Analysis of Silt Dam System Grade and Joint Regulation in Typical Small Watershed of Loess Plateau

Weiying Sun1, Pan Zhang1, 2*

1Key Laboratory of Soil and Water Loss Process and Control on the Loess Plateau of Ministry of Water Resources, Yellow River Institute of Hydraulic Research, Zhengzhou 450003, China

2Research Center of Soil and Water Conservation and Ecological Environment, Chinese Academy of Sciences and Ministry of Education, Yangling, 712100, China

*Corresponding author’s e-mail: zpyrcc@163.com

Abstract. When a silt dam system is formed, its function of flood detention and erosion reduction is not simply superimposed. The transport and transfer process of sediment between the dams system presents a nonlinear relationship, which we call the grade regulation function of the dam system. In order to study the mechanism of joint action and regulation of flood storage and sediment retention in silt dam systems in small watersheds, the Yulingou small watershed silt dam system in the first sub-region of the hilly and gully region of the Loess Plateau was taken as the research area. Based on the systematic analysis of different dam levels and different grading ways (series, parallel and mixed), the silt retention and sediment retention effect of silt dams in small watershed of the Loess Plateau is analysed. The spatial distribution model reveals the control relationship between the dam system and channel unit dam on the flood and cement sand in different layers, and clarifies the grade effect of the flood and sediment storage capacity of the small watershed. The results show that the reasonable arrangement of silt dam system in small watershed can effectively extend the service life of main dam, the reasonable arrangement of different types of dam system can extend the service life to different degrees, and the joint application of cascade dam system can realize the internal digestion of flood and sediment.

1. Introduction

In any small watershed with an area of 30 to 200 km² of Loess Plateau, the silt dam system always contains several relatively independent sub-dam systems, which belong to a control unit of the general silt dam system[1]. These sub-dam systems control a part of the upstream or branch gully of the watershed, which is called the dam system unit. Compared with the channel grade of the small watershed, the control range is exactly in accordance with the area characteristics of the tertiary channel. There is not only a position relationship but also some functional relationship between dam systems. The layout relationship between dam and dam is called dam system structure. Dam system structure can be divided into three basic forms: series connection, parallel connection and mixed connection[2].

Due to the large control area of a dam system unit, the control area contains channels of different levels. There are a large number of silt dams, and the channel topography is complex, which makes the distribution of silt dams relatively scattered and complex in structure. Therefore, the internal control and subordination relationship of the silt dam system is relatively complicated. It is difficult to
generalize all dam systems of small watersheds with a unified dam system structure[3]. At the same time, and it is also difficult to decompose and generalize each dam system in detail. The concept of dam system unit is proposed to seek the cascading relationship and the joint effect between them through the analysis method from the whole to the part[4]. In order to provide reference for the planning, layout and site selection of the dam system, and make timely adjustments to the dam system structure during the development of the dam system, to avoid problems that threaten the safety of the dam system during operation.

2. Materials and methods
This study takes the small watershed of Yulingou as the study area, which is located in the first sub-region of the hilly-gully region of the Loess Plateau. Its channel characteristics and dam system structure distribution are shown in Figure 1[5]. According to the survey data of the dam system of the Suide Soil and Water Conservation Scientific Experimental Station of the Yellow River Water Conservancy Commission in 1999, combined with the water system map and dam system configuration atlas of the Yulingou small watershed, the dam system structure of the Yulingou small watershed was analysed. According to the water system structure, channel characteristics and the distribution of silt dams in the small watershed, the distribution of silt dams in the dam system is classified, segmented, layered and divided, so as to analyse the cascade relationship within the dam system. The internal structure and control relationship of the main channel, the main channel dam system and each dam system unit are analysed by graphic method.

Figure 1. Channel characteristics and dam system structure distribution of Yulinggou small watershed

3. Results and discussion
3.1. General structure of dam system unit in Yulinggou small watershed
As can be seen from Figure 2, the dam system of Yulinggou small watershed can be generally divided into 1 main ditch dam system (Banjiagou main ditch dam system), two main ditch dam systems (Fengqugangou dam system, Liuqugangou dam system) and five dam system units (Majiagou, JiZhai, Chenjiagou, Jiangxingzhuang and Matiwa dam system units). In the dam system layout of the Yulingou small watershed, there is a certain control or subordination relationship between each single dam and the dam system unit. In the two Grade IV trenches, Liuqu and Fengqugangou dam systems were formed, which were controlled by the main dam system. The control area of Liuqugangou small dam system is 13.73km², and two dam systems of Jiangxingzhuang and Maatiwa are formed in the two III-
level channels respectively; the control area of Fengqugangou dam system is 14.38km², and three III-level channels form Jizhai, Majiagou and Chenjiagou three dam units.

