평형유사량을 주는 유사이동 공식의 평가

Evaluation of Selected Sediment Transport Formulas Giving an Equilibrium Sediment Discharge

李 勝 虎*
Lee, Sung-ho

사단법인 한국관개배수위원회
「한국관개배수」 Vol. 1 No. 2
1994. 12

Evaluation of Selected Sediment Transport Formulas Giving an Equilibrium Sediment Discharge

Lee, Sung-ho

Abstract

Many formulas have been developed based on laboratory test and field measuring. The application limit of these formulas is not always clearly stated in the aritcles. The selection of suitable formulas is necessary to apply for the real situation. The selection is not easy because different formulas give quite different results even with the same hydraulic conditions.

In this study, diverse evaluations and comparisons of these formulas in the literature have been made. Some formulas have been selected to analyze the sensitivity of formula with hydraulic parameters, and to study the application limit by computer simulation. The results can be used for the selection of the sediment transport formula applicable in irrigation and drainage canal, natural river, and computer simulation.

A verification analysis with computer simulation using some selected sediment transport formulas which give an equilibrium sediment discharge with various hydraulic parameters shows the following results:

The Meyer-Peter Muller formula is applicable for a steep slope of energy grade line and shallow water. But this formula is not suitable for a mild slope of energy grade line with deep water.

The proposed formula of Ackers-White stated that it is applicable for $0.04\ mm < D < 2.5\ mm$, but this formula is not recommendable to use for $D < 0.2\ mm$ and $D > 2.0\ mm$.

The Engelund-Hansen formula gives a good result of sediment discharge with a particle diameter of 0.005-100 mm.

The Rijn 2T formula is applicable for the range of $0.1\ mm < D < 2.0\ mm$ for a mild slope of energy grade line and deep water. Attention is recommended for using this formula for a very small depth and very fine sand.

The Rijn 3T formula is applicable for a range of $0.005\ mm < D < 2.0\ mm$. This formula is not suitable for a very shallow water($h < 0.8\ m$) with a mild slope of energy grade line.

한국관개배수 제 1 권 제 2 호
KCID J. Vol.1 No.2(1994. Dec.)pp 212-223

논 문

평형유사량을 주는 유사이동 공식의 평가

Evaluation of Selected Sediment Transport Formulas Giving an Equilibrium Sediment Discharge

李 勝 虎*
Lee, Sung-ho

초 록

여러가지의 유사이동 공식들은 각 저자들의 실험실이나 현장실측치를 바탕으로 발표되었다. 그리고 저자에 따라서 본인들의 공식의 적용한계를 명백히 명시한 것도 있지만 그렇지 않은 것도 많다.

동일한 수리학적 조건에서 이 공식들이 현장에서 적용될 때 이 공식에 의한 유사량은 공식에 따라서 유사한 것도 있고 차이가 많이 나는 것도 있다. 특히 St. Venant식(물의 연속 방정식과 물의 운동량 방정식)과 유사 연속방정식을 연립하여 컴퓨터 모의시험에 이용할 때 같은 수리학적 조건하에서도 공식에 따라서 유사량이 산출되거나 발산하는 경우가 있다.

이 논문에서는 자주 쓰이는 공식들의 장단점을 각종 논문이나 서적을 인용하여 평가를 하였고, 특히 많이 쓰이고 비교적 신뢰성이 높은 Meyer-Peter Muller, Ackers-White, Engelund-Hansen, van Rijn 식들에 대한 적용한계와 식 적용시 유의할 점을 논하였다.

여러가지 수리학적 조건에 대한 컴퓨터 모의시험에서 평형유사량을 주는 몇가지의 유사이동공식을 사용한 평가분석에서 다음과 같은 결론을 얻었다.

Meyer-Peter Muller 공식은 급한 에너지 경사와 적은 수심에 대해서 적용이 가능하다. 그러나 이 공식은 깊은 수심에서의 완만한 에너지 경사에 대해서는 부적합하다.

Ackers-White 공식은 0.04㎜ $<$ D $<$ 2.5㎜ 범위에서 적용가능하다고 저자는 언급하였다. 그러나 이 공식은 D $<$ 0.2㎜와 D $>$ 2.0㎜에서는 적용하는 것이 바람직하지 않다.

Engelund-Hansen 공식은 입경이 0.005㎜ − 100㎜까지 입경에 따라 규칙적으로 증가 및 감소하였다.

Rijn 2T 공식은 완만한 에너지 경사와 깊은 수심에 대하여 0.1㎜ $<$ D $<$ 2.0㎜ 범위에서 일반적으로 적용가능하다. 매우 적은 수심과 세립질 사질이나 silt에서는 적용에 주의를 요한다.

Rijn 3T 공식은 0.005㎜ $<$ D $<$ 2.0㎜에 대하여 적용이 가능하다. 완만한 에너지 경사를 가지는 매우 적은 수심(h $<$ 0.8 m)에서 이 공식은 적용이 불가능하다.

* 농어촌진흥공사 농어촌연구원

키워드 : Sediment transport, Bed load, Suspended load, Reference level, Reference cocentration

I. Introduction

The processes of erosion, transportation and deposition of fluvial sediment are complex. The entrainment and transportation depend on the solide particle(density, shape, size, status of surface) and fluid mouvement (type of flow, velocity and viscosity of fluid).

The problems created by the deposition of sediments are varied and serious. The sediments deposited in a channel reduce the flood control or carring capacity. The deposition of sediment in irrigation and drainage canal, navigation channel, reservoir and marine port cause to augment the cost of management or reduce the original purposes of structure.

A better understanding of sedimentation phenomenon is a vital interest for the conservation, development and utilization of water resources. It is necessary to know and understand the nature of sedimentation problem in the planning, design and management of the land related to the water resource development projects.

The principal object of studying the fluvial sedimentation is to predict that a condition of equilibrium or erosion-deposition will produce and to determine the quantity transported by the river.

Many formulas have been developed after Duboys(1879) had presented the first formula. We have to choose a formula to apply the real situation in nautral river and canal where we would like to apply sediment formula. Many formulas can be selected which will be applicable to each case. This selection is not easy because the different formula give very different results.

