MESSUNG DER GESAMTEN GESCHIEBEFRACHT IM ABE-RIVER MIT EINER GESCHIEBEFALLE

OBSERVATION OF SEDIMENT DISCHARGE BY TOTAL LOAD TRAPPING EQUIPMENT IN ABE RIVER

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ZUSAMMENFASSUNG

Will man das Problem der Geschiebefracht lösen, ist es erforderlich die Bereiche der Geschiebeentstehung als Teil des Geschiebetransportsystems zu behandeln. Um das zu ermöglichen ist es notwendig die Beschaffenheit der Geschiebefracht zu erfassen. In Gebirgsflüssen fließen Geschiebe, Suspensionen und Washload über das gesamte Abflussprofil.
Die Autoren haben ein Verfahren entwickelt um die gesamte Feststofffracht über eine Messeinheit auszufiltern. Die Instrumentierung wurde an der OSHIMA-SPERRE im OBERLAUF des ABE-Flusses zur Messung der Geschiebefracht installiert.
In vier Beobachtungsperioden gewann man nachstehende Erkenntnisse: (1) Die Hochwässer eines Normaljahres zeigten, dass Suspensionsfracht und Washload einen wesentlich höheren Anteil am gesamten Feststofftransport haben als das Geschiebe. (2) Die Ergebnisse für die Suspensionsfracht und die Washload waren höher als die in anderen Flüssen erreichten Werte. (3) Die nach den Formeln von Ashida, Takahashi, und Mizuyama angeschätzte Geschiebefracht, war in vielen Fällen größer als der gemessene Betrag. Im Bereich der Spitzenabflüsse wurde die Differenz jedoch geringer. Die nach der Formel von Meyer-Peter Müller errechneten Wertewaren im Allgemeinen geringer als die Messwerte. Auch bei den Spitzenabflüssen war der Abstand gleich.(4)Die Effektivität des "Japanischen Röhren - Hydrophons" wurde als Messmethode zur Messung des Geschiebes bestätigt.

Keywords: Geschiebetransportsysteme, Feststofffracht, Geschiebefracht, Suspensionsfracht,

ABSTRACT

To resolve the problems from sediment discharge, it is required to treat the area of sediment as the “sediment transport system”. To enable this, the state of sediment discharge must be grasped. In mountainous rivers, bed load and suspended load and washload were said to flow down at all depths. We developed the Total Load Trapping Equipment can trap all sediment at unit width. We placed it at the Oshima check dam located upstream of the Abe river and measured the sediment discharge. Based on the 4 observations, the following knowledge was gained; (1) In the floods at normal year, suspended load plus washload account for a far greater ratio than that of bed load in the total sediment discharge at this river; (2) The suspended load plus washload obtained was greater than those obtained at other rivers; (3) The bed load estimated by the Ashida, Takahashi, and Mizuyama’s formula was greater than

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the measured amount in many cases, but the difference became small at peak flow rate. The bed load estimated by the Meyer Peter, Muller's formula was generally smaller than the measured amount, but the difference remained small; (4)The effectiveness of the "Japanese pipe hydrophone" was confirmed as a observation method of grasping bed load.

Keywords: sediment transports systems, total load, bed load, suspended load

INTRODUCTION

The sediment discharge causes various problems to river basins, such as flooding due to river bed aggradation and a reduction in sediment transport capacity; a reduced water storage capacity due to sedimentation in a reservoir; scouring of a foundation bottom due to riverbed degradation; and retreat of a coast line due to reduced sediment transport to a river mouth. To tackle these problems resulting from sediment discharge, it is necessary to treat the entire area of sediment movement from mountain to littoral drift area as the "sediment transport system" and to take comprehensive sediment control measures over the entire basin (Subcommittee for Comprehensive Sediment Control, River Council, 1998). As the first step in this direction, it is required to grasp the temporal change of sediment amount and particle size which flow down a given river as a flood flow.

With this in the background, sediment discharge has been measured at the Tenryu river and the Hime river by collecting samples using a sampler placed at the overflow section of a check dam for collecting suspended load and bed load at various depths, or using a sampler inserted into the flowing water from a backhoe for collecting bed load (Nakano et al. 2001). At the Abe river, sediment observations has been conducted at various positions of the river basin, from sediment source to the river mouth. (Matsuki, Hashinoki et al. 2005, Mizuno et al. 2005, Imaizumi et al. 2003, Kondo et al. 2005).

