Where, D_c/D_f is used to represent mode separation while the proportion of sediment in the mode is expressed here as the sum in both modes $\sum P_m$. The proportion of sediment in each mode in bimodal sediment depends on mode width. A mode is assumed to have a width of one φ unit (factor of two). Each mode is defined as the four contiguous ¼ φ units containing the largest proportion. Wilcock concluded from flume and field data that only sediment with B > 1.7 had different entrainment and transport properties than sediments with a value of B < 1.7. Hence, accordingly those sediments with B > 1.7 are classified as bimodal sediments. Several data were collected from literature and only those with B > 1.7 are selected for our study.

4.3 VERIFICATION OF ROORKEE APPROACH (1995):

Transport rate of bimodal sediment, described in chapter-3 were calculated using Patel et al. (1995), described in chapter-2, for given fluid sediment and flow characteristics. Computed fractional bedload transport rates are compared with observed ones, see fig. 4.1 to 4.5. Also, total observed bed load transport rates are compared with corresponding computed rates.

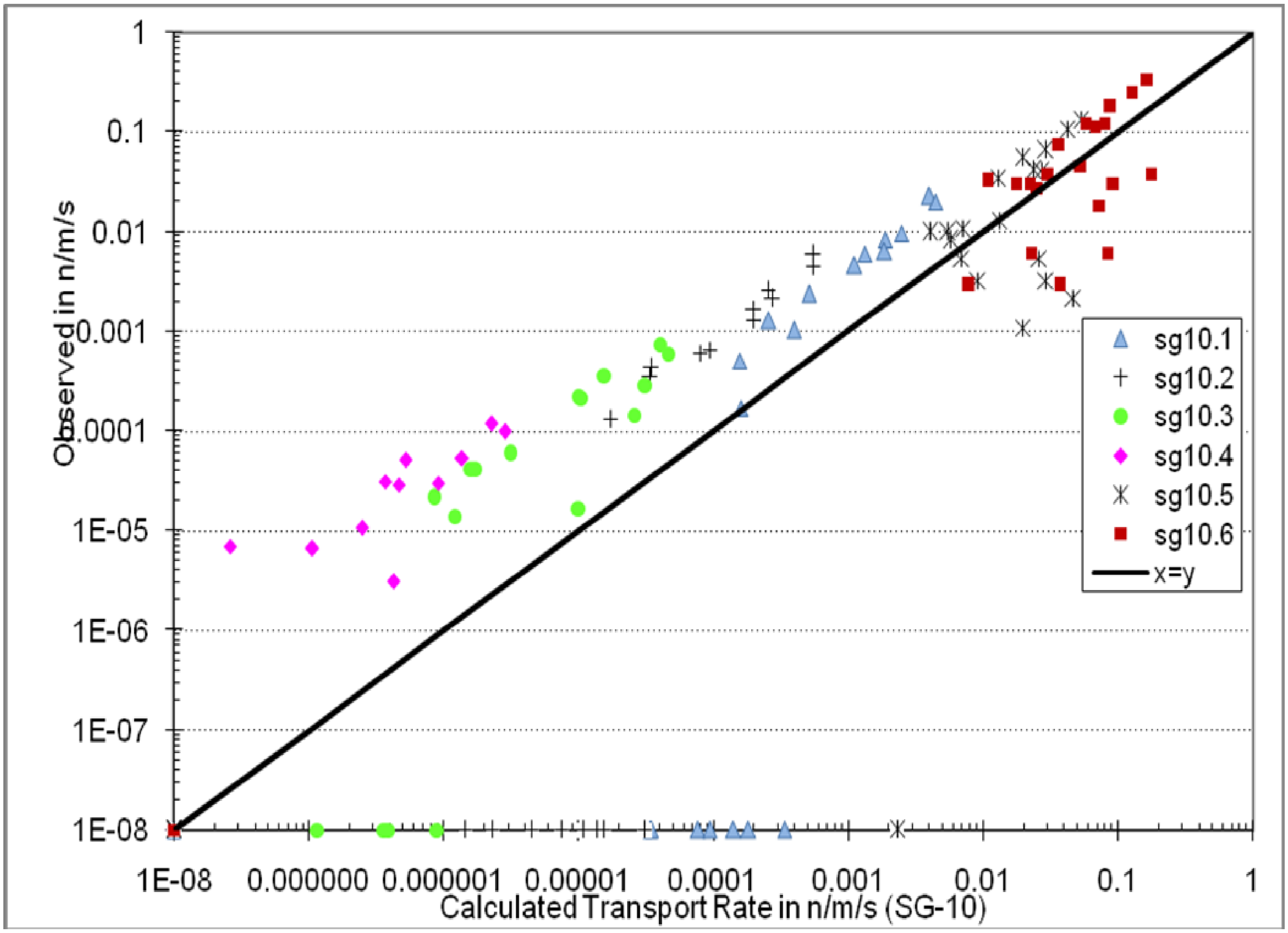

Fig. 4.1 Comparision of Observed and Calculated Fractional Transport Rate of Mixture SG-10

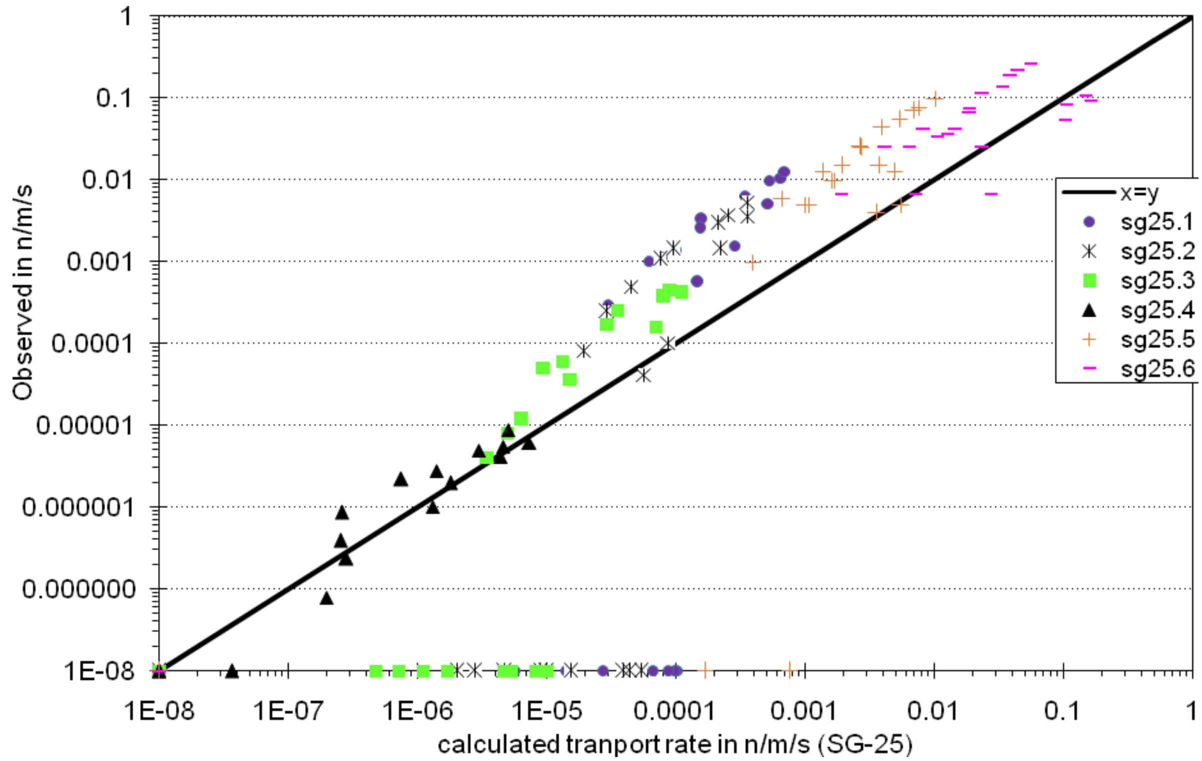

Fig 4.2 Comparision of Observed and Calculated Fractional Transport Rate of Mixture SG-25

