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Study on the Small Gravity Erosion on the Gully Slopes

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1.

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Abstract: Gravity erosion is active in the hilly-gully region of Loess Plateau which contributes large amount of sediment by conveying much earth into the valleys. Field observation on the gravity erosion was carried out in Qiaogou watershed. Erosion pins were used to measure erosion rate on the gully slope, and shear tests were done to discuss the effecting factors of the gravity erosion. Field survey showed that mainly small gravity erosions were occurred in Qiaogou watershed and which produce much sediment. Three types of small gravity erosion types, including loess grain fall, mass fall and slump, were measured, and their effecting factors were discussed. Study shows that the small gravity erosion are mainly controlled by the slope gradient, rainfall, weathering, etc. These influence factors can reduce the internal friction angle and cohesion of the intact loess and therefore lead to lowering the critical depth of the gravity erosion on the slope, this can explain the occurrence of the shallow gravity erosions on the slopes. Gravity erosion has different intensity in different evolution stages of the gully, so it is possible to estimate the intensity of gravity erosion by the evolution stages of the gully.

Keywords: Gravity erosion, Loess Plateau, Gully slope, Valley evolution, Erosion pin

1 Introduction

Gravity erosion on the loess slope is the result of potential gravity energy release of the earth as the topographic uplifting, but it is also an important agent in the process of valley evolution on the Loess Plateau. Macro-characteristics of the valley such as slope gradient and depth are mainly determined by the material nature and crust uplift height, but the micro-topography features of which is normally shaped by the actions of hydraulic and gravity erosion (Korup and Densmore, 2010). With the semi-arid climate, water, gravity and wind are the three main agents of erosion in the hilly-gully region of Loess Plateau. Although hydraulic erosion may be still the dominant force in forming valley landscape, gravity erosion is very active in the process, especially on the steep slopes as the weak consolidation of the loess in the region.

Gravity erosion contributes large amount of sediment yield by conveying much soil into the valleys directly or indirectly. For example, according to the field data provided by the Yellow River Conservancy Commission (1993) observed in three watersheds on the Loess Plateau, namely Nanxiaohed gully, Luer gully, and Jiuyuan gully, the ratios of sediment produced by gravity erosion to the total soil loss were
about 57.5%, 68.0% and 20.2%, respectively. Some studies based on the field observation data showed that gravity erosion is always an important source of sediment in the water flow from slope to the valley, and it may be responsible for the occurrence of high frequency of the hyperconcentrated flows on the Loess Plateau (Wang X. K., et al. 1982; Xu J. X., 2004a, 2004b; Han P., et al, 2003).


2 Study area

Qiaogou watershed, being located in Suide Country, Shanxi Province (about 37°30′N, 110°18′E), is a tertiary order tributary of the Yellow River. It drains an area of about 0.45 km² with an elevation range of about 900~990m. Qiaogou watershed is composed of a main channel and two branches. The main channel length is about 1.4 km, the first branch has a length about 870m and area of about 0.069 km², and the second branch has a length about 870m and area of about 0.069 km² (figure 1).

Qiaogou basin situates the typical hilly-gully landscape area of the Loess Plateau, and it has the typical structure and figure of that region. Slopes of Qiaogou gully can be conceptually divided into two parts by the gully-edge line, namely the hill and the valley (figure 2). The hill top is characterized by a gentle slope of 0~10° and high shrub cover, the hill slope commonly has a gradient about 30° and high grass cover, while the gully slope is often >40° and with a very sparse herbage cover. The bottom of the valley is the place where temporary water is concentrated.

The loess mantle depth in the study area is about 60m, which is mainly consisted of two types of loess. The upper layer of the earth is Malan loess, and the lower layer of which is Lishi loess. Malan loess contains about 5% of clay (<0.001mm), 30% of fine silt (0.001~0.01mm), 46% of silt (0.01~0.05mm), 19% of sand (>0.05mm), while the Lishi loess contains about 7% of clay, 24% of fine silt, 57% of silt, 12% of sand.

The region of Qiaogou catchment has a continental semi-arid climate, with an average annual temperature of 8°C. The average annual precipitation of the region is about 450mm, usually 70% of which occurred mainly in mid-June to mid-September.
3 Methods

The data used in this paper were measured with erosion pins and survey in Sept. 2009 to Sept. 2011. The steel erosion pin is about 35cm long and 3mm in diameter. A total of about 300 erosion pins were installed on the gully slopes of the second branches of the Qiaogou gully. Exposure lengths of pins were measured in March and September every year. The erosion pins can only be used to measure very shallow gravity erosion types, such as loess grain fall, small fall, shallow slump, etc. Field survey along the gully was done to observe and measure bigger gravity erosion after heavy rain because they mainly occur during or after heavy rain time in the summer and autumn seasons.