In this study, diverse evaluations and comparisons of these formulas in the literature have been made. Some formulas have been selected to analyze the sensitivity of formula with the hydraulic parameters(discharge, energy slope, velocity, depth, width and Froude number). The results can be used for the selection of the sediment transport formula applicable in irrigation and drainage canal, natural river and computer simulation.

II. Analysis of some selected sediment transport formulas

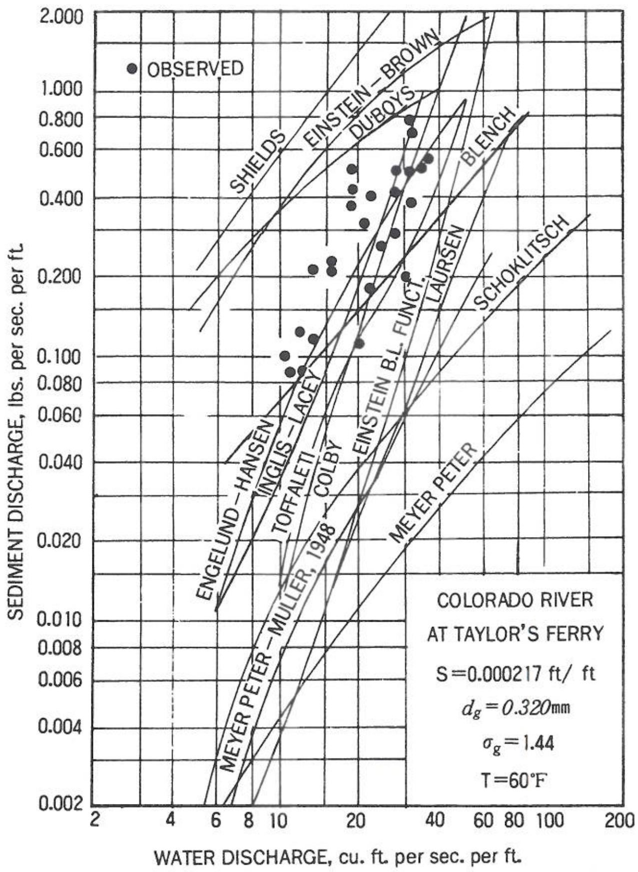
1. Literature study of sediment transport formula

In the following table 〈Table. 1〉, 21 formulas were selected which were utilized

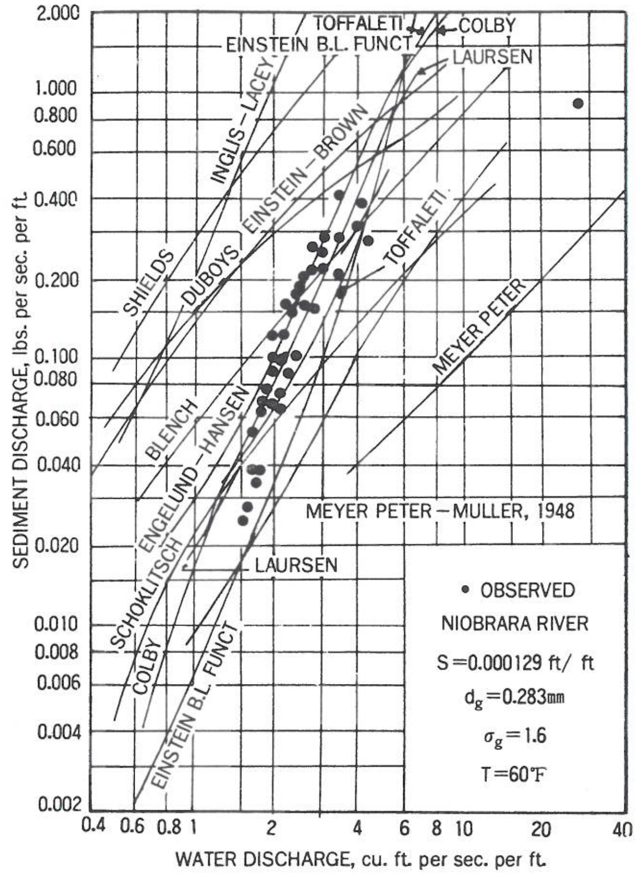
〈Table. 1〉 Sediment transport formulas(1~20)

Author	Dm	Velocity	Remark
Duboys(1879)	O	×	C
Schoklitsch(1935)	++	×	C
Shields(1936)	O	×	C
Meyer-Peter and Muller(1948)	O	×	C
Einstein-Brown(1950)	O	×	C
Einstein Bed Load function(1950)	++	O	T, S, C
Laursen(1958)	O	×	T
Shinohara-Tsubaki(1959)	O	×	T
Garde and Albertson(1961)	O	O	T
Colby(1964)	O	O	T
Engelund-Hansen(1967)	O	O	T
Inglis-Lacey(1968)	O	O	T
Toffaleti(1969)	++	O	T, S, C
Ackers-White(1973)	O	O	T
Yang(1973)	++	O	T
Engelund-Fredsoe(1976)	O	O	T, S, C
Holtorff(1983)	++	O	T, S, C
van Rijn(1984)	O	O	T, S, C
Celik and Rodi(1991)	O	O	S
Samaga, Ranga Raju and Garde(1986)	++	O	T, S, C
Rickenmann(1991)	O	O	C

where
O : This term exists explicitly in the formula
× : This term does not exist explicitly in the formula
++ : Serveral Classes of Sediment
T : Total Load
C : Bed Load
S : Suspended Load
Dm : Reperesentative Diameter



〈Fig. 1〉 Sediment discharge as function of water discharge for Colorado River(after Vanoni, 1977, Sedimentation Engineering)



〈Fig. 2〉 Sediment discharge as function of water discharge for Niobrara River(after Vanoni, 1977, Sedimentation Engineering)

very often. In this table we noted that T is total load, S is suspended load and C is bed load.

In the following figures 〈Fig. 1 and 2〉, those formulas of Shields, Einstein-Brown and Duboys tend to overestimate the sediment discharge and Meyer-Peter Muller formula tend to underestimate the sediment discharge. These formulas and the Schoklitsch formula give the results with less slope than straight lines fitted to the data. Those of Colby, Toffaleti and Engelund-Hansen give best agreement with the measured sediment discharges. The curves for the Einstein bed load function, Laursen and Inglis-Lacey formulas are close to those of a mean line for the data but the curves do not fit the data. The curve of Blench formula has a small slope intersecting the data (13).