It is considered that both suspended load and bed load are usually mixed at all depths when they flow down as a flood flow. Therefore, the sampling position should not be fixed in the water depth direction, but allowed to be flexible to trap sediment moving at all depths.

Therefore, by referring to existing measurement case (Nakano et al. 2001), we developed a sediment discharge trapping equipment (hereinafter referred to as the "Total Load Trapping Equipment") that can trap all the sediment passing through the unit width (1.0m) of a flood flow which flows down the overflow section. Using this Equipment, we conducted a field measurement with a view to grasping the actual state of sediment discharge at a mountainous river.

TARGET DRAINAGE AREA

As shown in Fig.1, the Oshima check dam at which observation was conducted is located at the confluence of the Oya river and the Yomogi river, both tributaries upstream of the Abe river which flows through Shizuoka city. The total drainage area of those rivers above the Oshima check dam is 8.8km^2. The Yomogi river originates from Mt. Yamabushi (2,014 m) and has drainage area 3.8km^2, channel length 4.0km, and average gradient 1/3.6 up to this check dam. The Oya river originates from Mt. Oya (2,000m) and has drainage area 4.0km^2, channel length 3.2km, and average gradient 1/2.9 up to the same dam. The "Oya Kuzure" said to have collapsed due to a severe earthquake in 1707 is located at the headwater area of the

Oya river. The horizontal area of the "Oya Kuzure" is estimated to be 1.8 km^2, altitude difference 800 m, and collapsed sediment 120 million m^3 (Shizuoka River Work Office of the Ministry of Construction (MOC), 1988) and it is considered as the primary sediment source of the Abe river basin. The geology in the upstream area above this dam belongs to the Setogawa formation group of the Palaeogene Period and mainly consists of sandstone, shale, and alternation of these rocks. Having the Itoigawa-Shizuoka tectonic line on the east and the Sasayama tectonic line on the west, the geology in this area upstream of the Abe river is prone to collapse because the bedrock is fractured due to tectonic movements.

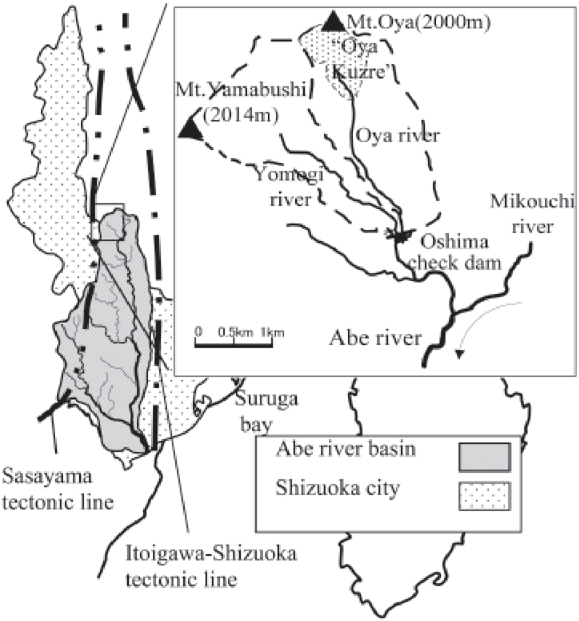

Abb.1: Umriß der Abe River-Ableitung Gebiet
Fig 1:Outline of the Abe River drainage area

The Oshima check dam, 22m high and sediment trapping capacity 410,000m^3, was constructed in 1977 (Shizuoka River Work Office, MOC, 1988), but it is almost full now because of large-scale floods in 1982 caused by Typhoons No. 10 and No. 18. The present sedimentation gradient is about 1/15. A open type check dam is installed at 500m upstream of the Yomogi river and a series of groundsels located at 500 m upstream of the Oya river.

THE TOTAL LOAD TRAPPING EQUIPMENT

The Total Load Trapping Equipment was developed with the following four design objectives (Kakimoto, Yasuda et al. 2003);

- Both the flowing water and sediment at the all depths, from riverbed to water surface, can be sampled
- Sampling can be made without disturbing flowing water as much as possible
- The flowing water in the river center direction can be sampled
- Change of sediment amount and particle size with time can be measured

To satisfy these design objectives, the equipment was placed in the river center in front of the overflow section where the floodwater shows a constant flow, which enabled direct sampling of floodwater.