Undisturbed soil samples of the Malan and Lishi loess were gotten in the study area. Particle size analysis was done with laser particle size instrument, and shear strengths of the two types of loess with different water content were measured by direct shear tests. Four types of soil sample were made with the water content of 7%, 13%, 19% and 25%, respectively. The sample of water content of 7% roughly equivalent to the drought situation, 13% represents to the semi-wet state, 19% represents the wet condition, and 25% is close to the state of water saturation state.

4 Results and discussion

Field survey showed that many types and sizes of gravity erosion occurred in the Qiaogou basin, but most of which were small types, rarely large ones. Small gravity erosion occurred with high frequency, and it had great influence on the sediment yield in the watershed. During the survey period, only the small gravity erosion types, containing 112 times of including loess grain falls, 28 times of small mass falls, and 14 times of small slumps, were observed. No landslides or other large gravity erosions
were observed.

(1) Loess grain fall

Loess grain fall is the phenomenon of sudden displacement of the loess grain or very small fragment by rolling down the steep slope. It is the most common and smallest size type of gravity erosion on the loess slope. During the time the new undisturbed loess is exposed to the air, cohesion is gradually lost because of weathering, and this is main reason of the occurrence of loess grain fall. This phenomenon can take place at any time in the year, but especially in spring and after rain time.

The data obtained by erosion pins show that erosion depth of loess grain fall on the slopes is considerable scattered (figure 3). In all the points, about 25% were near zero, 60% within 1 cm, and about 15% between 1~2 cm. Loess grain fall occurs mainly on the steep slopes more than 55°, especially on the slopes between 65° ~ 80°. The phenomenon of small loess grains rolling down slope may have close relation with the static friction angle of loess, which is about 55°. So, loess grain fall mainly occurs at gradient more than 55°, the slope is steeper, the easier it happened. In addition, loess weathering on the slope of 55° ~ 80° is severest, so it is most likely to happen at that gradient. Slope of more than 80° has a small rain-receiving area and slighter weathering degree, so loess grain fall at that gradient is weaker. Loess weathering on the shady slopes is weaker than that on the sunny slopes, so loess grain fall on the sunny slopes is much more remarkable. According to the observation data, average retreating rate caused by the loess grain falls on the slope more than 55° is about 2.0 mm/a on the sunny slope, and about 0.9 mm/a on shady slope. Then we can estimate that sediment produced by loess grain fall in Qiaogou’s second branch is about 3.2 t/y. Considering the catchment area of the second branch, that is equivalent to the specific sediment yield of 450t/km²·a.

![Figure 3 Distribution of the erosion depth by loess grain fall with the slope angle](image)

(2) Mass fall

Mass fall of the loess indicates the phenomenon of small blocks and fragments of
loess fall from the steep slope face usually separately. The mass falls always derived from a very narrow superficial part of the loess slope, so the size is usually very small (figure 4). Loess mass falls mainly occur on the slopes more than 60°, especially on the slopes at 65°~85°. A single mass fall is about $10^{-5}$ ~ 0.1 m$^3$ in volume. Similar to the loess grain fall, weathering also plays an important role in the process of loess mass fall. Field observation shows that it generally has three groups of joint-plane on the loess slope surface which breaks the intact loess into small pieces. So, under the condition of cyclical changes of temperature and humidity, frequency of the small loess mass fall is high. Although it is difficult to accurately estimate the material produced by mass fall from the slope, according to observation, it may be of the same order of magnitude as the loess grain fall.

![Figure 4 Distribution of the loess mass fall size with slope angle](image)

(3) Slump

Slump is the loess downward sliding along the shear plane in the slope. Scales of slump obtained in Qiaogou in the survey period were approximately between 0.3 m$^3$~3.5 m$^3$ (figure 5). Among them, magnitude of $<1$ m$^3$ occupies most proportion, and the part of $>1$ m$^3$ occupies a less proportion. Most slumps occur on the slopes at 60°~80°, especially on the slope at 70°~80°. According to observation, the slump bodies generally possess a wedge-shaped outline. Angles of the sliding planes usually reduce 10°~20° than that of the original slope, and the angle of sliding planes are generally remained more than 50°. Slump generally develops along the loess joint, and it is often happened after rainfall, rarely takes place in the dry season. Rainfall and soil weathering is the main triggering factors of loess slump.
5 Mechanism Analyses

The stability of a slope is determined by the relationship of the shear strength resisting the slide and the shear stress acting to induce movement. If there is a potential sliding surface in the loess, considering the simplest factors, shear stress (τ) along the potential sliding surface can be given by

\[ \tau = \gamma h \sin \beta \]  \hspace{1cm} (1)

Where \( \gamma \) is the unit weight of loess, \( h \) is the average thickness of the sliding mass, \( \beta \) is angle of the sliding plane.