The Cobly formula is not applicable to sediment transport in the river with a sand diameter, D>0.6mm and a depth, h>3m. The Engelund and Hansen equation is applicable to the stream with dune and ripples in the bottom. The Ackers and White equation is applicable for 0.04mm<D<2.5mm and for Froude number, Fr<0.8. Those formulas of Yand, Engelund and Hansen, and Ackers and White were better than others in the prediction of sediment discharge in the field and laboratory (20).

The bed-load prediction by the Einstein-Brown formula seems to be more than 10 times greater than those predicted by

Meyer-Peter Muller and Schoklitsch formulas. The suspended-load discharge prediction by the Toffaleti formula was the best among all the formulas tested. Yang's(1973) predictions of the total-load discharges seem to be very close to the measured suspended load discharges at a higher range of sediment discharge, but they are seen to be much greater at a lower range of sediment discharge. Both the Toffaleti and Yang formulas were able to predict sediment discharges for all the flow events (7).

Of seven formulas available in the literature for predicting the entrainment of uniform sediment into suspension, the relationships put forward by Smith and McLean(1977) and van Rijn(1984) perform best to the data(4).

〈Table. 2〉 Performance of various formula

Formula	Me	Ad
Einstein(1950)	1.37	3.45
Engelund and Fredsoe(1976)	0.50	5.3
Smith and McLean(1977)	0.88	2.42
Itakura and Kish(1980)	6.70	2.22
van Rijn(1984)	1.31	2.19
Celik and Rodi(1984)	2.57	2.03
Akiyama and Fukushima(1986)	0.12	8.15
Proposed formulation	1.00	2.12

Where

Me : mean value of discrepancy ratio Caep/ Caeo

Ad : mean absolute deviation of discrepancy ratio Caep/ Caeo

Caeo, Caep : observed and predicted values of equilibrium near-bed sediement concentration

The method of Yand yields excellent results for the flume data and the small scale river data, but very poor results for large-scale rivers(flow depth>1 m). This method must have serious systematic errors for large flow depths. On the average, the predicted values are much too small (14).

In summary, the formulas of Engelund-Hansen, Ackers-White and van Rijn were preferable in various cases. And the formula of Meyer-Peter and Muller is also tested for calculating the sediment discharge.

Therefore, seven formulas were used to test the perfomance in various hydraulic conditions ; Engelund-Hansen(E & H), Ackers-White(A & W), Meyer-Peter and Muller(MPM), van Rijn Part Ⅰ(Rijn 2B, Bed Load), van Rijn Part Ⅱ(Rijn 2S, Suspended Load), van Rijn Part Ⅲ(Rijn 3B, Simplified Bed Load), van Rijn Part Ⅲ(Rijn 3S, Simplified Suspended Load).

2. Selected sediment transport formulas

The formulas of MPM, E & H and A & W can be easily found in the literature. In this section the formulas of van Rijn is only presented.

Van Rijn have developped the empirical formulas for the bed load and suspended load (14, 15). After he gave the method of predicting the bed form, the effective roughness, the formulas of simplified bed load and simplified suspended load (16).

The following notations will be used to distinguish 4 equations :

van Rijn Part Ⅰ, Bed load : Rijn 2B

van Rijn, Part Ⅱ, Suspended Load : Rijn 2S

van Rijn, part Ⅲ, Simplified Bed Load : Rijn 3B

van Rijn, Part Ⅲ, Simplified Suspended Load : Rijn 3S

Rijn 2T=Rijn 2B+Rijn 2S

Rijn 3T=Rijn 3B+Rijn 3S

A. Bed Load(Rijn 2B)

For calculating the bed load in $m^3/s/m$, the following formula can be used :

$q_b=0.053[(s-1)g]^{0.5}D_{50}^{1.5}T^{2.1}/D^{*0.3}$

or

$q_b=C_bV_b\delta_b$

where,

q_b : bed load($m^3/s/m$)

T : transport stage parameter

D* : particle parameter

Cb : bed load concentration,

$Cb=0.117T/D^*$

Vb : velocity of bed-load particles,

$Vb=V^*[9+2.6\log D^*-8(\theta cr/\theta)^{0.5}]$

V* : overall bed-shear velocity

θcr : critical particle mobility parameter

θ : particle mobility parameter $\theta=V^{*2}/[(s-1)gD_{50}]$

δ_b : saltation height, $\delta_b=0.3D^{*0.7}T^{0.5}D$

B. Suspended Load(Rijn 2S)

For obtaining suspended load in $m^3/s/m$, the following steps will be followed :