Because the primary objective of this equipment was to grasp the actual state of sediment discharge at the time of flooding, the possible target floods ranged from small and medium floods that occur in normal years to large-scale floods that occur once in 10 years or more. However, if a very large-scale flood is targeted, a large equipment is needed and the safety and operability may be impaired. Therefore a rainfall with a return period of about 20 years was selected as the target rainfall for the Total Load Equipment. The peak flow rate of this rainfall and the water depth at peak time are $38m^3/s$ and 0.6m, respectively.

The Equipment was designed to be able to function up to the target discharge without problems as following;

Trapping bucket :
The size of the trapping bucket was made larger than the jumping distance (2.5m) of a water of the target flow so that all the flowing water from riverbed to water surface in the unit sampling width could be captured.
Water conveyance pipe : The conveyance pipe to send sediment and water from trapping bucket to sampling tank was sized 0.8 m in diameter because the target flow was not pressurized.

Sampling tank:
The capacity of the sampling tank was made to $6.5m^3$ (outside diameter 2.0 m, height 2.5 m) so that the target sediment and water could be sampled in several minutes at least. 7 sampling tanks were brought to the site to enable measurement of sediment discharge which changes as the flood discharge changes. Tanks were placed at the sampling position, one at a time, by crane and removed after sampling to measure the total sediment amount and the water amount in the sample.

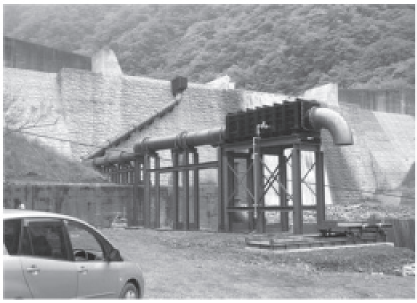

Abb.2: Überblick Totaler Last, der Ausrüstung fängt,
Fig 2: Overview of Total Load Trapping Equipment

The Total Load Trapping Equipment was placed in October 2004 as shown Fig.2,Fig.3.

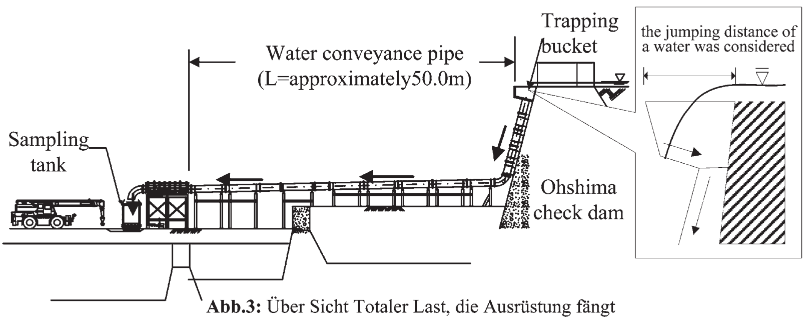

Abb.3: Über Sicht Totaler Last, die Ausrüstung fängt
Fig 3: Over view of Total Load Trapping Equipment

MEASUREMENT METHODOLOGY

Flow rate:
The flow rate at overflow section of Oshima check dam was measured with sampling. The velocity was obtained by a float. The water depth was measured by the supersonic wave type water gauge as shown in Fig.4. River width measured with the eye.

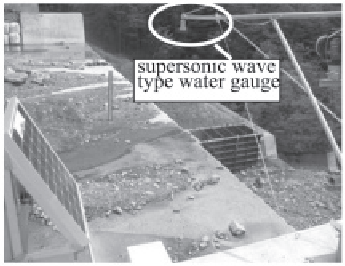

Abb.4: Der Überschall Wellenart Wassermaßstab für den Überlaufenteil des Oshima Scheckdammes
Fig.4: The supersonic wave type water gauge at the overflow section of Oshima check dam

Sampling tank:
It is necessary to separate the sediment from water to grasp of the actual of sediment discharge. But it is not practice to separate sediment from all sampled water because of the large size of the equipment. In order to estimate sampled sediment, contents of sampling tanks was divided into turbid water ingredients as Upper part and subsidence ingredients as Lower part as shown in fig.5, and each parts were measured.

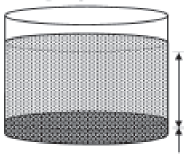

Abb.5: Einteilung probierten Bodensatzes
Fig.5: Classification of sampled sediment

The concentration of Upper part water was estimated by measuring only 1.5 liters turbid waters dipped immediately after sampling. The weight and particle size of Lower part was measured directly after draining other Upper part water by siphon and gathering. Total load corresponds to Upper part plus Lower part.