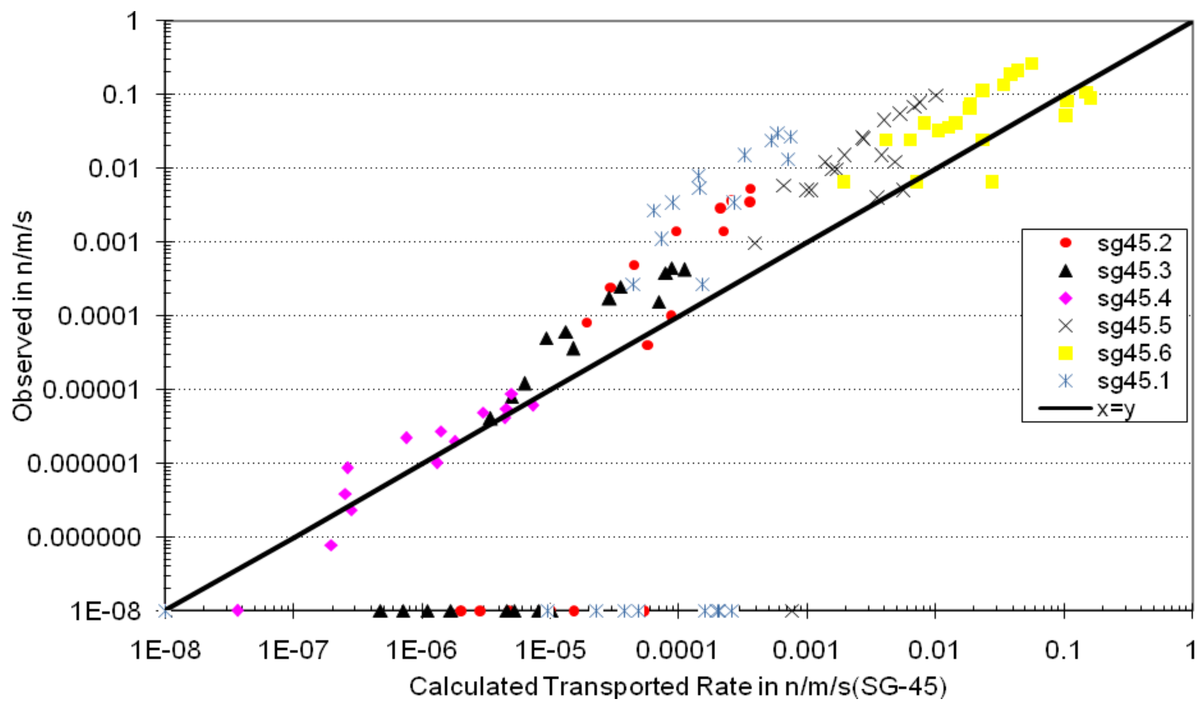

Fig. 4.3 Comparision of Observed and Calculated Fractional Transport Rate of Mixture SG-45

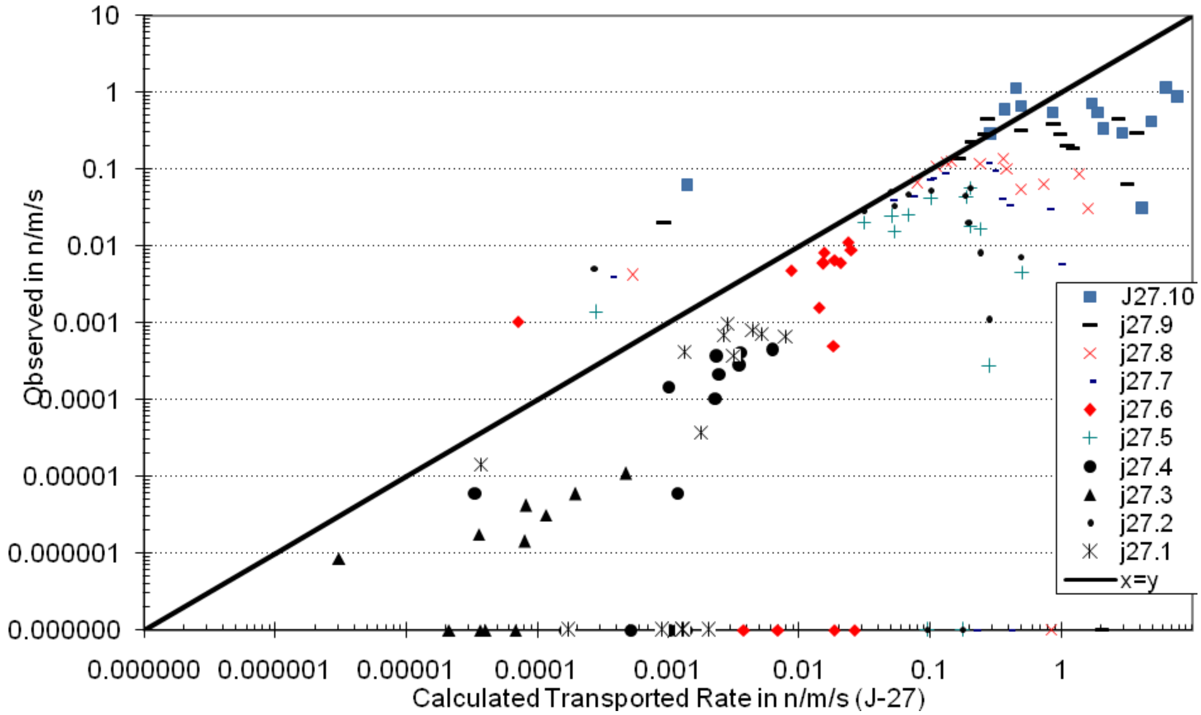

Fig. 4.4 Comparision of Observed and Calculated Fractional Transport Rate of Mixture J-27