(1) Calculate the particle parameter, D*

$D^*=D_{50}[(s-1)g/\nu^2]^{1/3}$

where

ν : kinematic viscosity coefficient

(2) Calculate critical bed-shear velocity according to Shields, V*cr

$V^*cr=[\theta cr(S-1)gD_{50}]^{0.5}$

(3) Calculate the transport stage parameter, T

$$T=\frac{(V^{*\prime})^2-(V^*\ cr)^2}{(V^*\ cr)^2}$$

where

$V^{*\prime}$: bed-shear velocity related to grains

V*cr : critical bed-shear velocity according to Shields

(4) Calculate the reference level, a ⟨Fig. 3⟩

$a=0.5\Delta$

or

$a=Ks(\text{with } a_{min}=0.01h)$

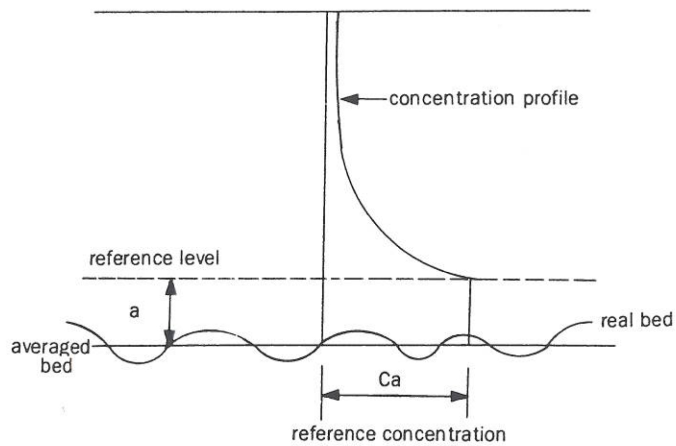
where

Δ : bed form height

Ks : equivalent roughness

(5) Calculate the reference concentration, Ca

$$Ca=0.015\frac{D_{50}}{a}\ \frac{T^{1.5}}{D^{*0.3}}$$



⟨Fig. 3⟩ Definition sketch for reference level and reference concentration

(6) Calculate the representative particle diameter of suspended sediment, Ds

$Ds=D_{50}[1+0.011(\delta s-1)(T-25)]$

where

δs : geometric standard deviation,

$\delta s=0.5[D_{16}/D_{50}+D_{84}/D_{50}]$

(7) Calculate the particle fall velocity, Ws

$$Ws=\frac{(s-1)gDs^2}{18\nu} \qquad 1<Ds<100\mu m$$

$$Ws=\frac{10\nu}{Ds}\{[1+\frac{0.01(s-1)gDs^3}{\nu^2}]^{0.5}-1\} \qquad 100<Ds<1,000\mu m$$

$$Ws=1.1[(s-1)gDs]^{0.5} \qquad Ds>1,000\mu m$$

The above formula of Ws is valid in a clear and still fluid. For normal flow conditions this formula must be modified, (Wsm)

(A) Richardson-Zaki formula

$Wsm=(1-C)^4Ws$

where

C : Concentration of Sediment

(B) Oliver formula

$$Wsm=(1-2.15C)(1-0.75C^{0.33})Ws$$

In this article the Oliver formula is chosen for calculating the particle fall velocity. 〈Fig. 4〉

(8) Calculate overall bed-shear velocity, V*

$$V^*=(ghI)^{0.5}$$

(9) Calculate the ratio of sediment diffusion and fliud diffusion coefficient, Cb

$$Cb=1+2[Wsm/V^*]^2$$

(10) Calculate the overall correction factor due to the reduction of particle fall velocity and damping of turbulence, Fc

$$Fc=2.5[Wsm/V^*]^{0.8}[Ca/0.65]^{0.4}$$

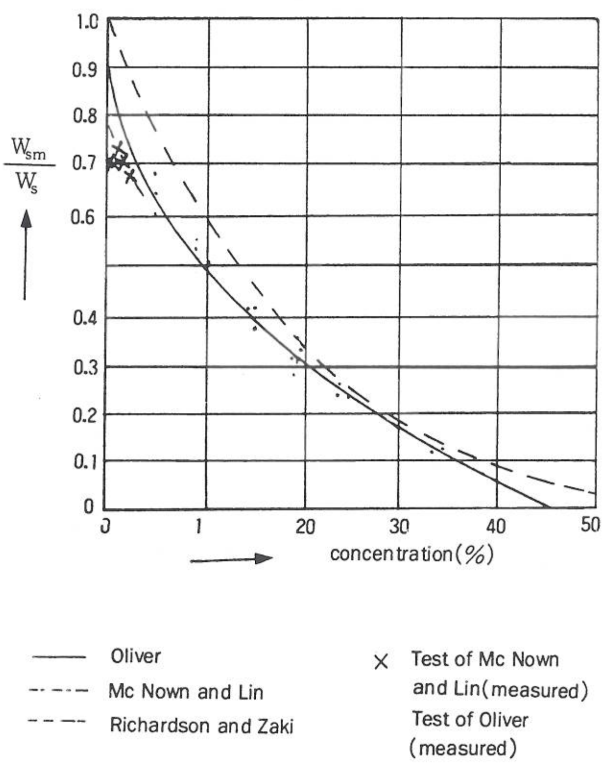
(11) Calculate suspension parameter Z and Z′

$$Z=Wsm/(Cb\kappa V^*)$$

where

κ : Von karman constant (=0.4)

$$Z'=Z+Fc$$



〈Fig. 4〉 Comparison of the fall velocity formulas with measured data

(12) Calculate the correction factor of suspended load, F

$$F=\{[a/h]^{z'}-[a/h]^{1.2}\}/\{[1-a/h]^{z'} 2-Z']\}$$

(13) Calculate the suspended load transport, qs

$$qs=F\ V\ h\ Ca$$

C. Simplified Bed Load Formula and Simplified Suspended Load Formula(Rijn 3B, Rijn 3S)

$$qb=0.005\{(V-Vcr)/[(s-1)gD_{50}]^{0.5}\}^{2.4}D_{50}^{1.2}V$$

$$qs=0.012\{(V-Vcr)/[(s-1)gD_{50}]^{0.5}\}^{2.4}D_{50}D^{*-0.6}V$$

with

$Vcr=0.19D_{50}^{0.1}\log(12R/3D_{90})$ for $100<D_{50}<500\mu m$

$Vcr=8.5D_{50}^{0.6}\log(12R/3D_{90})$ for $500<D_{50}<2000\mu m$

where

Vcr : critical mean velocity

3. Application of selected sediment transport formulas

The selected 7 transport formulas were tested about various hydraulic conditions by computer simulation.

The following hydraulic parameters were used 〈Table. 3~Table. 4〉. The diameter of sediment between 0.005mm(5μm) and 100mm (10cm) were tested for analyze the sensibility of the formulas with the following hydraulic parameters(discharge, energy line, velocity, depth, width and Froude number).

4. Evaluation of sediment transport formula

The results of the above 7 formules(4 formulas of van Rijn, MPM, E & H and A & W) were obtained for various conditions. About 32 figures were obtained, but here 6

〈Table. 3〉 Hydraulic parameters used by computer simulation

Depth h(m)	Width B(m)	Area A(m²)	n (Kst)	Hydraulic Radius R(m)	I	Velocity V(m / s)	Discharge Q(m³/ s)	Froude number Fr	Remark
0.2	1.0	0.2	0.014 (72)	0.14	1/ 500– 1/ 7500	0.88~0.23	0.17~0.05	0.62~0.16	Test 11~15
0.8	5.0	4.0	0.018 (56)	0.61	1/ 500– 1/ 7500	1.78~0.46	7.12~1.84	0.64~0.16	Test 21~25
1.0	10	10	0.020 (50)	0.83	1/ 500– 1/ 10000	1.98~0.44	19.8~4.44	0.63~0.14	Test 31~36
1.5	30	40	0.022 (46)	1.36	1/ 2500– 1/ 12000	1.12~0.51	50.3~23.0	0.29~0.13	Test 41~45
4.5	200	900	0.031 (32)	4.31	1/ 2500– 1/ 12000	1.71~0.78	1537~701	0.26~0.12	Test 51~55
10.0	300	3000	0.035 (29)	9.38	1/ 2500– 1/ 20000	2.54~0.90	7622~2695	0.26~0.09	Test 61~66

where

n : Manning roughness coefficient　　I : Slope of energy grade line　　Kst : Strickler coefficient