Washload is almost never exchanged with bed materials under natural conditions and almost never stay on the riverbed (Ashida et al. 1985). Hence, the particle with a size smaller than 0.1mm considered to be washload was excluded from subsidence ingredients samples when total load was calculated.

RESULTS OF OBSERVATIONS

The observations were conducted 10 times from 2003 to 2005. The results of the observations are shown in Table1.

As far as the current observation was concerned, it was rare that the flows from the Oya river flowed down the entire width of the overflow section. Hence, the discharge captured by the equipment was mostly the discharge from the Yomogi river. However, for the evaluation purpose, it was assumed that the flowing condition at the overflow section of the Oshima check dam was the same with that of water flowed into the unit width of the equipment. When the volume concentration was calculated, the weight of the soil grain was assumed to be 2.75 from the past soil test result (Kondo et al. 2004).

The total rainfall was obtained from the measurement at the Umegashima rainfall gauging station of the Japan Meteorological Agency (JMA). The return period was calculated from the

Tab.1: Ergebnisse totaler Lastbeobachtung
Tab.1: Results of total load observation

Target rainfall	Sampling data		Flow rate (m^3/s)	Sediment discharge $(10^{-6} \cdot m^3/s)$	Concentration (%)	Maximum particle size (mm)	cumulative rainfall (mm)
June,2003 (Typhoon No.6)	2003.6.20	9:26	1.6	5	0.0003	-	37
		10:09	1.6	77	0.005	-	
		11:12	1.4	46	0.003	9.5	
September,2003 (Typhoon No.15)	2003.9.22	9:15	3.2	5	0.0002	-	171
		9:37	3.2	3	0.0001	-	
		13:34	3.2	5	0.0002	-	
November,2003 (Typhoon No.19)	2003.11.6	9:00	0.6	2	0.0003	9.5	53
		10:00	0.6	0	0.00001	2	
		11:10	0.6	19	0.003	26.5	
		11:10	0.6	19	0.003	19	
		13:23	0.7	2	0.0003	19	
		14:27	0.6	0	0.00002	9.5	
		15:26	0.6	6	0.001	19	
June,2004 (Typhoon No.6)	2004.6.21	9:30	1.9	55	0.003	9.5	268
		10:00	1.9	97	0.005	9.5	
		11:00	1.9	43	0.002	4.75	
		12:00	1.6	125	0.008	9.5	
		13:00	1.4	2681	0.2	106	
		14:00	3.6	3954	0.1	19	
		14:45	28.5	831800	2.9	300	
August,2004 (Typhoon No.16)	2004.8.28	9:10	1.8	12	0.0009	4.75	310
		12:10	1.7	9	0.0008	4.75	
September,2004 (Typhoon No.18)	2004.9.7	8:00	2.4	9	0.0004	4.75	121
		9:00	2.3	13	0.0006	9.5	
		11:00	2.0	10	0.0005	9.5	
		13:00	2.3	42	0.002	19	
		14:00	5.8	938	0.02	19	
		15:00	3.1	931	0.03	37.5	
		16:00	3.0	8218	0.3	150	
		17:00	4.0	1470	0.04	53	
		17:30	3.6	277	0.008	26.5	
		18:00	2.9	210	0.007	26.5	
	2004.9.8	8:00	4.7	1045	0.02	19	

Target rainfall	Sampling data		Flow rate (m^3/s)	Sediment discharge $(10^{-6} \cdot m^3/s)$	Concentration (%)	Maximum particle size (mm)	cumulative rainfall (mm)
September,2004 (Typhoon No.21)	2004.9.30	8:20	1.3	2296	0.07	53	92
		9:00	0.9	712	0.02	26.5	
		10:00	0.4	1751	0.06	53	
October,2004 (Typhoon No.22)	2004.10.9	8:27	11.7	19604	0.2	75	338
		8:57	12.5	7808	0.06	26.5	
		9:57	12.8	12850	0.1	53	
		10:55	8.0	41211	0.5	150	
		11:55	14.1	32139	0.2	106	
		12:52	21.8	39662	0.2	53	
		13:53	21.1	81266	0.4	75	
		14:53	17.5	252323	1.4	150	
		15:53	13.0	107479	0.8	106	
July,2005 (Typhoon No.7)	2005.7.26	13:00	7.5	1150	0.02	37.5	139
		14:00	9.5	1596	0.02	53	
		15:00	13.5	2456	0.02	53	
		16:00	14.3	1092	0.008	9.5	
		17:00	15.2	567	0.004	26.5	
		18:00	13.5	636	0.005	26.5	
		19:30	12.6	376	0.003	26.5	
August,2005 (Typhoon No.11)	2005.8.25	9:00	0.5	3	0.0005	-	312
		12:00	0.9	48	0.01	19.0	
		15:00	1.9	799	0.04	26.5	
		16:00	2.6	8876	0.3	75	
		17:00	6.2	22693	0.4	106	
		18:00	9.6	65520	0.7	75	
		19:00	7.2	17894	0.2	75	
		20:00	9.3	58250	0.6	75	
		21:00	14.3	60774	0.4	106	
		22:00	10.8	54862	0.5	106	
		23:00	16.8	81199	0.5	75	
	2005.8.26	0:00	15.1	70140	0.5	75	

