Analysis on Composite Erosion Process Based on Multi Dynamic Erosion Environment Simulation

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Abstract. Using the compound erosion experimental device developed by ourselves, the compound erosion process simulation experiment of 35° steep slope were carried out under different combination modes of freeze-thaw, wind, rainfall. The runoff and sediment yield change process of Pisha sandstone slope under different dynamic combination environment were studied. The results show that the superposition of wind, freeze-thaw and rainfall conditions obviously promotes the occurrence of slope erosion, among which the effect of freeze-thaw increased the collapse phenomenon obviously in the erosion process.

1. Introduction
There was a large area Pisha sandstone distributed in the concentrated source area of coarse sediment in the Yellow River Basin \cite{1}. Pisha sandstone has lower diagenesis degree and structural strength, and its erosion resistance was weaker. In addition, the area has multiple erosion environment such as wind in spring, concentrated rainfall in summer and large temperature difference in late autumn and early spring. Rainfall erosion, wind erosion and freeze-thaw erosion occur alternately in a year. So the soil erosion is very serious \cite{2}. The regional soil erosion modulus is as high as 30000-40000 t/(km\textsuperscript{2}.a) \cite{3}. Serious soil erosion is not only the main source of sediment of the Lower Yellow River bed, but also the hidden danger of flood control safety in the Lower Yellow River. Therefore, it is of great significance to study the composite erosion process and mechanism of rainfall, wind, freeze-thaw for the ecological protection and soil erosion control.

Many studies has been done in single-phase erosion or wind-water two-phase erosion in this area in the past, but less research on the alternate process and mechanism of composite erosion was involved\cite{4}. We have few studies about the mechanism of occurrence and development of composite erosion, and the theoretical and methodological research was still very weak in the simulation and quantitative evaluation of composite erosion \cite{5,6}. Therefore, it is a basis to reveal the characteristics of runoff and sediment yield changes slope under different erosion forces combination for soil erosion control in Pisha sandstone area by compound erosion experimental device.

2. Materials and methods

2.1. Experimental designs
The experiment is completed in a self-made composite erosion simulation system. The composite erosion simulation system includes three parts: rainfall simulation, wind simulation and sub-zero temperature environment simulation. Three erosion environments are simulated in this experiment, which are rainfall erosion, freeze-thaw + rainfall erosion, freeze-thaw + wind erosion + rainfall erosion separately. The bulk density of soil layer is approximately controlled at 1.3g/cm³, and the surface soil moisture content is kept at about 35%. Three kinds of erosion force simulation methods are as follows: The rainfall erosion environment controls the rain intensity of 110mm/h and continued for one hour; the wind erosion environment controls the wind speed of 6m/s for 3 times and cumulatively duration 1440 minutes; the freeze-thaw environment controls including freezing under the temperature of -10°C and thawing at natural temperature. One freeze-thaw cycle is 24 hours, and six freeze-thaw cycles are simulated.

The experimental simulation system and experimental groups was seen in Figure 1 and Table 1.

![Experimental system and experimental groups](image)

**Note:** Consists of three parts:
- a. Simulated rainfall system, 0.5 ~ 3mm/min
- b. Simulated low temperature system, 0 ~ -20°C
- c. Simulated wind power system, 0 ~ 18m/s
- d. 3D laser scanner
- e. Simulated slope

**Figure 1 Compound erosion experimental device**

| Slope angle (°) | Experimental conditions | Rainfall intensity (mm/h) | Rainfall duration (min) | moisture content (%) |
|----------------|-------------------------|--------------------------|-------------------------|---------------------|
| 35             | rainfall                | 111.7                    | 61.53                   | 36.6                |
|                | freeze-thaw + rainfall  | 112.4                    | 64.54                   | 36.9                |
|                | freeze-thaw + wind + rainfall | 110                  | 63.52                   | 36.5                |
2.2. Observation and analysis method
Muddy water samples were taken every 2 minutes after runoff production. The slope surface was scanned every 10 minutes. In the experiment, the change of slope shape (rill erosion width and depth) was measured and recorded in time during the experiment.

The muddy water samples were weighed and volume measured, and the runoff and sediment yield were calculated and analysed by displacement method. And we further analysed the change process of erosion rate and runoff sediment content. The spatial distribution of erosion amount is analysed through the statistics of the changes of erosion and deposition on the slope surface.