Shear strength (τf) can be given by

\[ \tau_f = \gamma h \cos \beta + \phi + c \]  \hspace{1cm} (2)

Where \( \phi \) is the angle of internal friction, \( c \) is cohesion.

When gravity erosion happens, it meets the following condition

\[ \frac{\tau}{\tau_f} \geq 1 \]  \hspace{1cm} (3)

From function (1) and (2) we can see that shear stress (τ) depends primarily on the downslope component of the weight force, while shear strength (τf) is mainly provided by the forces of friction and cohesive of the material. The influence factors mainly includes \( \beta, c, \) and \( h \), etc., in which \( \beta \) and \( c \) can be changed by the environmental variables significantly and thus affect the slope stability. They also show that \( \tau \) changes little with time and environmental changes, while \( \tau_f \) may experiences a gradual reduction as the process of weathering.
Shear tests of the Malan loess and Lishi loess shows that $c$ and $\beta$ decline significantly with the increase of water content (Figure 7, Figure 8).

![Figure 6 Relationships between angle of internal friction and water content](image.png)

Decline of $c$ is the direct cause of small mass failure on the loess slope, especially to the occurrence of loess grain fall, small mass fall, etc. Rainfall falls $c$ and increases weight of the loess mass ($\gamma h$), and thus causes stripping of the weathered loess on steep slope. In addition, the process of the intact loess being fractured into debris as weathering also leads to losing of cohesive force. Therefore, loess grain falls and small mass falls always take place on the highly weathered loess slope, and the freeze-thaw, dry-wet circulations can often lead to the occurrence of such kinds of small gravity erosions.

Occurrence of slump has a close relation with the decrease of $c$ and $\beta$ of the loess. Angle of internal friction of the loess is about $20^\circ$~$40^\circ$, while slump usually occurs on the slope of $55^\circ$~$80^\circ$ (figure 5). So, once $c$ and $\beta$ decrease, slump
would be easily to occur. Slumps often occur along the joint planes after rainfall. Field measurements in the Qiaogou catchment show that slumps often happen when water content reach 12% ~15% for the Malan and Lishi loess, and the internal friction angle of the loess is about 25° ~35° at this stage. According to equation (3) and the shape of the slipping mass, we can get that cohesion at the slip plane is generally less than 5kPa, whereas the tested value of cohesion is about 25kPa in intact loess with the same water content (figure 7). This shows weathering and joins in the loess play important roles in the occurrence of slump.

Gravity erosion depth \( (h) \) have important influence to slump. With the process of downward erosion in the channel, weight of the loess above the potential slipping plane will continually increase, and it may exceed shear resistance and trigger occurrence of frequent deep-seated landslides, which means the valley has reached the critical depth. The critical depth of the valley can be calculated by the following formula (Korup and Densmore, 2010)

\[
H_c = \frac{4c \sin \theta \cos \phi}{\gamma [1 - \cos(\theta - \phi)]}
\]

Where \( \theta \) is slope angle.

By using equation (4) with \( c = 30 \text{kPa}, \ \rho = 1.6 \text{g/cm}^3, \ \theta = 45^\circ, \ \phi = 30^\circ \), we can get the critical depth is about 57.9 m in Qiaogou basin, which is close to the depth of the first branch of the Qiaogou gully (about 50m). But obviously, large landslides or landslips have never been seen there. This is because consolidation strength of the intact loess performs large cohesive force, but it is not contained in equation (4). In fact, many loess gully walls can often reach to the height of about one hundred meters in the Loess Plateau.