past 26-year data (1979-2004) at the same gauging station using the Iwai method. The daily rainfall during the observation period was mostly in the range of a return period of 1-2 years. Even the maximum daily rainfall that occurred on Aug. 25 - 26 in 2005 had a return period of only 2.2 years. Accordingly, the measured flood was inferred to be the normal scale which occurs in ordinary years.

At Typhoon No.6, No.11 and No.16 in 2004 and Typhoon No.11 in 2005, large scale discharge occurred, and sediment during peak flow rate was sampled. The maximum values of flow rate, sediment discharge, sediment concentration, and particle size were obtained at 14:45 At Typhoon No.6 in 2004. The maximum sediment concentration and the maximum particle size were 2.9% and 300 mm, respectively.

Fig.6 shows the relationship between flow rate and sediment discharge obtained from these four observations. From this figure, it is known that the relationship was linear. But, because the sediment discharge on the ordinate varies from 10^{-7} to 10^{0} and the flow rate on the abscissa varies from 10^{-1} to 10^{2}, it means that the sediment discharge was increased by 3-4 orders when the flow rate was increased by one order.

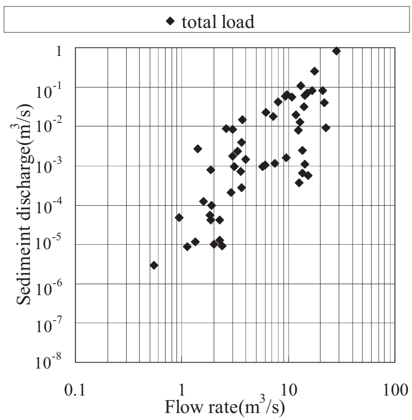

Abb.6: Beziehung zwischen Strömungsgeschwindigkeit und Bodensatzlöschung
Fig.6: Relationship between flow rate and sediment discharge

DIVISION BY SEDIMENT DISCHARGE TYPE

The observation results obtained from The Total Load Trapping Equipment were not directly usable for the evaluation of the sediment movement type, because the sediment was kept in a tank together with water. In order to compare the results of observations with the past result at other areas or calculated value, sediment movement type was defined and classified according to particle size. It is assumed that the subsidence whose fall velocity is faster than friction velocity flows as bed load, and that other subsidence ingredients and the turbid water ingredients flows as suspended load and washload. Friction velocity was calculated as follows(Eq.1)

$$u_0 = \sqrt{ghi} \quad (1)$$

u0:friction velocity (m^3/s) , g:gravity acceleration ($9.8m^3/s$), h:water depth(m),
i:bed slope gradient
The water depth was measured by supersonic waves type water gauge, and bed slope was defined as 1/15 from past observation. Fall velocity was calculated from Rubey's formula (Rubey,1933) as follows(Eq.2)

$$\frac{\omega_0}{\sqrt{sgd}} = \sqrt{\frac{2}{3} + \frac{36\nu^2}{sgd^3}} - \sqrt{\frac{36\nu^2}{sgd^3}} \quad (2)$$

w0:fall velocity (m^3/s), s:submerged unit weight(m^3/t) , d:particle size(m)
ν :coefficient of viscosity (0.01 cm^2/s at 25°C)
In the condition of observation, the division particle size of bed load and suspended load was ranges from 2.0 to 9.5mm.

