

## Check-Dam System in Gullies — The Most Effective Measure to Conserve Soil and Water in Chinese Loess Plateau\*

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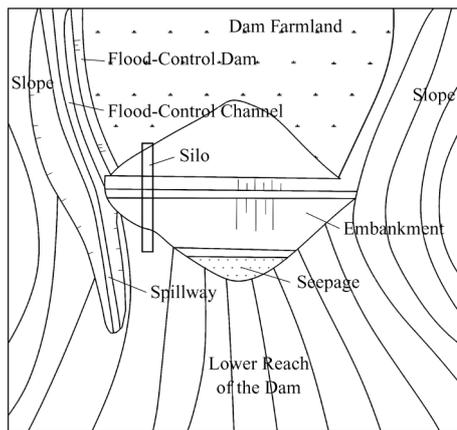
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**Abstract:** The *Loess Mesa Ravine Region* and the *Loess Hill Ravine Region*, which cover 200,000 km<sup>2</sup>, 30% area of the Loess Plateau in China, was seriously attacked by soil and water erosion. Two primary ways to control the sediment pouring into the Yellow River from this area are the planting measure and the engineering measure. The former is not suitable for the Loess Plateau due to the arid climate and the barren soil, and some of the later such as terrace farmlands are vulnerable to flood. As a widespread engineering measure, the check-dam system in gullies is the most effective way to conserve soil and water in the Loess Plateau. At present, the amount of sediment retained by check-dam systems is the largest in all measures and the potential is still tending upwards, and dam farmlands, celebrated for *Dam System Agriculture*, become the most important high-yield croplands or orchards for enriching in fertile soil and ample water.

The check-dams have been built for centuries in China, but the boom came about ever since the foundation of the People's Republic of China. Though the achievements of dam system construction are notable in the latest 50 years, it is urgent to arouse nationwide attentions on check-dam systems and their working theory should also be studied thoroughly. Physical model experiments are recommended in the context of a typical small watershed with fragmented physiognomy in the *Two-River* and *Two-Chuan Zone*.

**Keywords:** the loess plateau, check-dams, check-dam system, soil and water conservation, strategy to control the yellow river

Check-dams for Building Farmland had been built for a long time in the Loess Plateau of China, and the Check-dams at Kanghe Gou watershed, FenXi County, built in Ming Dynasty 400 years ago, still run in good condition. As the most primary measure to conserve water and soil, the check-dam project had been attached great importance since the foundation of People's Republic of China. About 100,000 check-dams have been built till 1998, which formed 1,300,000 hm<sup>2</sup> farmland with high and stable productivity and intercepted total 700 million tons sediment pouring into the Yellow River. Thus it is obvious that the check-dam is the most important well-known project to conserve water and soil and the ultimate line of defense in the comprehensive control system.



**Fig. 1** Sketch map for a check-dam  
(Wang Lixian, 1995)

*check-dam*, means the dam built in gullies to hold up sediment and form farmland. The farmland formed by check-dams is called dam farmland. In general, a check-dam is composed of three parts: embankment,

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spillway, and outlet. Sometimes some simple check-dams are constructed without spillway or outlet. Fig. 1 illustrates a sketch map for a typical check-dam. In a small watershed, various dams could be built such as product dams for forming farmland to plant, flood-control dams for preventing floodwater and intercepting sediment, store-water dams for irrigating, etc. Group of the above dams constitutes the check-dam system in gullies.

### **1 The most effective way to control sediment pouring into the Yellow River is to construct the modern engineering taking check-dam system in gullies as a principal project**

The Loess Plateau is located in the upper and middle reaches of the Yellow River, encircled with the western Ela Mt., eastern Taihang Mt., northern Yinsan Mt., and southern Qinglin Mt. and Funiu Mt.. It covers a total area of 624,000 km<sup>2</sup>, and over 60% of the land is subjected to soil and water loss. The most urgent place to manage is the *Loess Mesa Ravine Region* and the *Loess Hill Ravine Region*, which cover 30% of the total area. As the most severe soil and water loss area in the world, the erosion modulus reaches 5,000 t/km<sup>2</sup>—10,000 t/(km<sup>2</sup> • year), sometimes it even arrives at 20,000 t/km<sup>2</sup>—30,000 t/(km<sup>2</sup> • year) (Meng Qingmei, 1996).

The Yellow River is distinguished for its sandy and vagrant characteristics. To conserve the soil and water in the watershed of the Yellow River, arduous efforts have been made for thousands of years, especially since the foundation of the People's Republic of China. With the achievements expanded and experiences accumulated, more and more people come to the unanimous viewpoint: The most effective way to control sediment pouring into the Yellow River is to develop the modern engineering taking check-dam systems in gullies as principal project.