〈Table. 4〉 Hydraulic parameters for Test 11–66

Test No.	Depth h(m)	Width B(m)	Area A(m²)	n	I	Velocity V(m / s)	Discharge Q(m³/ s)	Froude number Fr
11	0.2	1.0	0.2	0.014	1/ 500	0.87	0.175	0.62
12					1/ 1000	0.62	0.123	0.44
13					1/ 2500	0.39	0.078	0.28
14					1/ 5000	0.28	0.055	0.20
15					1/ 7500	0.23	0.045	0.16
21	0.8	5.0	4.0	0.018	1/ 500	1.78	7.12	0.64
22					1/ 1000	1.26	5.03	0.45
23					1/ 2500	0.80	3.18	0.28
24					1/ 5000	0.56	2.25	0.20
25					1/ 7500	0.46	1.84	0.16
31	1.0	10.0	10.0	0.020	1/ 500	1.98	19.80	0.63
32					1/ 1000	1.40	14.00	0.45
33					1/ 2500	0.89	8.85	0.28
34					1/ 5000	0.63	6.26	0.20
35					1/ 7500	0.51	5.10	0.16
36						0.44	4.44	0.14
41	1.5	30.0	45.0	0.022	1/ 2500	1.12	50.31	0.29
42					1/ 5000	0.79	35.57	0.21
43					1/ 7500	0.64	29.00	0.17
44					1/ 10000	0.56	25.12	0.15
45					1/ 12000	0.51	22.94	0.13
51	4.5	200.0	900.0	0.031	1/ 2500	1.71	1537.0	0.26
52					1/ 5000	1.21	1087.0	0.18
53					1/ 7500	0.99	886.0	0.15
54					1/ 10000	0.85	768.0	0.13
55					1/ 12000	0.78	701.0	0.12
61	10.0	300.0	3000.0	0.035	1/ 2500	2.54	7622.0	0.26
62					1/ 5000	0.80	5389.0	0.18
63					1/ 7500	1.47	4394.0	0.15
64					1/ 10000	1.27	3811.0	0.13
65					1/ 12000	1.16	3479.0	0.12
66					1/ 2000	0.90	2695.0	0.09

representative figures are given in figure 5~10. In these figures the variation rate of sediment discharge/water discharge(Qt/Q) in function of diameter D is given, but the parameter or h(depth), n(Manning roughness coefficient) and I(slope of energy grade line) were fixed for each case.

The following results are obtained :

A. The sediment discharge of MPM increase abnormally with the sediment diameter and diminish rapidly in all cases. For the depth($h>1.5$ m) the formula of MPM give almost constant sediment discharge during the diameter change from 0.005mm to 100mm ⟨Fig. 5~10⟩.

The MPM formula is not sensible to diameter when the depth is greater enough($h>1.5$ m). Because the value of hI(depth*slope of energy grade line) is more greater than the term of diameter of sediment, this formula is not sensible to diameter with mild slope of energy grade line.

This formula is based on the experiences of uniform flow in laboratory test with a following parameters(6) :

(1) Slope of energy grade line, I : 1/50~1/2,500

(2) Representative diameter, Dm : 0.4mm$<$Dm$<$30mm

(3) Depth, h : 1cm$<h<$1.2m

Therefore the MPM formula is applicable to steep slope of energy grade line and to small depth. It is not suitable for mild slope of energy grade line and large depth.

B. The A & W formula give an abrupt augmentation of sediment dishcarge for the fine sand(D$<$0.2mm) about almost all the cases of simulation test⟨Fig. 5~10⟩.

For a coarse sand(D$>$1mm) with a little mild slope of energy grade($I<1/7{,}500$) it is diminished rapidly⟨Fig. 7~10⟩. For a sand with very small depth($h=0.2$ m) the result can be obtained within a certain limit of sediment diameter(0.4mm$<$D$<$2mm). According to the articles of A & W, they mentioned that their formula are valuable for a range of sediment diameter of 0.04mm$<$D$<$2.5mm(1). But this equation give an inacceptable sudden variation at a limit of application because of the exponential coefficient, m in the formula

In this figure the exponent, m of A & W formula tend to infinite when Dgr decrease to 0.

C. The E & H formula give the results varying in a good sense when the sediment diameter vary in the range of 0.005mm~100mm.

D. The results given by the Rijn 2T and Rijn 3T were very close to the sediment discharge given by E & H and A & W in the sediment diameter range of 0.1mm~3.0mm for a depth $h=0.8$ m and $I=1/1000$⟨Fig. 6⟩. But for a very small depth($h=0.2$ m) the result of Rijn 2T and Rijn 3T can not be obtained for the diameter D$<$0.4mm⟨Fig. 5⟩.

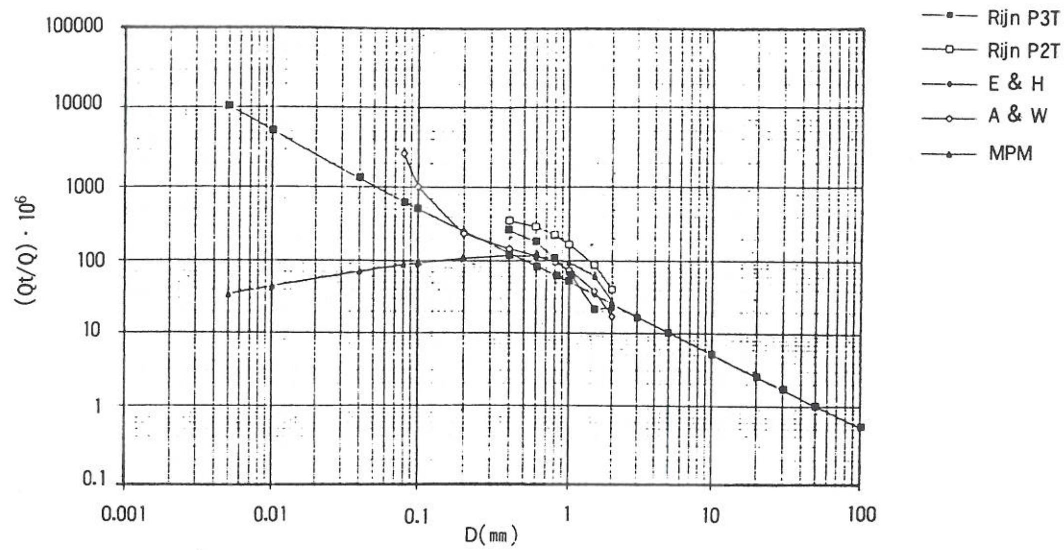
If the sediment diameter is more finer than 0.1mm(D$<$0.1mm), the sediment discharge of Rijn 2T diminish regularly when D diminish in the case of steep slope of energy grade line with a small depth($h<1.0$ m)⟨Fig. 6⟩.

