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Current Conditions of Reservoir Sedimentation in Irrigation Dams in Japan

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Abstract

Field data of 53 high dams were comprehensively analyzed to clarify the current conditions of sedimentation in irrigation dams in Japan compared with dams for other purposes. At first, it was shown that the CI ratio was an important index which markedly affected the sedimentation factors, the stages of sedimentation and the trap efficiency. Next, the sedimentation characteristics of the irrigation dams were analyzed and clarified by using the CI ratio. Main results obtained are as follows: (1) The annual sediment deposit rate of irrigation dams is relatively smaller than that of power generation dams in general, implying that the locations of irrigation dams are usually suitable for preventing the occurrence of sedimentation problems. (2) The specific sediment rate of irrigation dams is relatively large in general. Accordingly, it is necessary to investigate the factors which cause the increase of the specific sediment rate rather than the sediment deposit rate in irrigation reservoirs.

Discipline: Agricultural engineering, irrigation, drainage and reclamation
Additional key words: annual sediment deposit rate, CI ratio, specific sediment rate, trap efficiency

Introduction

Three years ago, a sediment flushing experiment in an actual dam reservoir was carried out for the first time in Japan, raising some concern about environmental problems.

In Japan, a large number of dams were constructed mainly during the period of high economic growth and as a result, food production increased after World War II. However, the number of suitable sites for the construction of dams has decreased in recent years. In addition, the negative impact of dams on the natural environment has been recently emphasized.

Therefore it is unlikely that new dams will be constructed and it is necessary to develop a new technology to prolong the useful life of dam reservoirs and to evaluate the effect on the environment.

Although many studies on reservoir sedimentation have been carried out so far, sedimentation in irrigation dams has not been well documented. Field data of 53 high dams have been comprehensively analyzed to clarify the current conditions of sedimentation in irrigation dams in Japan[7]. The objective of the current studies is to develop countermeasures to alleviate sedimentation problems in the irrigation dam reservoirs through the analysis of sedimentation factors.

Sedimentation analysis

1) Causes of sedimentation

The specific sediment discharge rate is defined as the total amount of sediments which pass through the unit watershed area (km^2) per year in a specific area in one river. It is considered that the long-term average value of the specific sediment discharge rate reflects the characteristics of the watershed. If dams were constructed at the same site in a river, some of the sediments transported should be stored, resulting in sedimentation. Fig. 1 shows the relationship between the factors described above. In this paper, the factors affected by the watershed conditions are referred to as the watershed factors. Likewise, the factors affected by the reservoirs are referred to as the reservoir factors. This classification of factors is related to the difference in the countermeasures adopted to alleviate sedimentation problems. Kira[3] described the major factors that influence sedimentation in reservoirs. Fig. 2 shows the relationship between Kira's factors and sedimentation factors,