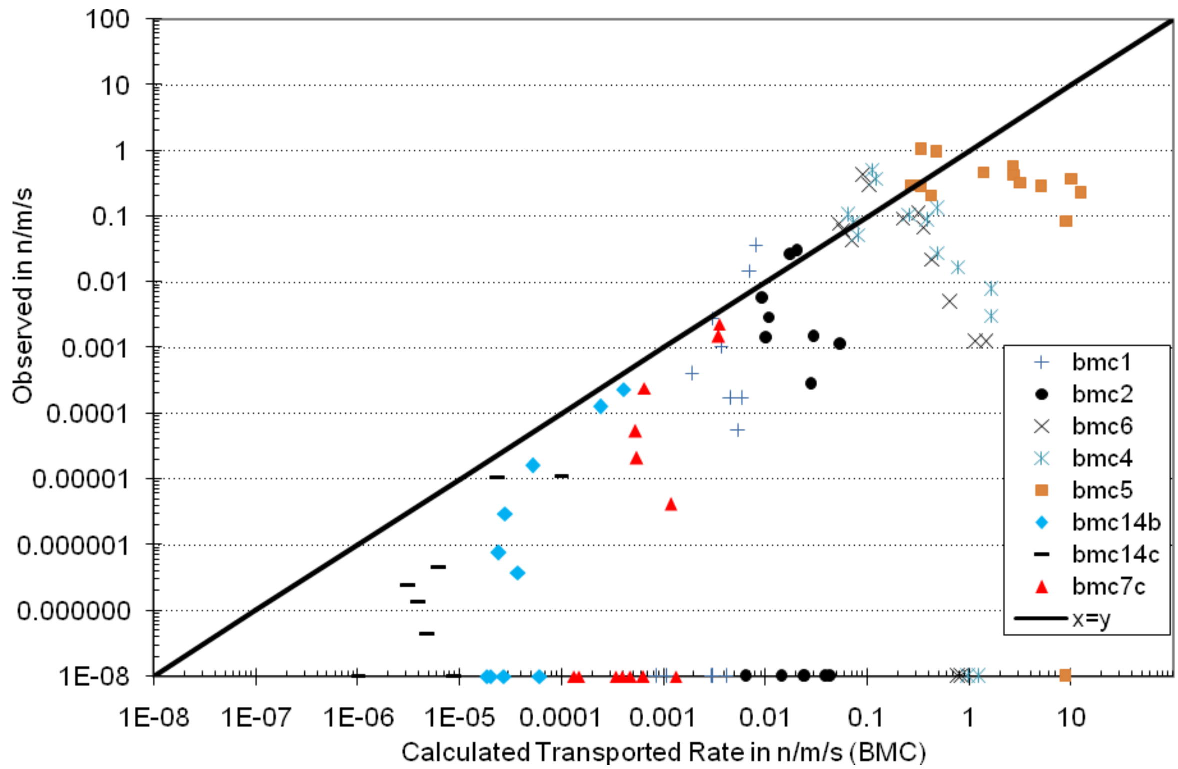

Fig. 4.5 Comparision of Observed and Calculated Fractional Transport Rate of Mixture BMC

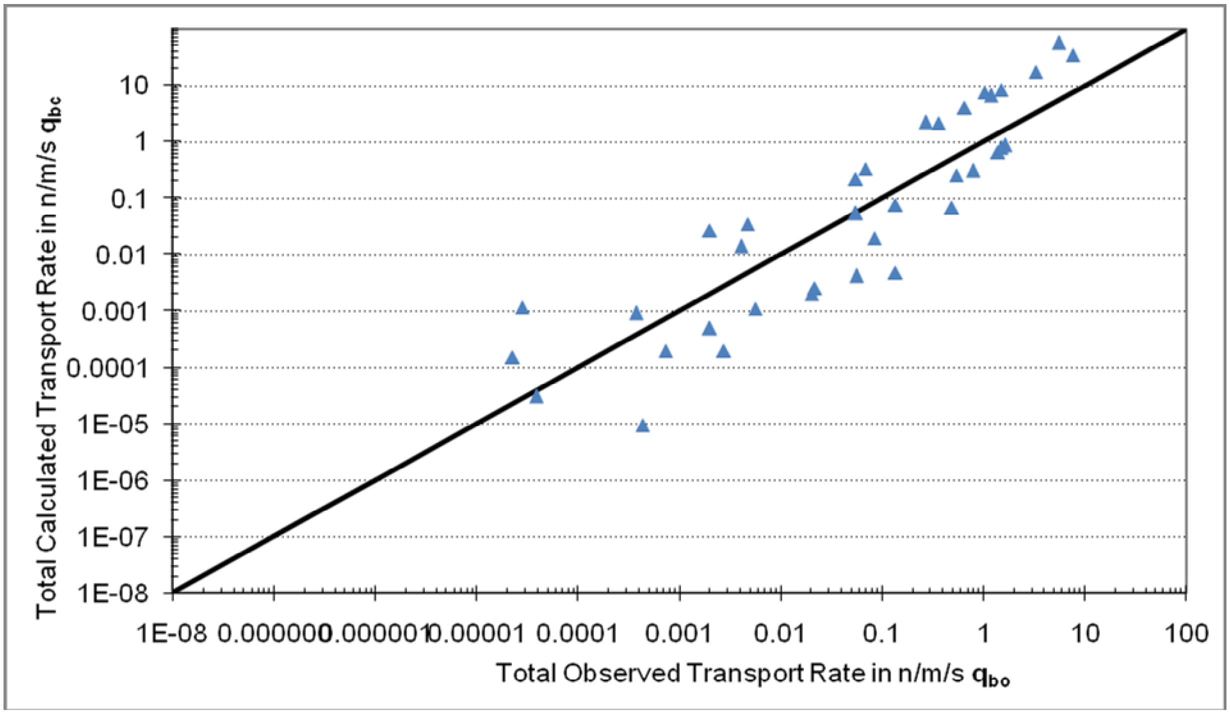

Fig. 4.6 Comparision of Observed and Calculated Total Transport Rate of all Mixtures

4.4 DEVELOPMENT OF NEW RELATIONSHIP:

4.4.1 Exposure and Sheltering Effect:

In nonuniform sediment the coarser gravel becomes more exposed to the hydrodynamic forces and can be moved by shear stresses lower than that necessary for the same uniform sized sediment. The situation is reversed for the finer fraction due to their sheltering in the wakes of gravel fractions, thus sand mode in bimodal sediment requires a higher shear stress to move as compared to that necessary for the same size sediment available on uniform sediment bed. This exposure and sheltering effect can be seen from plot developed between $\tau_o'/\Delta\gamma_s d_i$ vs φ_{bi}. The exposure and sheltering parameter defined by Misri et el. can be expressed as

$$\xi_b = \tau_{eff}' / \tau_o' \qquad \text{........4.2}$$

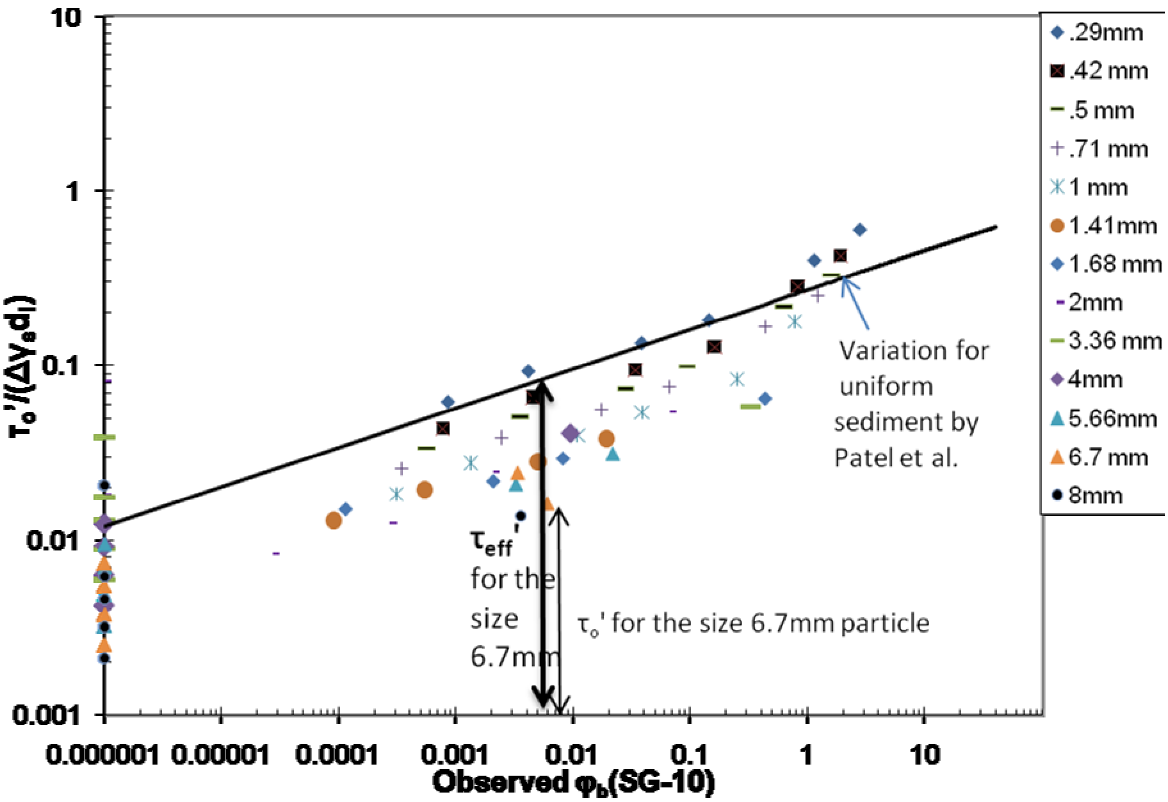

Fig 4.7: Exposure and Sheltering Effect of Bimodal Sediments (SG-10)

Exposure cum sheltering parameter, ξ_b was calculated for all sizes of different mixture for given flow conditions.