It is abruptly diminish when D increase in the case of $I<1/7{,}500$⟨Fig. 7~10⟩.

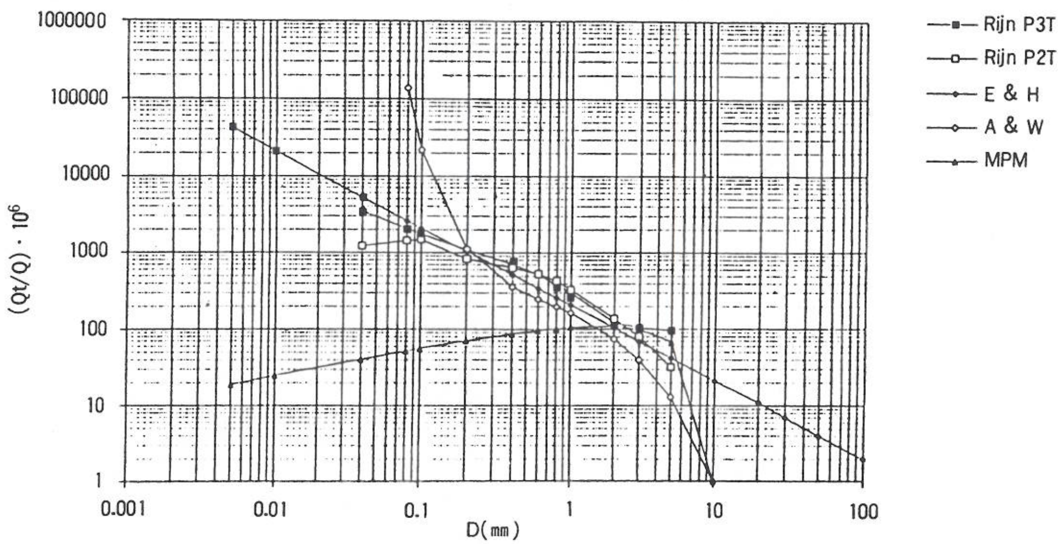
If the sand diameter is more coarser than D=2.0mm, the sediment discharge of Rijn 2T is close to that of E & H in the case of steep slope of energy grade line and small depth ⟨Fig. 6⟩.

But for a mild slope($I<1/7{,}500$), if D decrease, the solid discharge decrease very rapidly, but this is not a reasonable sense ⟨Fig. 7~10⟩.

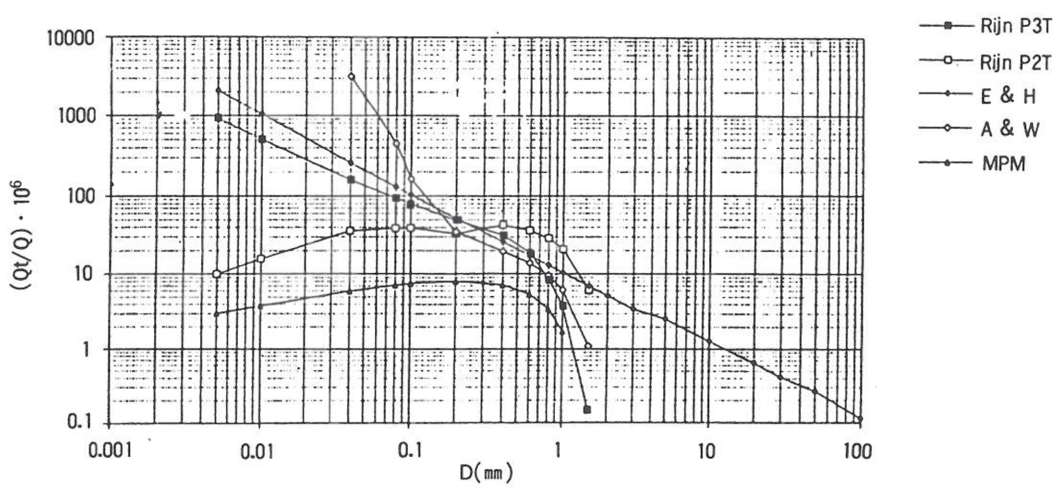
Therefore the Rijn 2T formula is generally valuable for the range of 0.1mm$<$D$<$2.0mm ex-



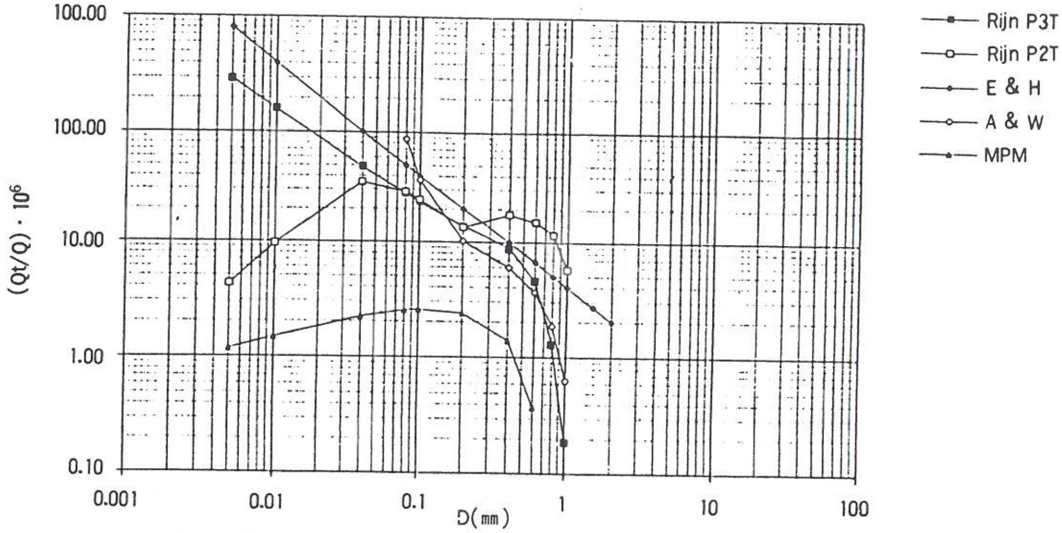
〈Fig. 5〉 Relation between Qt/Q and solid diameter
(Test 12 : h=0.2 m, I =1/1,000, n=0.014)