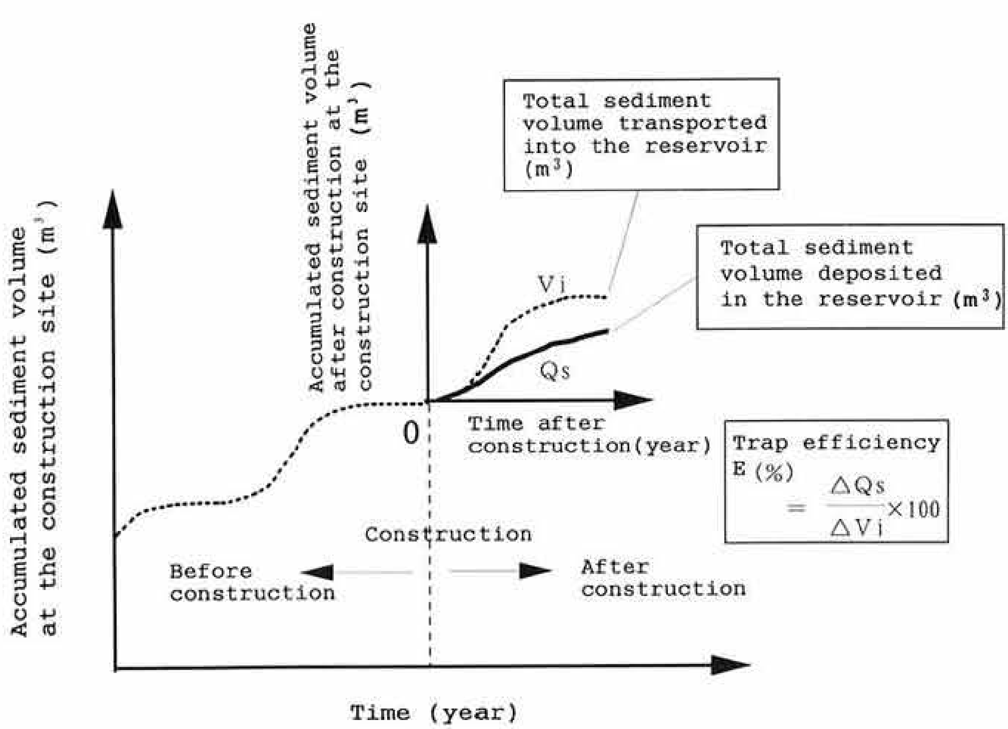

Fig. 1. Relationship between accumulated sediment volume and sediment deposit in the reservoir

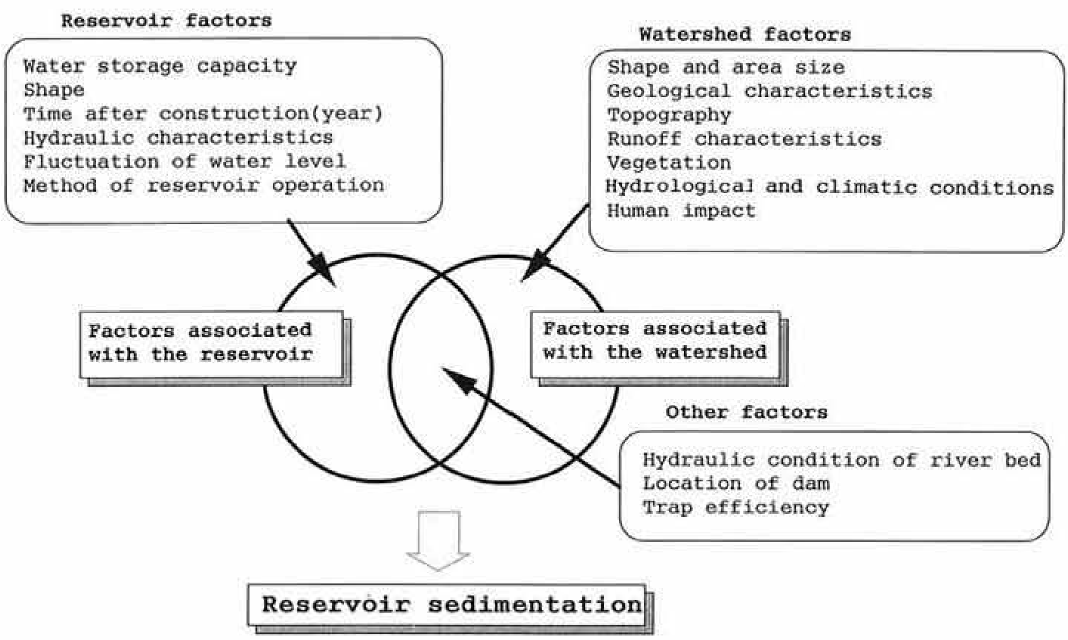

Fig. 2. Relationships among sedimentation factors

including the watershed factors and the reservoir factors defined above. Some of the Kira's factors belong to only one part of the sediment factors listed in Fig. 2, while the others belong to both parts.

2) CI ratio

The ratio of C to I (C/I) is designated as CI ratio in this paper, where C (m^3) is the storage capacity of the reservoir and I (m^3) is the annual inflow of water into the reservoir. C is one of the factors related to the reservoir factors, and I is one of the watershed factors. That is, the CI ratio is a dimensionless value related to both factors. Moreover, the CI ratio is a reciprocal number of the annual revolving rate (I/C) of the reservoir. It is obvious that the annual revolving rate of the reservoir markedly affects the reservoir operation or hydraulic conditions of the reservoir, the tributaries, the watershed, etc. Therefore, it is assumed that the CI ratio is closely correlated with the reservoir sedimentation process. The analysis of reservoir sedimentation based on the CI ratio is important to clarify the sedimentation factors and the sedimentation characteristics in the irrigation dams.