4.4.2 Identification of Parameters of New Relationship for a Particular Mixture:

All available data were grouped into different range of $\tau_o^{'}/\tau_{ci}$ for a particular mixture and plotted in the form of ξ_B v/s $(\tau_o^{'}/\Delta\gamma_s d_i)$, see fig.4.8. Here τ_{ci} is the critical tractive of a particular size fraction, d_i and its method of calculation is described as follows:

For calculation of the CTS for bimodal sediment the following Patel et al.(1999) equation is used

$$C\,\frac{\tau_{ci}^{*}}{\tau_{c\sigma}^{*}} = \left(\frac{d_i}{d_\sigma}\right)^{-0.96} \qquad \ldots\ldots\ldots\ldots 4.3$$

Where, C = 1;   for B < 1.7

$= 1.1\ (d_i/d_\sigma)^{-n}$;   for $B > 1.7$

$n = 0.086\ \sigma_g^{-0.12}$

d_i = geometric mean of two sieve sizes d_1 and $d_2 = \sqrt{(d_1 d_2)}$

d_σ = representative size = $d_g.\ \sigma_g$

d_g = geometric mean size, $\log d_g = \sum (\log d_i.\Delta p_i)/100$

σ_g = geometric standard deviation of sediment mixture = $\sqrt{(d_{84}/d_{16})}$

$\tau^*_{c\sigma} = 0.06\ (\sigma_g)^{-1.87}(d_\sigma)^{0.37}$ = dimensionless CTS of representative size d_σ

τ^*_{ci} = dimensionless CTS of size fraction d_i.

τ_{ci} = CTS of size fraction $d_i = \tau^*_{ci}/\Delta\gamma_s d_i$

From fig. 4.8, it can be seen that ξ_B vs $(\tau_o'/\Delta\gamma_s d_i)$ shows a systematic variation with τ_o'/τ_{ci} as third parameter,all the data points corresponding to different τ_o'/τ_{ci} were brought on single line corresponding to $\tau_o'/\tau_{ci} = 2.11$ by applying correction factor C_p see fig.4.9. Similar process is repeated for other mixtures also and a plot of C_p vs. τ_o'/τ_{ci} is prepared as shown in fig.4.10. The relationship between C_p and $\tau o'/\tau_{ci}$ can be expressed as

$$\mathbf{C_p = 2.01(\tau_o'/\tau_{ci})^{-0.90}} \qquad \text{……….4.4}$$

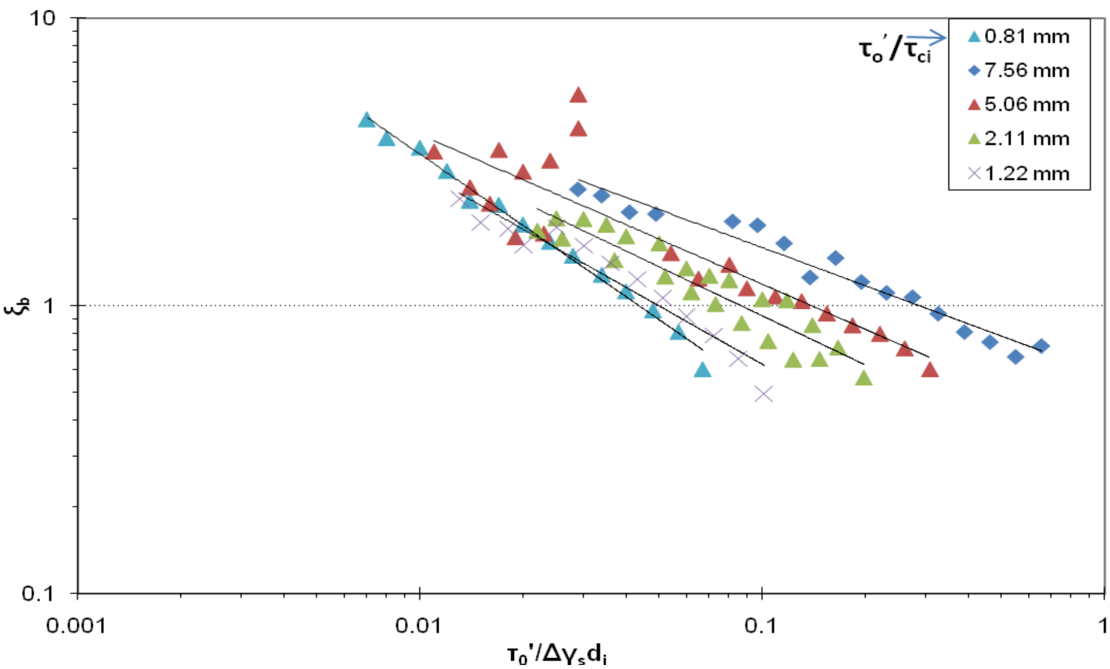

Fig 4.8: Variation of ξ_b v/s ($\tau_o^{'}/\Delta\gamma_s d_i$) for mixture SG-10

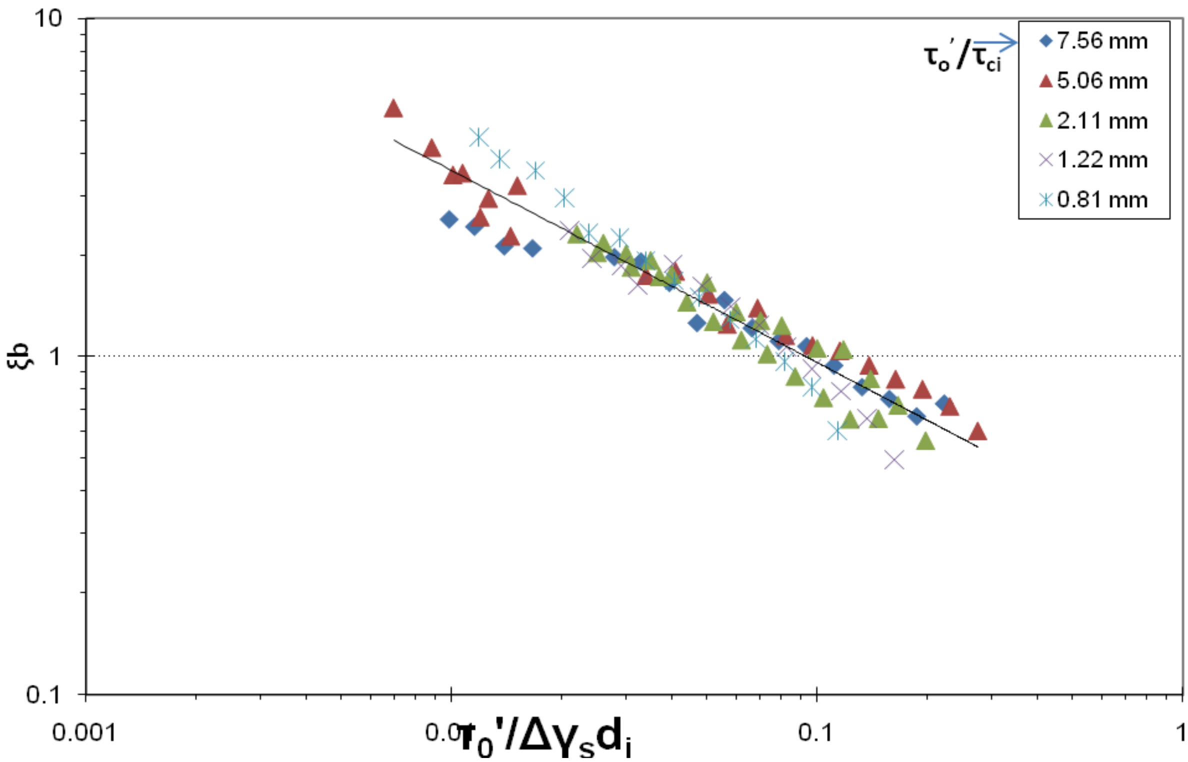

Fig 4.9: Variation of ξ_b v/s ($\tau_o^{'}/\Delta\gamma_s d_i$) after applying correction factor for SG-10