![Diagram of dam system units in Yulinggou small watershed]

3.2. Analysis of cascade control relationship of dam system units in Yulinggou small watershed

According to the definition and division principle of dam system unit, Yulinggou dam system includes 5 dam system units, and the distribution and characteristics of dam system units are shown in Table 1. From table 1, it can be seen that the average area of grade III channel in Yulinggou small watershed is 6.24km², the average length of the channel section is 2.33km, and the average gradient is 1.82%. It is suitable for the construction of large-scale silt retaining dam, which is the main place for flood and sediment storage in the basin. The average control area of the dam system unit is 5.74km², the number of dams built by each dam system unit is between 9 and 14, the average dam layout of each dam unit is 11, and the configuration ratio of large, medium and small silt dam is 1.2:3.26. An average large dam controls 2.7 medium-sized dams and 5 small dams. The number of large, medium and small dams in each dam unit is 1.5, 3.2 and 6 respectively. The control relationship of flood cement and sand between the dam units is shown as joint storage, supplementation and coordination. Among them, in Fengqu main ditch dam system, JiZhai and Majiagou dam system units are located in the upstream, which are in parallel relationship with each other. Through flood retaining cement sand, the flood control pressure of the downstream main ditch dam is reduced, and the internal small and medium-sized dams are silted up quickly to form land for agricultural production.

| Item                  | Majiagou | Jizhai | Chenjiagou | Jiangxingzhuang | Matiwa | Total | Average |
|-----------------------|----------|--------|------------|----------------|--------|-------|---------|
| Grade III channel area /km² | 6.9      | 6.1    | 6.7        | 8.2            | 3.5    | 31.2  | 6.2     |
| Unit dam area /km²     | 6.8      | 4.5    | 6.6        | 7.4            | 3.4    | 28.7  | 5.7     |
| Ditch length /km       | 2.5      | 2.8    | 2.8        | 2.1            | 1.5    | 11.7  | 2.3     |
| Gradient /%            | 1.6      | 2.3    | 1.5        | 1.7            | 2      | 9.1   | 1.8     |
| Quantity of dam /piece | 9        | 11     | 11         | 14             | 10     | 55    | 11      |
| Large dam / piece      | 3        | 1      | 1          | 2              | 1      | 8     | 1.6     |
| Medium dam / piece     | 4        | 1      | 4          | 4              | 1      | 14    | 2.8     |
| Small dam / piece      | 1        | 9      | 5          | 7              | 8      | 30    | 6       |
From table 2, it can be seen that the average control rate of the five dam system units over the drainage area is 90.1%, among which the control rate of medium-sized dam is 41.7%, and that of small-sized dam is 28.9%. It can be seen that the large-scale backbone dam is in a high level in the small-sized dam system, and the water and sand flow are basically controlled in the general control field. At present, the average siltation rate of reservoir capacity has reached 80.1%, and the average area siltation rate has reached 83.8%. Among the five dam system units, except for the Matiwa which was raised in the middle period and still able to withstand a 200-year flood, the rest of the dam systems can only withstand a 20-year flood. At present, the pressure of flood control is large, so it is urgent to adjust the structure of dam system, increase the height and capacity, so as to ensure the safety of dam system.

The total storage capacity of Fengqu main dam system is 5.2019 million m³, of which the total storage capacity of the two dam system units of Majiagou and Jizhai is 4.222 million m³, accounting for 80% of the total storage capacity. Among the 7.275 million m³ of total silt in the main dam system at present, Majiagou and Jizhai have a total of 2.943 million m³ of silt, accounting for 48.3% of the total silt, which has a very good decompression effect on the downstream dam system. Chenjiagou dam system unit, located in the middle reaches, currently has 1.253 million m³ of silt retention, accounting for 21.3% of the total. With large surplus storage capacity, it can continue to play a role in protecting the downstream main dam in a long period of time. The main dam system of Liuqu has a total storage capacity of 3.686 million m³, and the two dam system units, Jiangxingzhuang and Matiwa, which have silt retaining capacity of 1.247 million m³ and 1.615 million m³ respectively, accounting for 77.4% of the total silt retaining capacity of the main dam system, which has a very obvious protective effect on the downstream.

| Item                          | Dam unit         | Majiagou | Jizhai | Chenjiagou | Jiangxingzhuang | Matiwa | Total | Average |
|-------------------------------|------------------|----------|--------|------------|-----------------|--------|-------|---------|
| Unit area control rate /%     |                  | 99       | 78.9   | 99.4       | 78.6            | 98.1   | 90.1  |
| Medium-sized dam control rate /% |                | 38.5     | 19.8   | 73.6       | 49.3            | 27.6   | 41.8  |
| Small dam control rate /%     |                  | 3.8      | 40.6   | 19.8       | 33.6            | 46.9   | 144.7 |
| Unit capacity /10⁴ m³         |                  | 298.3    | 125.3  | 203.7      | 168.9           | 200.1  | 996.3 |
| Silted storage capacity /10⁴ m³ |                  | 174.4    | 120    | 174.1      | 124.7           | 161.5  | 754.7 |
| Remaining storage capacity /10⁴ m³ |                | 123.9    | 5.3    | 29.6       | 44.2            | 38.6   | 241.6 |
| Proportion of large dams /%   |                  | 61.4     | 40.4   | 35.1       | 0               | 64     | 40.2  |
| Proportion of small dams /%   |                  | 62.5     | 71.4   | 63.2       | 74.1            | 54.5   | 65.1  |
| Siltation rate of storage capacity /% |            | 58.5     | 89.2   | 95.5       | 76.7            | 80.1   | 80.1  |

4. Conclusions
From the above analysis, it can be seen that the distribution of dam system elements in Yulinggou is relatively symmetrical and the structural configuration is reasonable. As for the problems existing in the dam system, they are mainly as follows: the operation condition of Yulinggou dam system is aging seriously, the remaining storage capacity is insufficient, and the sediment retention capacity is poor, which is also a common problem after the long-term operation of the dam system. Due to the long-term focus on production, the utilization rate of dam land area is up to 80.1%, while ignoring the supplementary construction and maintenance management, at present, the dam system has gradually lost its function, most of the upstream flood and sediment discharge, causing serious pressure to the main ditch, and it is necessary to further heighten and strengthen some large dams with limited storage capacity, or build new control dam and reservoir projects.
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