3) Sedimentation stages

Ishikawa et al.[2] pointed out that a typical pattern is observed in the temporal variation curve of the accumulated sediment volume in the reservoir. They classified the accumulation of sediments into 3 stages, referred to as the stages of sedimentation, based on data analysis. The stages of sedimentation are composed of an initial rapid increase stage, a mid-term gradual increase stage and the final steady stage. It is necessary to define the sedimentation stage for the correct evaluation of sedimentation conditions in the reservoir. For instance, the sediment data of a 'young' dam, less than 10 years after construction, are often overlooked for preventing overestimation at the initial rapid stage of sedimentation. Fig. 3 shows the stages of sedimentation by using the annual revolving rate of the reservoir. It is considered that the amount of sediments transported into the reservoir depends on the amount of inflow water. Accordingly, the aging speed of the reservoir, in which the annual revolving rate is larger, should be faster in terms of stages of sedimentation.

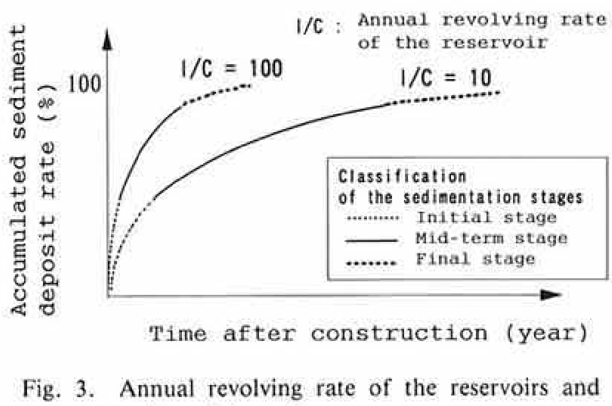

Fig. 3. Annual revolving rate of the reservoirs and sedimentation stages

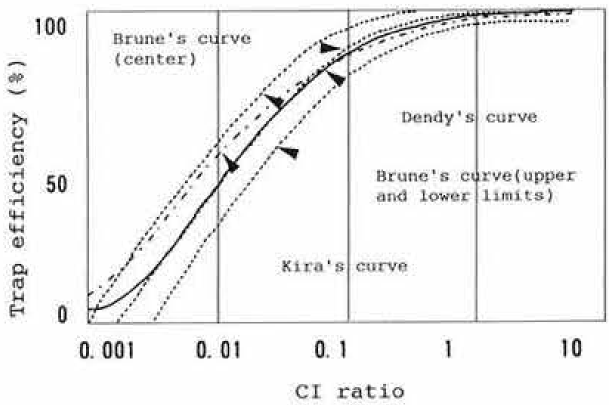

Fig. 4. Relationship between CI ratio and trap efficiency determined in previous studies

4) Trap efficiency

The trap efficiency is defined as the percentage of $\Delta Q/\Delta V$, where ΔQ is the amount of sediments deposited in the reservoir and ΔV is the sediment increase in the reservoir shown in Fig. 1. Obviously the trap efficiency is meaningless for a bed load in which 100% is trapped by the reservoir. Although it is an important index for the analysis of fine sediments such as suspended load or wash load. Fig. 4 shows the relationship between the CI ratio and the trap efficiency determined in previous studies[6]. In general, the trap efficiency is considered to increase with the increase of the CI ratio. However, the relationship between the trap efficiency and the mechanism controlling the reservoir sedimentation has not been studied sufficiently so far. Moreover, it is difficult to obtain reliable trap efficiency data for rivers.

Sedimentation characteristics of irrigation dam

In this chapter, the sedimentation characteristics of the irrigation dam reservoir are discussed based on the considerations presented in the previous chapter.

1) Catchment area and CI ratio of irrigation dam

In general, water storage in an irrigation dam is designed in considering the annual revolving rate of the reservoir. As a result, suitable catchment area which can supply a sufficient volume of water as that planned, is selected. On the other hand, in a dam for electric power generation both the volume of water and the water level must be secured. The catchment area of the irrigation dam is smaller than