Fig.7 shows relation of flow rate and sediment discharge of four observations divided by movement type, and Fig.8 shows the relationship between the total load vs. suspended load plus washload. According to this figure, the ratio of suspended load plus washload to the total

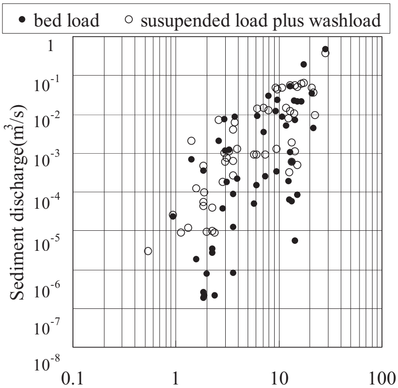

Abb.7: Beziehung zwischen Bettlast und schloß Last plus washload aus
Fig.7 Relationship between bed load and suspended load plus washload

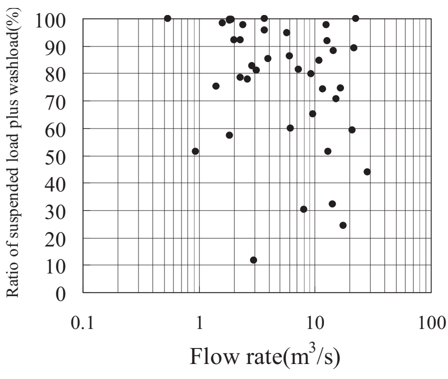

Abb.8:Beziehung zwischen Strömungsgeschwindigkeit und Verhältnis zu ausgeschlossener Last plus washload in totaler Last
Fig.8 Relationship between flow rate and ratio of suspended load plus washload in total loadt

load is over 50% in most cases, many are over 80%, and even cases close to 100% are not a few. This suggests that, in the case of floods expected to occur in normal years, suspended load plus washload account for a far greater ratio, sometimes 80% or more, compared with bed load in the total load flowing down a mountainous river.

TRANSITION OF FLOW RATE AND SEDIMENT DISCHARGE

Fig.9 shows the transition of flow rate and sediment discharge obtained from the 4 observations. The amount of suspended load plus washload was larger than the amount of bed load in most cases, but when the bed load increased, its amount approached or exceeded the amount of suspended load plus washload (e.g. in Typhoon No.6 at 13:00 and 15:00; in Typhoon No. 18 at 16:00; in Typhoon No.22 at 15:00, in 2004). These are considered to indicate the discontinuous movement of bed load.

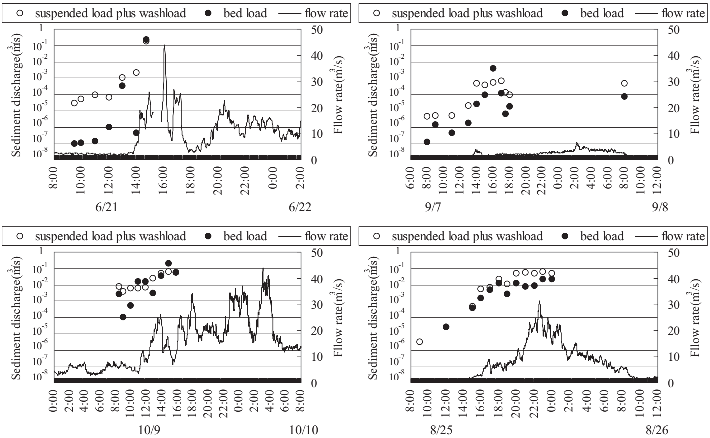

Abb.9: Übergang von Strömungsgeschwindigkeit und Bodensatzlöschung
Fig.9: Transition of flow rate and sediment discharge

COMPARISON OF CURRENT RESULTS AND RESULTS OF OTHER RIVERS

Fig.8 compares the relationship between flow rate and suspended load obtained from the current obsevation and past observations at other rivers (Yoshida et al. 1983, Terada et al. 2002). The relationship between flow rate and suspended discharge plus washload at four observations at the Oshima check dam was approximated using following equation;

$$Q_s = 2.8 \times 10^{-4} \times Q^2$$

Qs:suspended load plus washload (m^3/s)
Q:flow rate(m^3/s)
The outline of a past observation is shown in Tab.2.