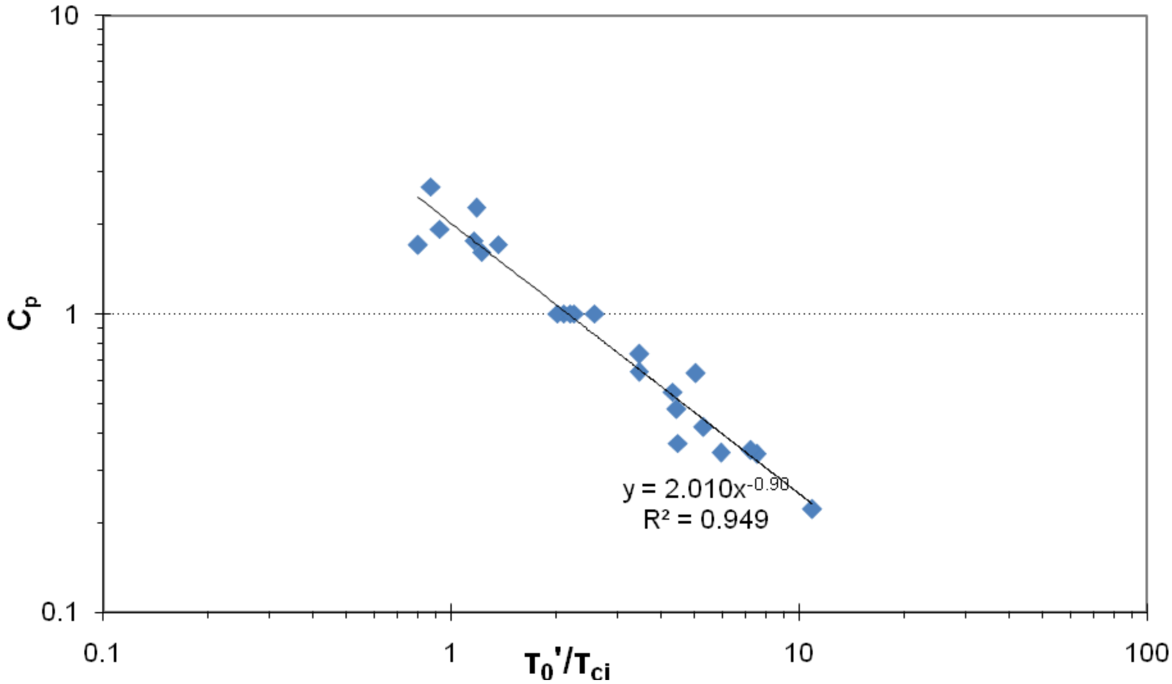

Figure 4.10: Variation of C_p v/s $\tau_o^{'}/\tau_{ci}$

The plot of ξ_b v/s (C_p $\tau_o'/\Delta\gamma_s d_i$) were prepared for all the mixture and their best fit curve were plotted on single plot to explore any possibility of third parameter like B, σ_g or M. however, these parameters did not show any influence at this stage may be their effects have already been accounted for in critical tractive stress $\tau_{ci.}$

All the data points of all mixtures were brought together on single plot of ξ_b v/s (C_p $\tau_o'/\Delta\gamma_s d_i$) see fig. 4.9. The best fit equation through data come be expressed as

$$\boldsymbol{\xi_b = 0.151(C_p.\ \tau_o^{'}/\Delta\gamma_s d_i)^{-0.67}} \qquad \ldots\ldots\ldots 4.5$$

Where, C_p= correction factor and can be calculate by equation 4.4.

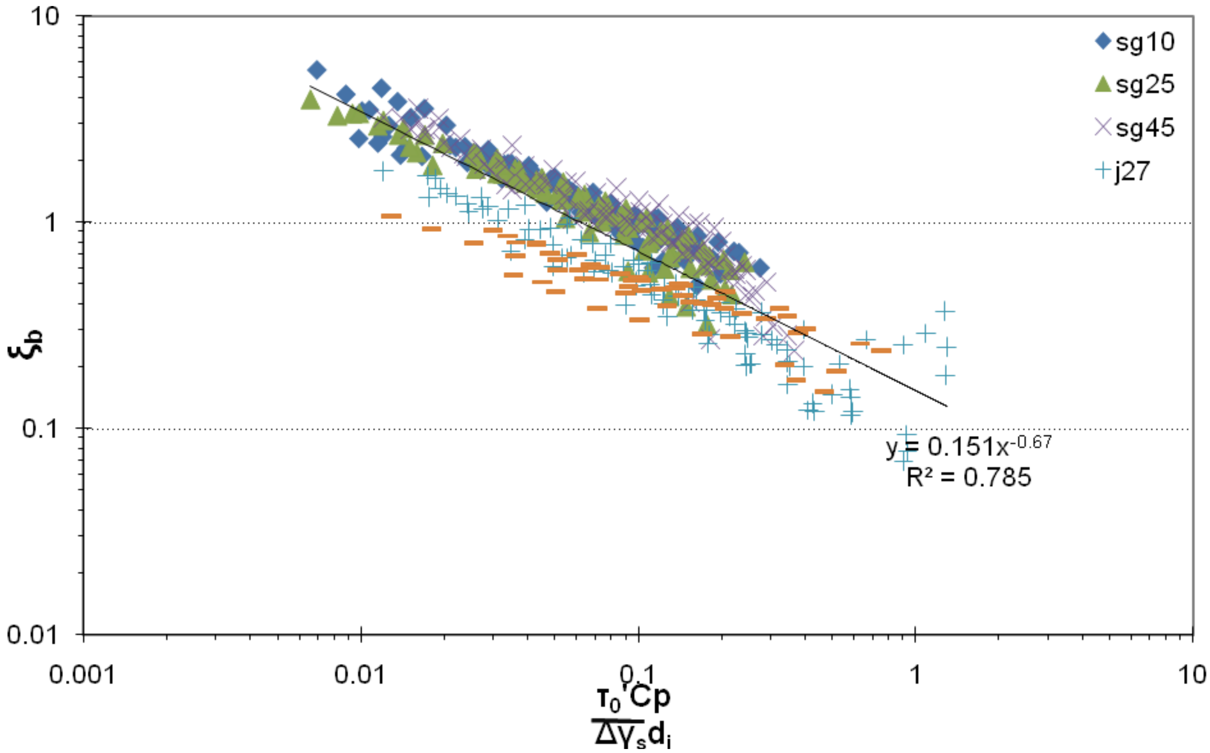

Fig 4.11: Variation of ξ_b v/s (C_p τ_o'/$\Delta\gamma_s d_i$) of all mixtures in a single plot

Thus using Eq. 4.4 and 4.5 and uniform sediment transport law fig.2.4, bed load transport of a particular size fraction can be calculated. Proposed relationship in computation of bed load transport of bimodal sediments the following steps are used in computation of bed load transport using present method:

1. Divide the bed material into different size fractions, and determine corresponding proportion in bed mixture, i_b.
2. Compute geometric mean size d_g and σ_g of sediment mixture.
3. Calculate critical tractive stress τ_{ci} for the different fractions by Patel et al.(1999) method describe in 4.3.and also calculate $\tau_o^{'}$ by following relationship

$$\tau_o^{'} = \gamma_f R' S_0$$

$$U = R'^{2/3} S_0^{1/2}/n' \text{ and } n' = d_{65}^{1/6}/24$$

4. Determine C_p for the known value of τo'/ τ_{ci}. From Eqn.4.4
5. Compute ξ_b for known size d_i from eqn. 4.5 and than compute ξ_B τ_o'/($\Delta\gamma_s d_i$).
6. Read φ_B from fig 2.4 and determine $i_B q_B$ from following eqn.

$$i_B q_B = i_b \gamma_s \, \varphi_B (g d_i^3)^{1/2} (\Delta\gamma_s/\gamma_f)^{1/2}$$

7. total transport rate could be summation of all fractional transport rates

   $q_B = \sum i_B q_B$

   A sample calculation for a sediment mixture is appended in appendix 2.