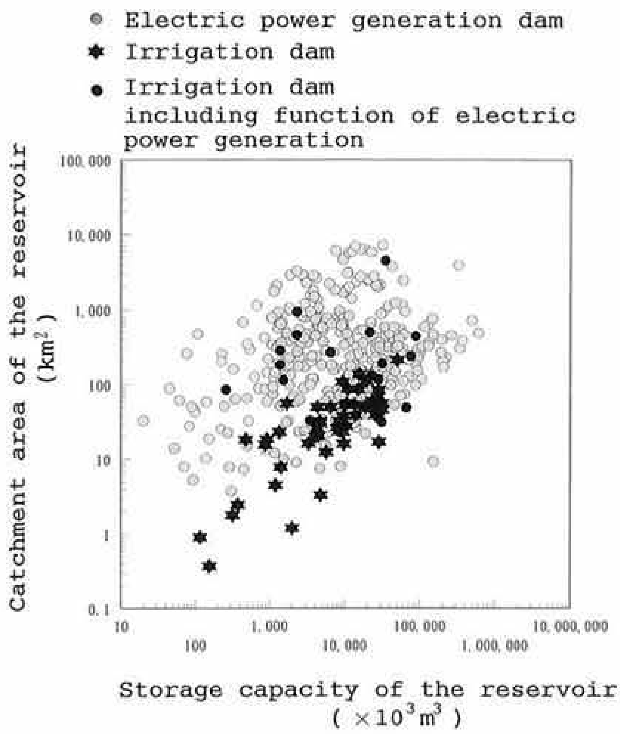

Fig. 5. Relationship between storage capacity and catchment area

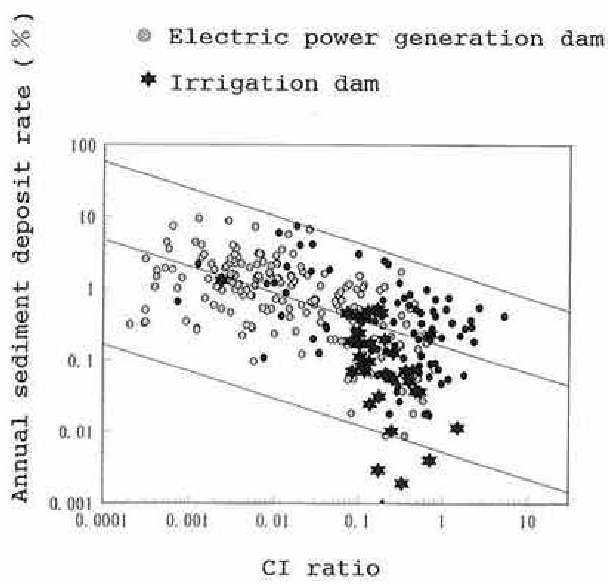

Fig. 6. Relationship between CI ratio and annual sediment deposit rate

that of the dam for electric power generation when the storage capacity is identical. Fig. 5 shows the relationship between the water storage capacity and watershed area of each dam. Sedimentation data of the irrigation dam were originally collected in this study and the previous data, mainly data for electric power generation[5)], were used in the analysis. The symbols in Fig. 5 indicate the kind of dams, either for irrigation or for other purposes. Fig. 5 shows that the dams for electric power generation have large catchment areas. Assuming that all the dams sampled had the same storage capacity, the watershed area F and the annual water inflow I of the irrigation dams would be smaller than those of the power generation dams. In fact, based on the same assumption, the CI ratio of the irrigation dams is considered to be larger than that of dams for electric power generation.

2) CI ratio and annual sediment deposit rate

Fig. 6 shows the relationship between the CI ratio and annual sediment deposit rate of the dams[4,7)]. The purpose of the reservoirs is indicated by the symbols. The annual sediment deposit rate is defined as the average percentage of storage capacity lost by sedimentation in a year (%/year). As stated in the previous paragraph, the values of the CI ratio of an irrigation dam are mainly included in the range of the value zone indicated in Fig. 6. Moreover, their distribution is in agreement with the general tendency observed in Fig. 6. Furthermore the plots of their distribution show a smaller value for the following reason. The annual sediment deposit is expressed as Q/Y/C, where Q is the total volume of accumulated sediment (m^3), Y is the number of years after dam construction, and C is the storage capacity (m^3). Assuming that A and B dams have the same degree of storage capacity C, if the annual revolving rate (I/C) of A dam is larger (CI ratio is smaller) than that of B dam, the annual sediment deposit (Q/Y) of A dam is considered to be larger in general. It is generally assumed that the values of Q/Y/C of irrigation dams are relatively smaller than those of other dams. In other words, it is considered that in the irrigation dams the sedimentation stages are longer than in the power generation dams. Therefore, it is assumed that the irrigation dams are located in suitable sites for avoiding the sedimentation problems.