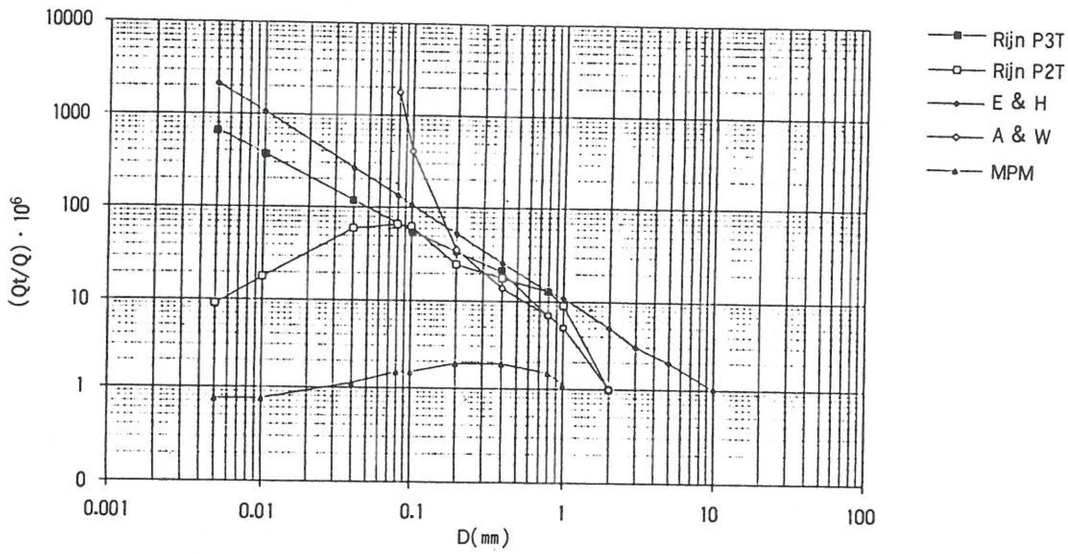
〈Fig. 6〉 Relation between Qt/Q and solid diameter
(Test 22 : h=0.8 m, I =1/1,000, n=0.018)



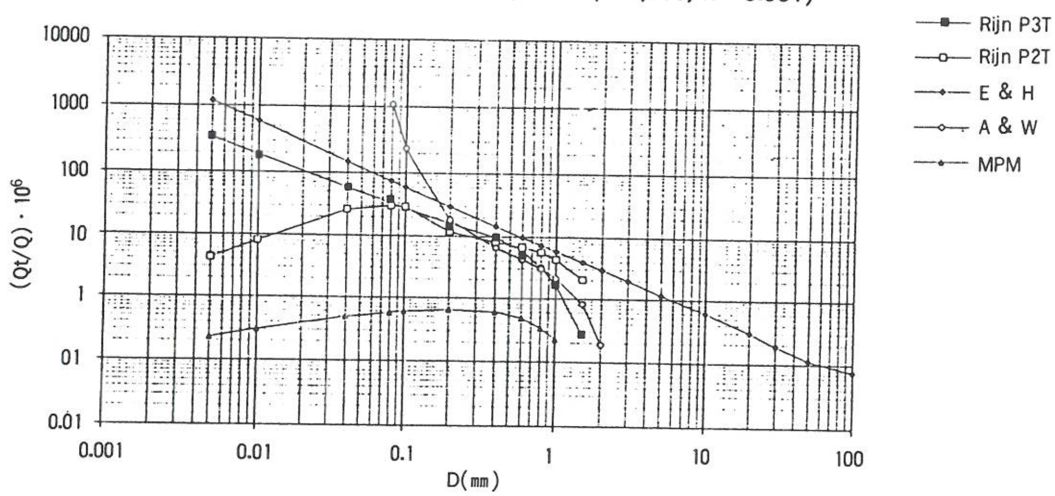
〈Fig. 7〉 Relation between Qt/Q and solid diameter
(Test 34 : h=1.0 m, I =1/5,000, n=0.020)



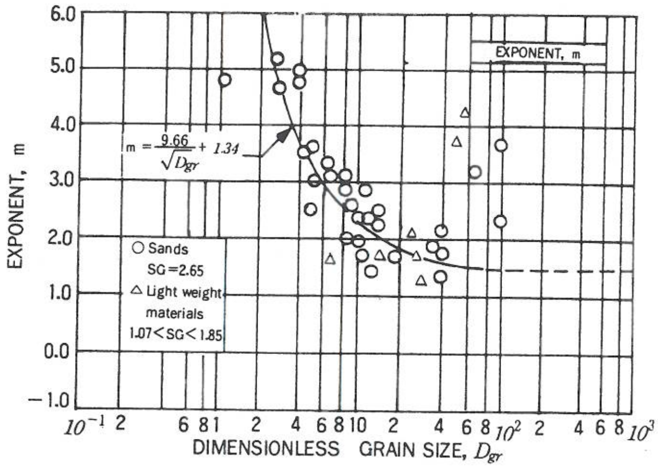
〈Fig. 8〉 Relation between Qt/Q and solid diameter
(Test 44 : h=1.5m, I =1/10,000, n=0.022)



〈Fig. 9〉 Relation between Qt/Q and solid diameter
(Test 54 : h=4.5m, I =1/10,000, n=0.031)



〈Fig. 10〉 Relation between Qt/Q and solid diameter
(Test 66 : h=10m, I =1/20,000, n=0.035)



⟨Fig. 11⟩ Exponent, m, used by A & W formula

cept in the case of steep slope(I =1/500∼1/1,000) and the small depth(h<1.0m), but for a mild slope with coarse diameter the solid discharge decrease abnormally.