4.5 performances of existing method with Patel and Ranga Raju Method (1995):

Using above proposed method, the bedload transport rate for different fractions are compared with observed values of bedload transport (fig. 4.12 to 4.16). Also, the total transports of different sediment mixtures are plotted for different flow conditions. The computed total bed load transport rates are compared with observed total bedload transport rates. Also, the computed values of total bed load transport ratio are expressed in terms observed bed load transport rates for both the methods and included in table 4.1 and table 4.2. It is evident that performance of proposed method is relatively better than Patel et al. (1995) method which was developed for unimodal and weekly bimodal sediments.

Table 4.1 Comparison between proposed method and Patel and Ranga Raju (1995) method

Calculated transport rates in terms of observed transport rates							
Total no of data points	**Mixture name**	**Proposed model**			**Patel et al(1995)**		
		1/2 to 2 of observed	**1/3 to 3 of observed**	**1/4 to 4 of observe**	**1/2 to 2 of observed**	**1/3 to 3 of observed**	**1/4 to 4 of observe**
85	**SG10**	33	46	51	17	30	37
88	**SG25**	40	64	69	23	31	40
97	**SG45**	30	47	73	24	39	49
111	**J27**	17	34	51	26	41	52
97	**BMC**	17	27	29	15	26	32

Table 4.2 Comparison b/w recommended method and Patel and Ranga Raju method for total transport rate

Total calculated transport rates in terms of total observed transport rates							
Total no of data	Mixture names	Proposed model			Patel et al(1995)		
		1/2 to 2 of observed	1/3 to 3 of observe	1/4 to 4 of observed	1/2 to 2 of observed	1/3 to 3 of observed	1/4 to 4 of observed
38	All mixtures	9	15	24	5	9	12

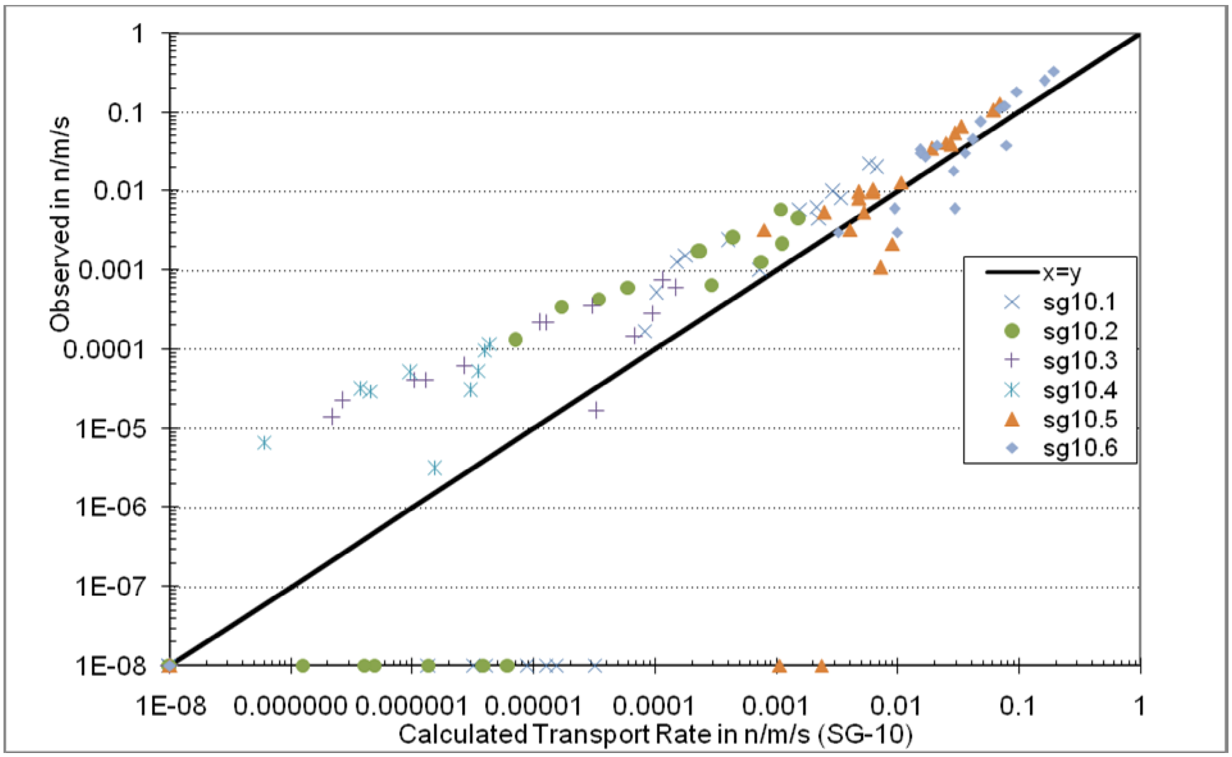

Fig 4.12 Comparision of Observed and Calculated Fractional Transport Rate of Mixture SG-10

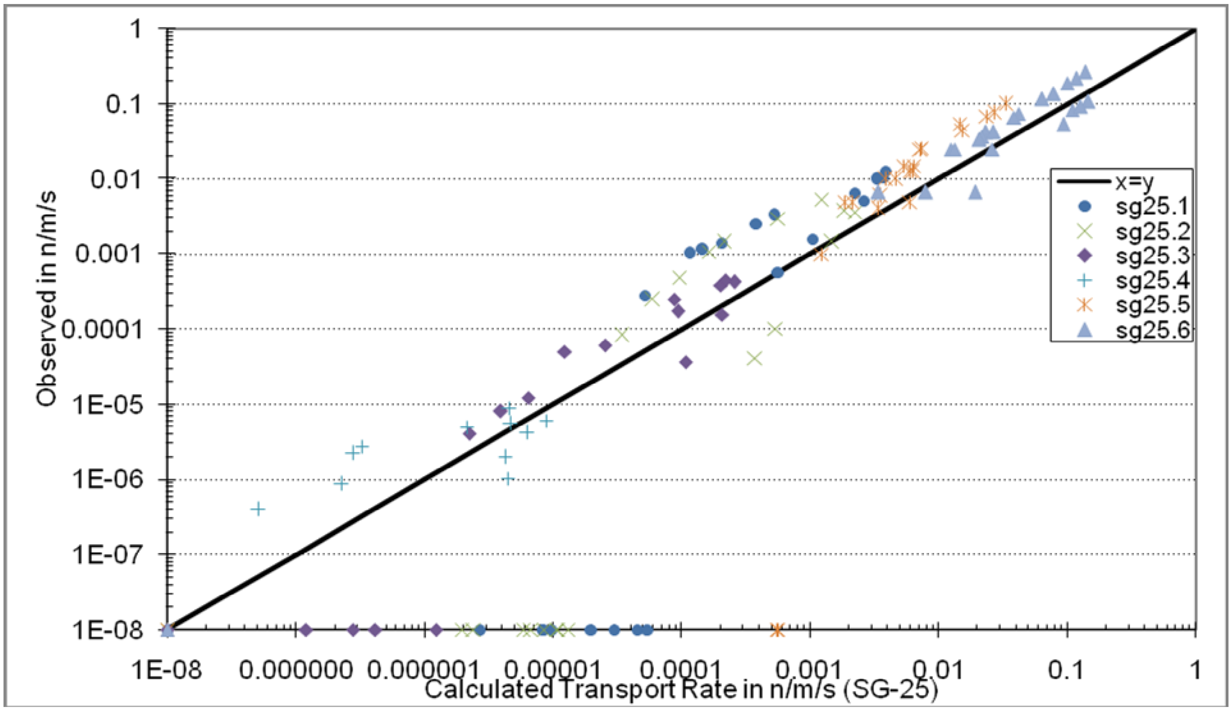

Fig 4.13 Comparision of Observed and Calculated Fractional Transport Rate of Mixture SG-25