3) CI ratio and specific sediment rate

Fig. 7 shows the relationship between the CI ratio and specific sediment rate[4,7)]. The purpose of the reservoir is indicated by the symbols. The specific sediment rate is defined as the total amount of accumulated sediments deposited in the reservoir per unit catchment area, averaged in a year

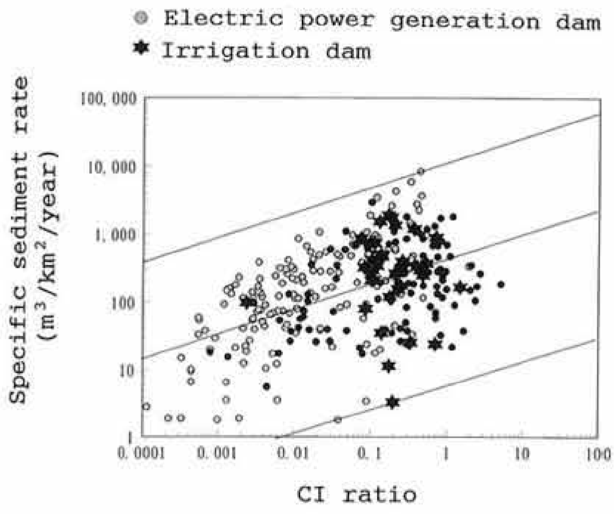

Fig. 7. Relationship between CI ratio and specific sediment rate

(m^3/km^2/year). The distribution of the specific sediment rate of irrigation dams shows a similar pattern to that of other dams as depicted in Fig. 7 and larger values are recorded, especially when the CI ratio is close to 0.1. The macroscopic tendencies mentioned above can be explained as follows. The specific sediment rate is expressed as Q/Y/F, where F is the watershed area (km^2). First of all, attention should be paid to the value of F and it should be assumed that these dams have the same storage capacity C. It was already indicated in Fig. 5 that the watershed area F of irrigation dams tends to be smaller than that of the power generation dams. Ashida et al.[1] observed that the specific sediment discharge rate shows a reverse correlation with the watershed area F. The difference between the specific sediment rate and the specific sediment discharge rate was disregarded here for simplicity, since the specific sediment rate (Q/Y/F) of the irrigation dams is considered to be larger than that of other dams. These observations are in agreement with the results indicated in Fig. 7.

The results can also be interpreted by paying attention to Q/Y which corresponds to the amount of annual sediments deposited in the reservoir. At first, it is assumed that all the dams sampled show the same values of F and Qin, where Qin refers to the annual sediment volume transported into the reservoir. As seen from Fig. 4, the irrigation dams tend to trap sediments effectively and Q/Y/F of an irrigation dam shows relatively larger values (Fig. 7).

Conclusion

The sedimentation data of irrigation dams were comprehensively compared with the data obtained from past studies. At first, it was shown that the CI ratio was an important index which markedly affected sedimentation factors, the stages of sedimentation and the trap efficiency. Next, the sedimentation characteristics of the irrigation dams were analyzed and clarified by using the CI ratio. The major findings of the analysis are as follows: (1) The annual sediment deposit rate of irrigation dams is relatively smaller than that of power generation dams, which implies that locations of irrigation dams are suitable for avoiding the sedimentation problems generally. (2) The specific sediment rate of irrigation dams is relatively large in general.

It should be noted that the specific sediment rate is different from the total sediment rate (Q/C), which refers to the rate of sediment accumulated Q to the storage capacity C. A large specific sediment rate does not necessarily imply that the total sediment rate is large. If a serious sedimentation problem should occur in an irrigation dam, detailed investigations of the specific sediment rate and its sources should be conducted.

Two aspects should be emphasized in the analysis using the CI ratio. The first is that the cause of the increase of the specific sediment rate in the irrigation dams has not been elucidated. The other is that the figures related to the CI ratio are not suitable for practical and specific operations relating to the sedimentation factors. For instance, the value of the spindle in each figure varies widely and maximum uneven value is in the range of 10^2-10^3. It is assumed that the above-mentioned fact might be caused by many other unexpected events such as earthquakes, volcanic eruption, downpours, and human impact, etc. that were not considered in this paper. However, the CI ratio appears to be useful for predicting the sedimentation trend in an irrigation dam.

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