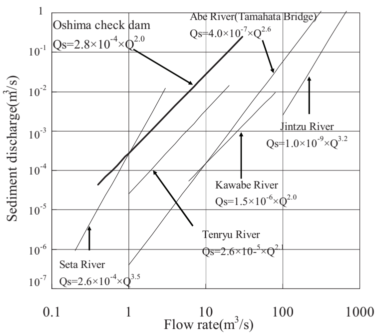

Abb.10: Schloß Löschung plus washload bei anderen Flüssen aus
Fig.10: Suspended discharge plus washload at other rivers

Tab.2: Der Umriß einer vergangenen Beobachtung
Tab.2: The outline of a past observation

Name of river	Location of measurement	drainage area(km^2)	average gradient	observation period
Abe river(Tmahata bridge)		146	-	2000-2001
Jinzu river		551	-	1979-1981
Kawabe river	Oduru river, tributary of the Kawabe River	15	1/8	1979-1981
Seta river	average of twenty four points	1-105	1/6-1/78	1980-1981
Tenryu river	average of three points from two catchment area	31,62	-	1975-1981

(Biwako Work Office, MOC, 1982, Jinzu Sabo Work Office, MOC, 1982, Kawabegawa Work Office, MOC, 1982, Shizuoka River Work Office, MOC, 1988, Tenryugawa-Joryu Work Office, MOC, 1982)

The target drainage area is small and hence the flow rate is small compared with other rivers as hown in Fig.10.

Therefore, it is difficult to directly compare the results of current observation with the results of those rivers, but it is shown that the suspended load of the current observation was larger than other results by one order in the flow rate range of 10^{-1}-$10m^3/s$.

OMPARISON OF BED LOAD BY SEDIMENT DISCHARGE FORMULA AND ACTUAL MEASUREMENT

Fig.11 shows the relationship between non-dimensional tractive force and non-dimensional sediment discharge by particle size, estimated from the current observation results, estimated by the Meyer Peter, Muller's formula (M.P.M) (Meyer et al. 1948), and estimated by the Ashida, Takahashi, and Mizuyama's formula (A.T.M) (Ashida et al. 1978). In this case, the critical tractive force at single particle size was calculated from the average particle size of the bed material by Iwagaki formula(Iwagaki,1956) at firstl, and the critical tractive force at each particle size was calculated by Egiazaroff modified formula (Egiazaroff,1965) secondly. Effective tractive force was used at M.P.M formula. The particle size was due to the particle size distribution test conducted in 2003 using sediment from the sedimentation site at the Oshima check dam , were utilized (Kondo et al. 2004). According to the comparison, there was a tendency that the A.T.M formula results were larger than the measurement results and the M.P.M formula results were smaller than the measurement results.

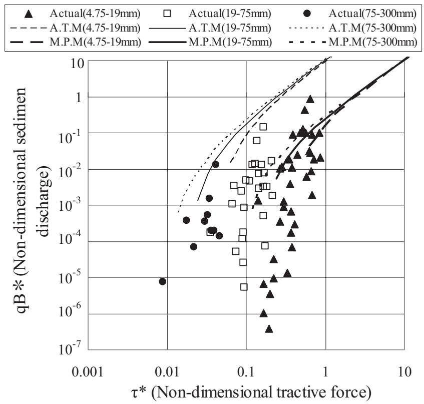

Abb.11: Beziehung zwischen nicht-dimensionaler tractive-Macht und nicht-dimensionaler Bodensatzlöschung
Fig.11: Relationship between non-dimensional tractive force and non-dimensional sediment discharge

Fig.12 shows the four cases comparing the bed load amounts obtained by actual measurement, by the MPM formula, and by the A.T.M formula. The bed load obtained by the A.T.M formula exceeded that of actual measurement by 3-5 orders in most cases, but when the sediment discharge increased, the difference between them was within one order (Typhoon No. 6 - 15:00; Typhoon No. 22 - 15:00, 2004). The bed load obtained by the M.P.M formula was generally smaller than the actual measurement results, but often within the range of 1-2 orders.

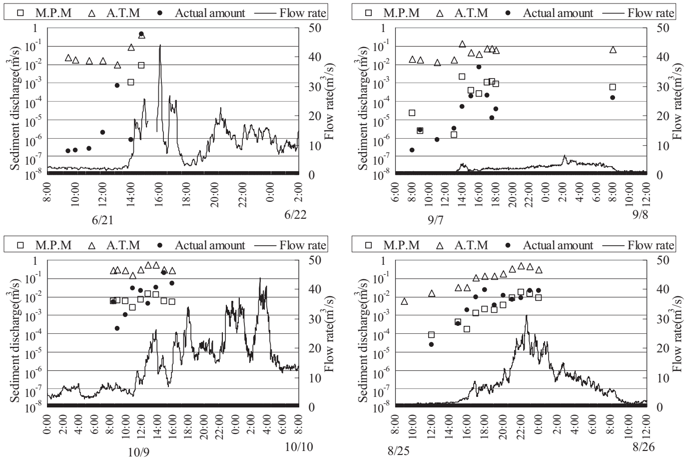

Abb.12: Die beobachteten und vorsätzliche Bodensatzlöschung
Fig.12: The observed and calculated sediment discharge