3. Result analysis

3.1. The characteristics of runoff and sediment of different dynamic combinations
The runoff and sediment yield characteristics were counted and showed in Table 2. It can be seen that the runoff and sediment yield increased by 31.97% and 67.6% respectively, compared with the single rainfall erosion process. The sediment concentration increased from 1.54kg/L to 1.96kg/L. The erosion rate increased from 8.56 kg/min to 15.12kg/min. Superposed the wind conditions again, the runoff and sediment yield increased again. For example, the runoff and sediment yield increased by 53.73% and 97.30% respectively compared with the single rainfall erosion process; and the runoff sediment concentration and erosion rate increased to 1.98kg/L and 17.48kg/min respectively. It can be seen that the dynamic superposition significantly increased the runoff and sediment yield on the slope.

| Number | Experimental conditions | Runoff (L) | Sediment yield (kg) | Sediment content (kg/L) | Erosion rate (kg/min) | Compared to rainfall erosion |
|--------|-------------------------|------------|--------------------|------------------------|----------------------|-----------------------------|
|        |                         |            |                    |                        |                      | Increased runoff (%)       | Increased sediment (%)      |
| 1      | rainfall                | 322.00     | 497.22             | 1.54                   | 8.56                 | /                           | /                           |
| 2      | freeze-thaw + rainfall  | 424.93     | 833.33             | 1.96                   | 15.12                | 31.97                       | 67.60                       |
| 3      | wind + rainfall         | 495.02     | 981.00             | 1.98                   | 17.48                | 53.73                       | 97.30                       |

3.2. Runoff and sediment yield process of different dynamic combinations
The perspective of runoff generation process are both show a trend of increasing first, then fluctuating and then decreasing (Figure 2). There is not very obvious difference in the runoff process under different dynamic superposition conditions. But, the difference of sediment yield process is obvious under different dynamic superposition conditions. The runoff process of single rainfall is lower than others with one peak value of sediment yield process; The runoff process of rainfall freeze-thaw +rainfall has two peak value of sediment yield process, but it's not the highest process line in Figure 3. The highest process line is the sediment yield process of 3 kinds of erosion dynamic superposition conditions. There are two peaks of sediment yield, which appeared at 12-14 minutes and 30-32 minutes respectively in the runoff duration.

Why there are two peaks and what kinds of erosion happened? It is observed that the phenomenon of collapse on the slope superimposed freeze-thaw is obvious accompanied the runoff generation process. This phenomenon is related to the influence of freeze-thaw on soil structure and infiltration performance.
3.3. **Temporal and spatial distribution characteristics of slope erosion**

Based on the topographic survey data of erosion during rainfall, we analysed the spatial-temporal distribution of erosion under freeze-thaw + wind + rainfall conditions. There were 1-3mm cracks in the soil surface after the effect of freeze-thaw, which gradually increased from the top to the bottom of the slope. At the initial stage, rainfall infiltration increased, but when the rainfall went on and lasted for 11 minutes, erosion rill began to appear at the bottom of the slope, followed by rapid retrogressive erosion, expansion of the rill bank, advance of the rill head, and accompanied by the collapse of both banks. When the rainfall lasted for 14-17 minutes and 35-39 minutes, there were two large scale and obvious soaring erosion. It can also be seen from Table 3 and Figure 4.

| Rainfall duration (min) | Distance to slope bottom | The hohol slope |
|------------------------|--------------------------|-----------------|
|                        | 5-4m  | 4-3m  | 3-2m  | 2-1m  | 1-0m  | 0-0m  |
| 0                      | 0     | 0     | 0     | 0     | 0     | 0     |
| 11                     | 0.01  | 0.01  | 0.01  | 0.01  | 0.01  | 0.01  |
| 14                     | 0.02  | 0.02  | 0.02  | 0.02  | 0.02  | 0.02  |
| 17                     | 0.11  | 0.11  | 0.22  | 0.22  | 0.22  | 0.22  |
| 30                     | 0.07  | 0.12  | 0.15  | 0.33  | 0.33  | 0.33  |
| 35                     | 0.09  | 0.17  | 0.18  | 0.44  | 0.44  | 0.44  |
| 39                     | 0.06  | 0.15  | 0.16  | 0.17  | 0.20  | 0.73  |
| 51                     | 0.09  | 0.15  | 0.17  | 0.18  | 0.20  | 0.78  |
4. Conclusions
The process of slope erosion is more obvious after multi dynamic superposition than that of single rainfall erosion. The freeze-thaw erosion has obvious damage to the soil structure and affects the rainfall infiltration. At the same time, the erosion in the form of collapse is easy to form in the freeze-thaw layer. So the corresponding protective measures need to be taken in the production practice.

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