#### **1.1 Sediment pouring into the Yellow River could not be retained only by vegetative measures**

It is said that the former Loess Plateau in the ancient China was an area with luscious grasslands and dense forests (Shi Nianhai, 1981). However, it was destroyed and attacked by severe soil and water erosion for human's estrepement and denudation for centuries. A typical viewpoint (Mei Qingmei, 1996.10) proposed by Mr. Wang Shoucun is that the forest cover rate on the Loess Plateau had ever been up to 53% in the history, which implies that soil and water conservation could be realized only through planting trees and grasses on the deserted slope,.

Undoubtedly, human's activity accelerated the destruction. Nevertheless in the middle reaches of the Yellow River, especially the areas presently suffering soil and water loss most severely, the rigorous environment has last all through the ages. The accelerated erosion starts at 250,000—300,000 years ago and the farther acceleration comes in the latest 50,000 years, which is far prior to the era mankind positively impacting the environment (Comprehensive Investigation Group of Chinese Academy of Science for the Loess Plateau, 1992). By this token, the ultimate determinant to cause severe soil and water erosion in the Loess Plateau is not the man-made activities but the arid climate and the execrable geology and physiognomy. Further analyses are revealed as follows.

First, climate is the essential control on alluvial sedimentation and erosion (Tilman Rost, Karla, 2000.1). Most area of the Loess Plateau belongs to the arid or semi-arid region, abounding with dry air, little cloud and abundant illumination while short of moisture. The annual average precipitation on the Loess Plateau is only 350 mm to 550 mm, which gradually decreases from the southeast to the northwest. Moreover, the precipitation is mainly concentrated in the rainy season of June to September, which accounts for 60%—70% of the total rainfall and most of them are in the form of high intensity rainstorms. For these reasons, soil erosion predominately occurs in this period.

Second, tectonic movement accelerates the erosion. The Loess Plateau is one of the most active areas in the tectonic movement in China. From the Quaternary period on, large proportion of the crust uplift about 150 m to 200 m. When the crust uplifts, valleys are formed and water assembles into rivers. Soil erosion in the valleys was aggravated by the increased energy of the water. Besides, earthquakes could not only bring on gravitational erosion and destroys of structure but also lead to large areas of collapse and slide on the Loess Plateau (Hui Shi & Mingan Shao, 2000).

Particular landform is another important effect. The main geomorphic landforms on the Loess Plateau are flat-ridge, weir, mound and various gullies. Little erosion takes place on flat-ridges because of the flat landforms. While in gullies, weirs and mounds, soil erosion occurs intensely, thereout unique geomorphologic features with numerous gullies and fragmented landforms were formed gradually. As a rule, an area with a high gully density is often the area of high tense ground cracking and soil erosion.

High erodibility of the loess also affects the erosion. The Loess Plateau is a typical loess landform capped with the deepest loess layer in the world. The Quaternary loess is widely distributed on the Loess Plateau, covering more than 70% of the total area. With loose structure, well proportion and plenty calcium, loess on the Loess Plateau is apt to melt and erode.

Meanwhile, the opinion on the forest cover rate ever been to 53% in the history is still hanged in doubt (Meng Qingmei, 1996.10). It is regarded that the modern geographical circumstance inherits what in the history, that is, forest and grassland ever existed in the history should still be in existence except for the scale or type changes. After entering the Quaternary, on account of Qinghai-Tibet Plateau uplifting 3,500 m, monsoon circumfluence in the Southeast Asia was formed and the climatic difference between the humid southeast coast and the dry northwest inland was augmented accordingly. Further more, local peculiar landform, for example, Qinglin Mt., with an altitude of 3,000 meter, celebrated itself by retarding the southeast way of the northward monsoon, also affects the climate of the Loess Plateau. Under such a particular climate, distinct life zones, forests doted with grasslands, are created on the Loess Plateau. As a result, the forest cover rate has never been to 53% of the total plateau. Pollen study combined with stable carbon-isotope analysis of organic matter displayed that changes on the paleovegetation are profound in response to the climate forcing. Persistent steppe vegetation and elephant fossil fauna also suggest the long-lasting dry and warm climate conditions without large changes during the latest 3.0—2.7 million years (Han J, *et al.*, 1998.4).