The results of Rijn 3T are very close to that of E & H in the case of steep and medium slope of energy grade line(I =1/500∼1/5,000) and the small depth(h<1.0m). But the sediment discharge given by Rijn 3T diminish abnormally with the diameter of sediment D>2.0㎜⟨Fig. 6⟩.

In the case of mild slope of energy grade line(I <1/7,500) and small depth, there is a constant difference between the curve of Rijn 3T and that of E & H and the sediment discharge also diminish rapidly when the solid diameter D>1.0㎜⟨Fig. 7,8,10⟩.

For the case of large depth the curve of Rijn 3T have a same slope of that of E & H in the all cases of slope of energy grade line. But if D>2.0㎜, the sediment discharge of Rijn 3T augment abruptly for the slope of energy grade line I =1/500∼1/5,000.

Therefore the equation of Rijn 3T is applicable to the range of 0.005㎜<D<2.0㎜.

Ⅲ. Conclusion

The MPM formula is not sensible to solid diameter when the depth is greater than h=1.5m and it is not recommendable for a mild slope of energy grade line.

This formula is not suitable for a mild slope of energy grade line and deep water.

For the A & W formula the author stated that it is applicable for 0.04㎜<D<2.5㎜. But in this study this formula give an inacceptable results at a limit of its application. It is not preferable to use this formula for D<0.2㎜ and D>2㎜.

The E & H formula gives a good result of sediment discharge with a particle diameter of 0.005㎜−100㎜.

The Rijn 2T formula is generally applicable for the range of 0.1㎜<D<2㎜ with a mild slope of energy grade line and deep water.

For a small depth(h<1.0m) and a sleep slope of energy grade line, this formula works well for the range of 0.1㎜<D<5㎜. For a very small depth(h=0.2m) and a sleep slope of energy grade line, the sediment discharge of this formula is bigger than that of other formulas for 0.4㎜<D<2㎜. Attention is recommended for using this formula for a very small depth and very find sand.

The Rijn 3T formula is generally applicable in the range of 0.005㎜<D<2㎜ except for a very small depth(h<0.8m). But for the mild slope of energy grade line with this upper limit of application(D>2㎜) the sediment discharge decrease abruptly. For a very small depth with a mild slope of energy grade line this formula is not suitable.

References

1. Ackers, P. and W.R. White, 1973. Sediment Transport : New Approach and Analysis, ASCE, Vol. 99, No. HY11, pp. 2041~2059.
2. Celik, I. and W. Rodi, 1991. Suspended Sediment-Transport Capacity for Open-Channel Flow, ASCE, Vol. 117, No. 2.
3. Einstein, H.A. and F.M. Abdel-Aal, 1972. Einstein Bed-Ioad Function at High Sediment Rates, ASCE, Vol. 98, No. HY1, pp. 137~143.
4. Garcia, M. and G. Parker, 1991. Entrainment of Bed Sediment into Suspension, ASCE, Vol. 117, No. 4, pp. 421~432.
5. Holtorff, G., 1983. Steady Bed Material Transport in Alluvial Channels, ASCE, Vol. 109, No. 3.
6. Meyer-Peter, E. and R. Muller, 1948. Formula for Bed-Load Transport, IAHSR, Second Meeting, Stockholm 7-9, Vl, pp. 35~58.
7. Nakato, T., 1990. Tests of Selected Sediment-Transport Formulas, ASCE, Vol. 116, No. 3, pp. 372~376.
8. Rickenmann, D., 1991. Hyperconcentrated Flow and Sediment Transport at Steep Slopes, ASCE, Vol. 117, No. 11.
9. Samaga, B.R., K.G. Ranga Raju and R.J. Garde, 1986. Suspended Load Transport of Sediment Mixtures, ASCE, Vol. 112, No. 11.
10. Samaga, B.R., K.G. Ranga Raju and R.J. Garde, 1986. Bed Load Transport of Sediment Mixtures, ASCE, Vol, 112, No. 11.
11. Shen, H.W. and C.S. Hung. 1983. Remodified Einstein Procedure for Sediment Load, ASCE, Vol. 109, No. 4, pp. 572~576.
12. Toffaleti, F.B., 1969. Definitive Computations of Sand Discharge in Rivers, ASCE, Vol. 95, No. HY1, pp. 225~248.
13. Vanoni, V.A., 1977. Sedimentation Engineering, ASCE Task Committe, pp. 1~20, pp. 152~230.
14. van Rijn, L.C., 1984. Sediment Transport, Part Ⅰ : Bed Load Transport, ASCE, Vol. 110, No. 10, pp. 1431~1452.
15. van Rijn, L.C., 1984. Sediment Transport, Part Ⅱ : Suspended Load Transport, ASCE, Vol. 110, No. 11, pp. 1613~1638.
16. van Rijn, L.C., 1984. Sediment Transport, Part Ⅲ : Bed Forms and Alluvial Roughness, ASCE, Vol. 110, No. 12, pp. 1749~1754.
17. Woo, H.S., P.Y. Julien and E.V. Richardson, 1986. Washload and Fine Sediment Load, ASCE, Vol. 112, No. 6.
18. Woo, H.S., P.Y. Julien and E.V. Richardson, 988. Suspension of Large Concentration of Sand, ASCE, Vol. 114, No. 8, pp. 888~891.
19. Yang, C.T., 1976. Minimum Unit Stream Power and Fluvial Hydraulics, ASCE, Vol. 102, No. HY77.
20. Yang, C.T. and A. Molinas, 1982. Sediment Transport and Unit Stream Power Function, ASCE, Vol. 108, No. HY6.

이 승 호

약 력

1979. 동아대학교 공과대학 토목공학과 졸업.

1986. 화란 Delft 국제수리 및 환경공학 과정(IHE) 수료

1989. 벨지움 브뤼셀 자유대학(VUB) 대학원. M.S.

1993. 프랑스 국립 그레노블 과학기술원 (INPG), Ph. D.

현재 농어촌진흥공사 농어촌연구원 농공기술연구소 환경연구실