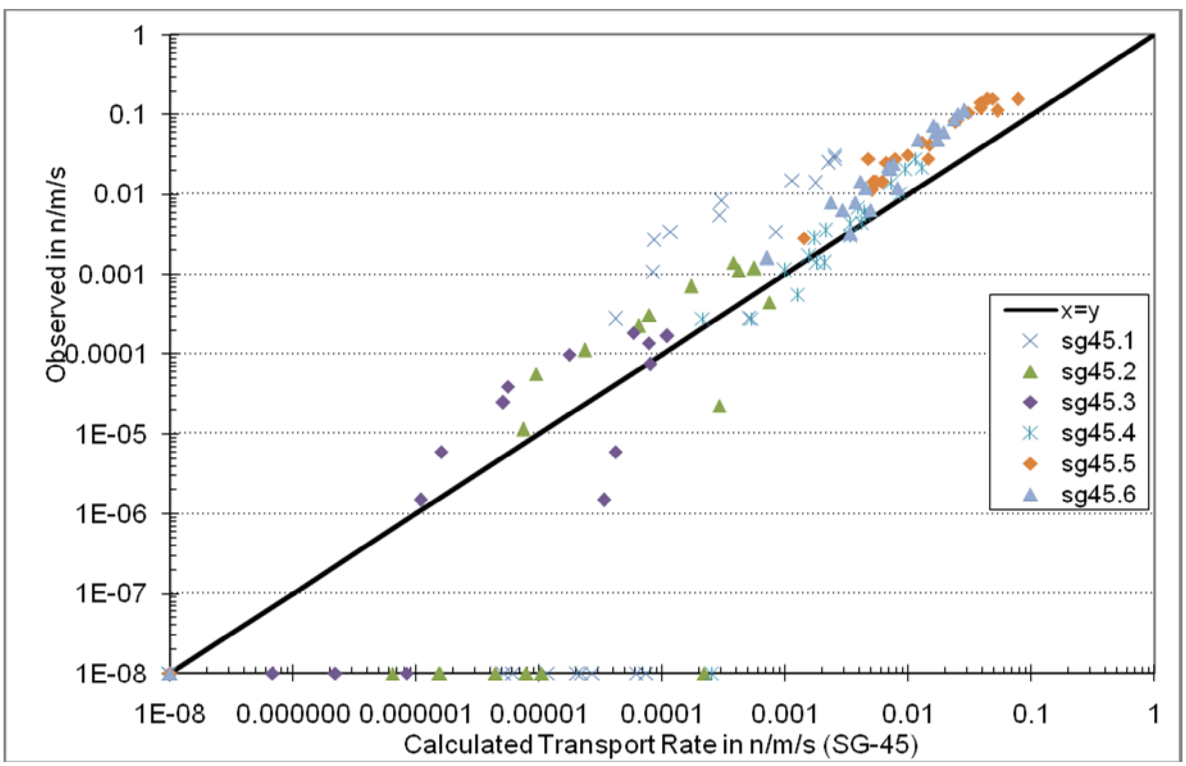

Fig 4.14 Comparision of Observed and Calculated Fractional Transport Rate of Mixture SG-45

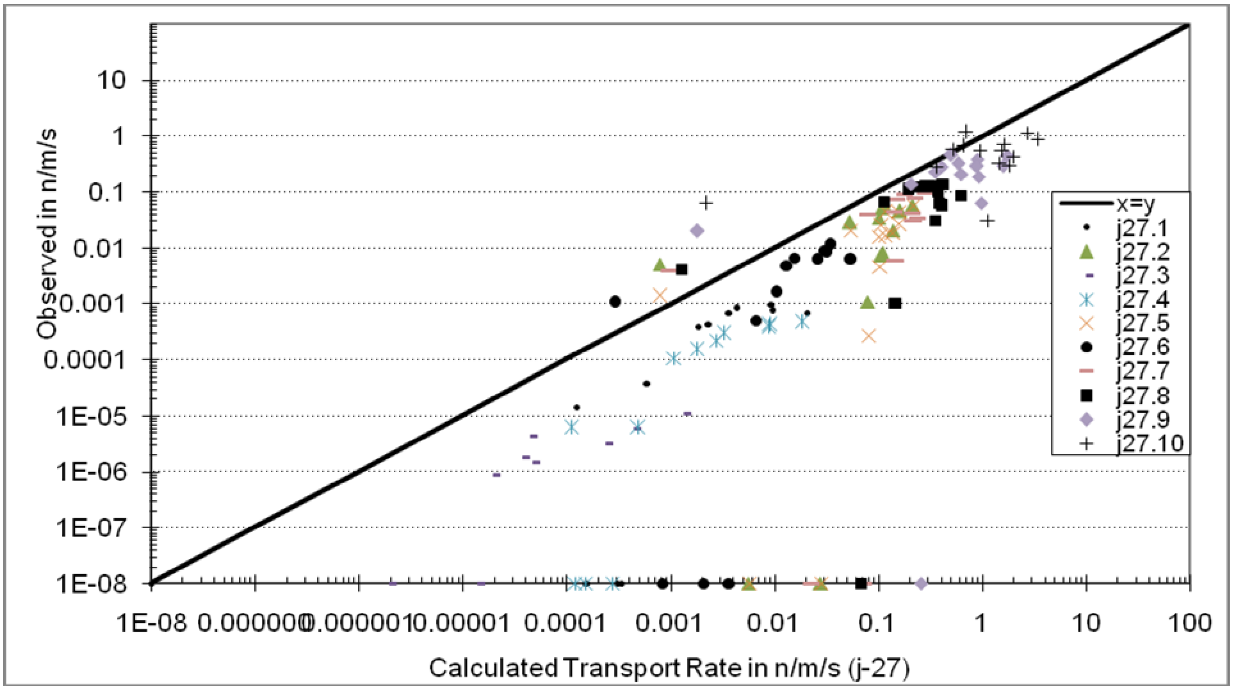

Fig 4.15 Comparision of Observed and Calculated Fractional Transport Rate of Mixture J-27