As a matter of fact, to control soil and water erosion only by planting measures on the Loess Plateau are proved to be unsuccessful in the recent decades. Firstly, trees are difficult to keep alive owing to the arid climate and barren soil, and though they could keep alive, most of them could not grow strong enough to control soil and water loss. An investigation put up in 1998 shows that the live rate of trees was 53% and that of grasses was 24.2% in the Hekou-Longmeng region with an area of 110,000 km<sup>2</sup> (Xu Mingquan, 2000.1). Next, even though appropriate vegetative engineering measures are taken, it is impossible to accomplish the entire plan as expected. In the early 1980s, the emphases of soil and water conservation on the Loess Plateau were focused on planting, however, sediment pouring into the Yellow did not decrease markedly. With the measures regulated, check-dams system gained a renewed interest in the middle age of 1980s, and the backbone project to control gullies, a new type of check-dam system with strong-structured high dam, was also successfully developed (Feng Guoan, 2000.7).

## 1.2 Key to retain Sediment pouring into the Yellow River is to control the gullies

Up to the present, emphases on regulating gullies or regulating slopes in controlling the *Loess Mesa Ravine Region* and *Loess Hill Ravine Region*, i.e. are still in dispute.

Many researchers take regulating slopes for stress, whose chief idea is to intercept the rainfall on the spot. Now that most of the rainfall is lost for it fails filtering into the local slope, soil and water loss could be controlled as long as the total rainfall filtered out on the spot. However, some mortal deficiencies are existed in this theory. 1. Gully erosion accounts for more than 80% of soil erosion in the watershed. Even though sediments from the slopes are fully captured, leaking sediment from the small watershed could not be reduced so much. 2. Sediment on steep slopes is difficult to be intercepted on the spot. 3. Structural stability of the slope control engineering is not satisfied. 4. The slope control engineering is inept at confronting a drought, and store-water dams for irrigating have to be built as a complement.

While some others insist on regulating gullies and regulating slopes simultaneously. However, some conflicts appear in the initial stage of building check-dams in gullies for that the slope control engineering constructed to retain sediment from the slopes will slow down the speed on forming dam farmland, and more time would be needed to reach relative stability for the whole check-dam systems.

Recently, Gully Control Engineering was proposed on control Yellow River (Feng Guoan, 1994.4; Zhang Hongwu, *et al.*, 1999). It is suggested that in order to retain the total sediment and floodwater in

small watershed, check-dams should be built step by step along the volleys to form the “relative plain”. Moreover, in order to make the dam system become relatively stable more quickly, advanced modern engineering measures, such as directional blasting, hydraulic fill and transport by bulldozer should be introduced to cut the mounds and fill the volleys. As to the slope surface, optional plant should be selected to avoid reducing the erosion modulus and the velocity of forming farmland at the beginning of building dams.

It is anticipated that when the mounds and weirs erecting on the Loess Plateau were cut and the volleys were filled to form layers of “relative plain”, geographical environment would be greatly improved, soil and water loss would be thoroughly controlled as well.

### 1.3 General benefit of the check-dam system in gullies

The check-dam system, especially the backbone project for control gullies is the largest engineering to harness the soil erosion effectively, which construct the last line of defense to impound water and conserve soil. In addition, the formed fertile dam farmland constructs an excellent producing base for agriculture.

(1) *Check-dam system in gullies is the most effective measure to control sediment pouring into the Yellow River.* Due to the serious deposition in the lower reaches, an Above Ground River is formed with the riverbed 10 meter higher than the ground nearby. Compared to dredging up and dike heightening etc., reducing the sediment pouring into the Yellow River is the most thorough solution in all the methods actualized. Enormous sediments retained from the small watershed by check-dams do not only form large-scale fertile farmland but also safeguard the Yellow River against overflow. Thus their social benefit is remarkable. The mean decrement of sediment pouring into the Yellow River in every decade from the three main tributaries between Hekou and Guanbao city is shown in Table 1.

**Table 1 The mean decrement of sediment pouring into the Yellow River from the three main tributaries: Wuding River, Fenhe River, Huangpucuan River (Xu Mingquan, 2000.1)**

Items		Wuding River (Mt)	Fenhe River(Mt)	Huangpucuan River(Mt)
Mean decrement of sediment in every decade	1960s	43	50	1
	1970s	125	52	3
	1980s	96	53	9
	1990s	99	54	16
Percentage to the total sediment yielded from the small watershed(%)	1960s	16.04	59.00	1.20
	1970s	51.83	72.90	4.44
	1980s	64.40	92.20	16.57
	1990s	50.51	92.40	36.62

Table 2 reveals a comparison of check-dams with the total measures on the retained sediment from the Yellow River watershed. It is indicated that 7,127 Mm<sup>3</sup> sediment was held up by the check-dam system, which takes up 66.9% of the total. Meanwhile, 381,200 hm<sup>2</sup> dam farmlands are formed accordingly.