"JAPANISE PIPE HYDROPHON"

In addition to the direct measurement of the total load at this observation, the indirect measurement using a "Japanese pipe hydrophone" was carried out, which observed the collision sound of gravels to the metal pipe. The pipe was installed crossing the flow in the upstream of the trapping bucket. This device has six channels, Ch.1 to Ch.6, and the collision sounds of gravels from small particles to large particles are captured by Ch.l to Ch.6, respectively (Oda et al. 2004). The number of collisions, bed load, susnpended load plus washload captured at Typhoon No.11,in 2005 was shown in Fig.13.

Ch.1 and Ch.2 that were most sensitive rose from 13:30 as flow rate and discharge increase, and recorded a high value after 20:00. Ch.3 and Ch.4 rose from 13:30 and fell from 24:00 as flow rate and sediment discharge change. Ch.5 and Ch.6 responded slowly. Ch.5 and Ch.6 rose from 14:30 and 18:00, fell at 20:00, and rose again from 23:00 as bed load change. However, they did not respond to decrease of sediment discharge at 19:00. The effectiveness of the "Japanese pipe hydrophone" of this amplification extent was shown as a means of grasping the transition of bed load. But, further examination is would be necessary to use it for the quantitative observation.

CONCLUSION

To grasp the actual state of sediment movement at mountainous rivers, sediment discharge was measured at the Oshima check dam located at the upstream of the Abe river using a newly-developed Total Load Trapping Equipment. Observations were conducted 10 times at the site. Using the results of 4 times which were conducted under flooding, the total load was quantified by classifying sediment into bed load and suspended load plus washload. Using the obtained discharge amount, various comparisons were made, such as comparison by sediment

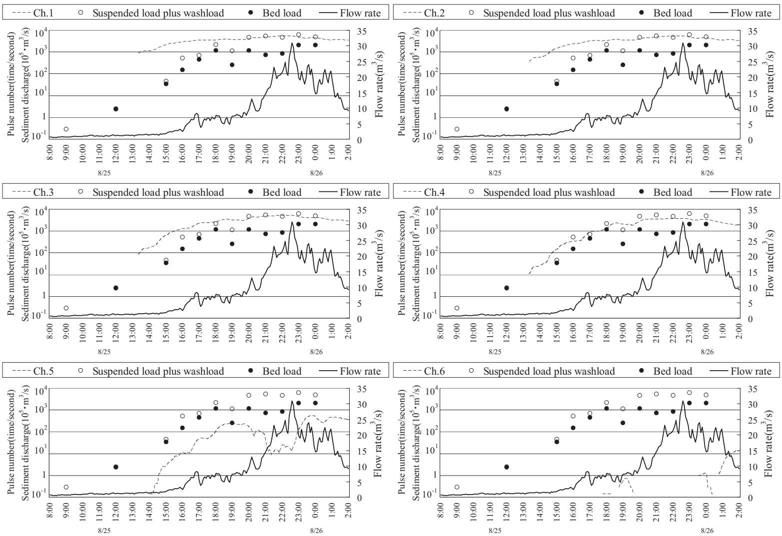

Abb.13: Die Bodensatzlöschung und der Puls numerieren dadurch “japanischer Leitung hydrophone”

Fig.13: The sediment discharge and pulse number by “Japanese pipe hydrophone”

movement type, comparison of suspended load with that of other rivers, comparison with the results estimated by sediment discharge formula. From the current research, the following conclusions were obtained:

- The ratio of suspended load plus washload to the total load was mostly 80% or more and sometimes very close to 100%. This suggests that, in the case of floods expected to occur in normal years, suspended load plus washload account for a far greater ratio, sometimes 80% or more, than that of bed load in the total load flowing down a mountain river.
- In the flow rate range of 10^{-1}-10 m^3/s obtained from the current observation, the amount of suspended load was larger than that of other rivers by one order.
- According to the comparison of bed load obtained from actual measurement and by two formulas, the amount derived by the A.T.M formula exceeded the actual amount by 3-5 orders in most cases, but remained within 1 order at the time of peak flow rate. The amount derived by the M.P.M formula tended to be smaller than the actual amount with a difference of 1-2 orders.
- The effectiveness of the “Japanese pipe hydrophone” was confirmed as a means of grasping bed load.

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