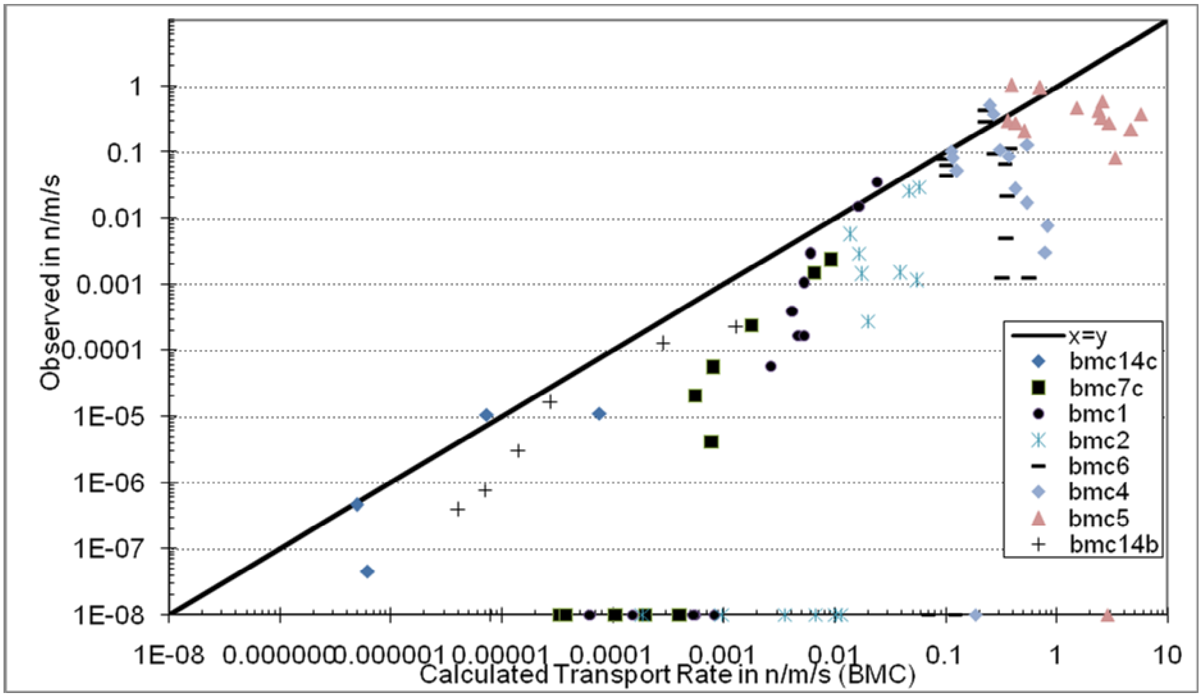

Fig 4.16 Comparision of Observed and Calculated Fractional Transport Rate of Mixture BMC

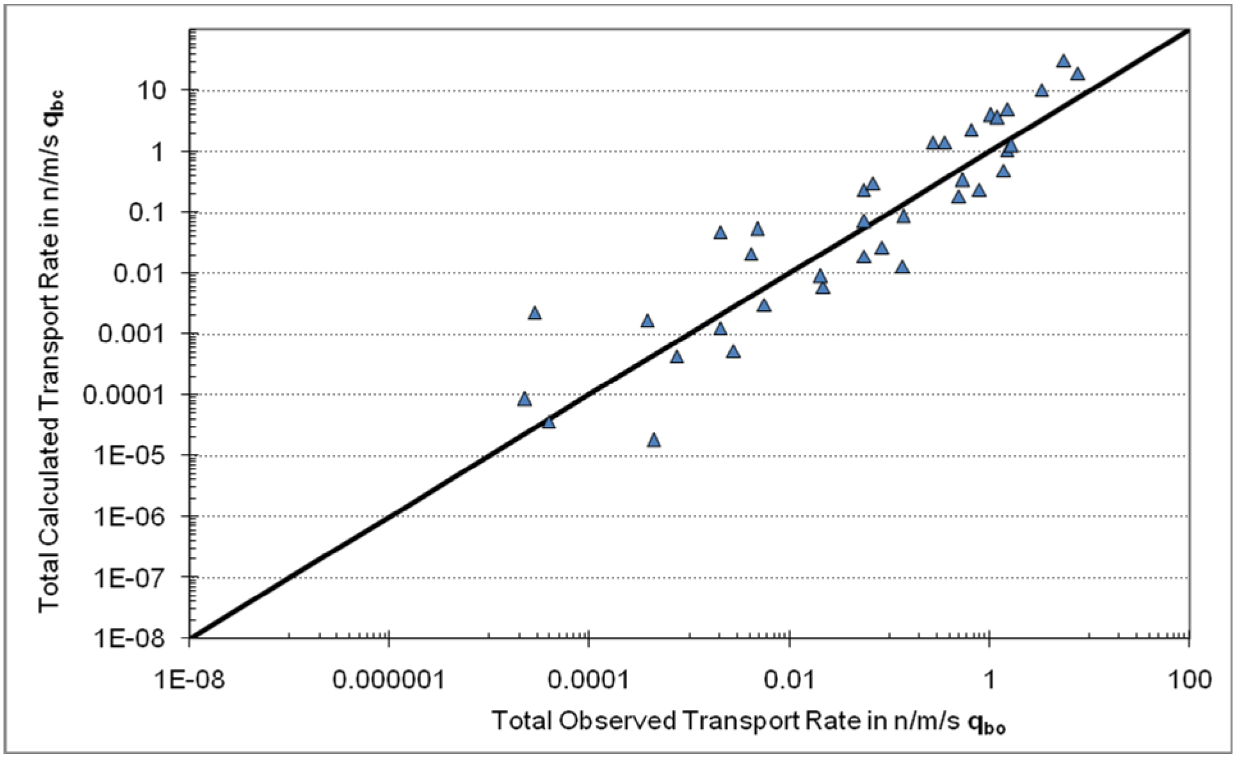

Figure 4.17 Comparision of Total Observed and Calculated Transport Rate of all Mixture

Chapter-5

CONCLUSION

5.1 GENERAL:

The collected data on bimodal nonuniform sediments were analysed and the reported results can be summarized in succeeding paragraphs.

5.2 SUMMARY OF RESULTS:

1. The existing method on bed load transport of nonuniform sediments performs fairly with existing bimodal sediments.
2. The parameters for development of new relationship based on CTS concept are identified.
3. The performances of developed relationship are compared with existing method. The method performs better.

5.3 LIMITATIONS OF PRESENT STUDY AND SCOPE OF FURTHER STUDY:

Due to unavailability of data on bimodal sediments the present analysis could not be carried out for a wide range of data. It would be more rational to carry the proposed analysis for more data in laboratory to make the analysis more generalized.

REFERENCES

1. Almedeijj. H., Diplas P. (2003) “Bedload Transport in Gravel Bed Streams with Unimodal Sediment” Journal of Hydraulic Engg. Vol.129, No. 11,896-904, ASCE.

2. Almedeijj. H., Diplas P., Fawjia Al-Ruwaih.(2006) “Approach to Sand From Gravel for Bedload Transport Calculations in Streams with Bimodal Sediment” Journal of Hydraulic Engg. Vol.132, No. 11, 1176-1185, ASCE.

3. Andrews E.D. (1994), “Marginal Bed Load Transport In A Gravel Bed Stream, Sagehen Greek, California” Water Resources Research, Vol.30, No.7, 2241-2250.

4. Diplas P. (1987) “Bedload Transport in Gravel Bed Streams” Journal of Hydraulic Engg. Vol.113, No. 3, 277-292, ASCE.

5. Garde R. J., and Raga Raju K.G. “Mechanics of Sediment Transportation and Alluvial Streams Problem”, Second Edition, Wiley Eastern Limited, New Delhi, India.

6. Kunhle R.A. (1993), “Incipient Motion of Sand-Gravel Sediment Mixtures”. Journal of Hydraulic Engg. Vol.119, No. 12, 1400-1415, ASCE.

7. Sambrook Smith G.H., Nicholas A.P. and Ferguson R.I. (1997), “Measuring and Defining Bimodal Sediments: Problems and Implications”.Water Resoureces Research, Vol.33, No. 5, 1179-1185.

8. Wathen S.J., Ferguson R.I. and Werritty A. (1995), “Unequal Mobility of Gravel and Sand in Weakly Bimodal River Sediments” By American Geophysical Union. Paper No. 95wr01229

9. Wilcock P.R. (1993). “Critical Shear Stress of Natural Sediments”, Journal of Hydraulic Engg. 119(4), 491-505.