From the above tables, it can be concluded that Check-dam systems play an important role in holding the sediment pouring into the Yellow River.

(2) *Develop the Check-dam Agriculture.* Dam farmland is suitable for the plants because of the fertile soil and abundant water. In contrast with the slope farmlands, dam farmlands are much enriched in nitrogen, phosphorus and organic matter, which content is higher in the amount of 7%—12%, 8%—10% and 120%—140% respectively. Water content in dam farmlands is 2—3 times higher than that in the slope farmlands too (Li Zhaoshu, 1995.9). According to the field investigations on check-dam systems in

**Table 2** Amount of retained sediment of the Yellow River watershed (Xu Mingquan, 2000.1)

Time	Retained sediment by check-dams (Mm <sup>3</sup> )	Total retained sediment (Mm <sup>3</sup> )	Percentage of the retained sediment by check-dams
1952—1962	600.72	647.42	92.8
1963—1969	1,004.42	1,135.26	88.5
1970—1979	2,151.37	2,694.69	79.8
1980—1989	1,823.77	3,144.77	58.0
1990—1995	1,547.04	3,032.65	51.0
Total	7,127.32	10,654.79	66.9

Shanxi province including Kanghe Gou in Fenxi county, Dong Gou in Lingshi county and Liu Gou in Ji county, 750 kg—1,500 kg maize per hectare could be harvested in the dam farmland, which is 8—10 times of that in the slope farmland. At present, the dam farmlands only occupy 9% of the whole area of farmlands in the Loess Hill Ravine Region, but their grain yield makes up 23.5% or more (Xu Mingquan, 2000.1). Thus a celebrated proverb was widespread; “One would rather own a hectare of dam farmland than ten hectares of slope farmland.”

Comparing to importing food supplies from other provinces, the *Check-dam Agriculture* is a feasible path to convert slope farmlands to woodlands or grasslands and improve the environment in the Loess Plateau, for the agricultural population in this area reaches 40 million and widely scatters in the remote village with unfavorable transportation. However, if the existing terrace farmlands were reserved and all the potential dam farmlands were developed, the food supplies could be self-supported and all slope farmlands could be withdrawn.

## 2 Problems and suggestions on the check-dam system

According to the present condition of the Loess Plateau, 6,758 gullies are suitable for check-dam systems, where 21,000 backbone projects including 242,000 check-dams could be built (Huang Ziqiang, 2000.10). Nevertheless, in recent years, check dam systems in gullies on the Loess Plateau get along slowly. Compared with the 100,000 check-dams in 1960s and 1970s, only 1,118 check-dams had been put up from 1986 to 1999 (Feng Guoan, 2000.7). With such a constructing speed, more than 100 years would be needed to control the main soil and water loss in the Loess Plateau. Thus it is urgent to arouse nationwide attentions on controlling the Yellow River by check-dam systems. In addition, with more investment from the government proposed, some policies encouraging individuals and local governments to develop check-dams ought to be established also.

At the same time, theory on developing check-dam systems should be extended and improved. Physical model experiments should be carried out in the context of typical small watersheds with fragmented physiognomy in the *Two-River* (Kuye River and Tuwei River) and *Two-Chuan* (Huangpu Chuan River and Gushan Chuan River) Zone. Problems worthy of study are illustrated as follows:

(1) *To put forward and testify similarity law for the hydraulic models of small watershed in the Loess Plateau.* Since the loess is so fine and erosive, and other erosive factors such as rain, slope fluid and so on are so complicated that integrated similarity law for the hydraulic models of small watershed in the Loess Plateau has not been produced yet. In despite of many in situ hydraulic experiments have been taken on the Loess Plateau in these decades, few model experiments with strict enlarging (or shrinking) scales have been completed for short of the similarity law. As known that scale model is essential in re-demonstrating the process and studying the mechanism of soil and water loss on a large scale or at high speed, an appropriate scale model is an important necessity for the hydraulic study.

(2) *To study the relative stability and optimum design of check dams.* Basing on the ample data and investigations on spot, hydraulic models should be made for the soil and water erosion area in the Loess

Plateau. Then studies on condition and standard of the relative stability for check-dam system in gullies should be carried out, and scientific methods on relevant frequency flood should also be anticipated. After that, rules on programming the check-dam systems in various gullies through computer, theory on check-dam stability, system method and optimum means all should be put forward. Thus, it is hopeful that the floodwater and sediment on the spot be controlled completely and the dams become relatively stable at last.

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