Relationships of \( h, \ \phi \) and \( c \) can be represented in figure 8. It shows that the value of \( H_c \) decreases significantly with the reduction of \( c \) and \( \phi \). The environmental factors of weathering, cracks, joints, rainwater, etc. can make the shallow gravity erosions take place in a relatively shallow depth. Kevin’s (1995) study at Washington and California showed that cohesion and angle of internal friction can be reduced to very low levels in the loose debris, this perhaps can interpret the occurrence of the shallow slumps happened in the Qiaogou watershed.
Figure 8 Changes in critical depth of gravity erosion with cohesion and internal fraction angle
c is cohesion of intact loess, c’ is cohesion of the weathered surface layer loess, Hc is critical depth of the intact loess, Hc’ is critical depth of the surface layer loess

6 Coupling relationship of slope process and gravity erosion

The two branches of Qiaogou gully are in different stages (figure 9). The first branch is in the young and unstable stage, with a V-shaped cross section. Width of the first branch is only 1~2 m at the bottom, but its depth has reached about 50 meters. Gully slope of the first branch is very steep, usually more than 55°, as the action of deep-cutting in it is very severe. Many scars of gravity erosion are visible on the gully slopes, showing the mass failure is active in the first branch. Though having no exact measured data, we can estimate from observation that more than half of the sediment yield in the gully are produced by gravity erosion.

Figure 9 Cross-sections of the master channel and two branches of Qiaogou gully

The second branch is a middle-aged gully with a U-shaped cross section. After a long period of adjustment, the width of the gully reaches about 5~15 m at the bottom, and gradient of the gully slope is about 40°~55°. With the gully slope gradient decreasing, hydraulic erosion is enhanced and gravity erosion is weakened. We can
see that terrace terrain is shaped on the gully slopes of the second branch under the compositive effects of hydraulic and gravitational erosion. Two levels of terrace on the shady gully slope and about five levels of which on the sunny gully slope are formed. The nearly vertical terraces have the height of about 1 m ~ 7 m, where are the main regions for occurrence of the gravity erosion. Usually, a straight slope is below the terrace face, where is the depositional place of the sediment coming from the terrace face by gravity and hydraulic erosion. Thus, the straight slope under the terrace can be termed “gravity slope” here. The gravity slope is the delivery route of the sediment produced from the upper terraces, and it is an equilibrium transportation slope on which equal quantities of earth are being supplied and removed.

Figure 10 Distribution of the angles of hill slopes and gravity slopes on Qiaogou catchment

Slope form can reflect the relative relationships of soil erosion, transport and deposition processes. Profile of the upper hill slope is convex, while the lower part of the hill slope is generally straight at about 30°, and the gravity slope is generally straight at about 40°. We measured randomly 20 of gravity slopws and hill slopes respectively, and the percentage frequency of the slope angles are shown in figure 10. Field observation shows that hill slopes have no soil layer, which indicates a weathering-limited erosion process on the slope, and flow on the slope is generally unsaturated of sediment concentration. Obviously, the gravity slope is formed because the sediment supply from upper slope exceeds sediment transport capacity of the slope flow.

Sediment transport capacity of the overland flow can be calculated by the following formula (Julien, 1985)

\[ q_s = aS^aq^d i^b (1 - \frac{\tau_c}{\tau})^d \]  

(5)

\( q_s \) is unit sediment transport capacity, \( S \) is slope angle, \( q \) is unit discharge, \( i \) is rain intensity, \( \tau \) is shear stress, \( \tau_c \) is critical shear stress, \( a,b,d,f,k \) is coefficient, and \( b=1.2~1.9, \ d=1.4~2.4. \)
Using this equation, we can compare sediment carrying capacity of water on the hill slope with that on the gravity slope. If considering the difference of slope gradient only, and taking \( b = 1.5 \), using (5), we can get that sediment transport capacity on the gravity slope is 1.75 times higher than that on the hill slope. Thus we can estimate that sediment coming from the gravity erosion on the terrace account for more than 42% of the total sediment yield on the whole slope.

7 Conclusions

(1) Many types of gravity erosion take place in the Qiaogou drainage basin, but they are usually small in volume, such as loess grain fall, small mass fall, small slump, etc. These small and shallow gravity erosions commonly occur on the basis of weathering of the intact loess. The influence factors consist of slope gradient, rainfall, weathering, etc., this make the small gravity has the character of high randomness.

(2) Small gravity erosion mainly takes place on the slope more than 55°, but the correlations of size and frequency of the small gravity with slope angle are scattered. The depth of small slump occurs in roughly the same depth with rainfall infiltration, it generally happened along the joints in the shallow loess slope. Rainfall and weathering reduce the cohesion force and internal friction angle of the loess, thus reducing the critical depth of gravity erosion occurring. This is the main reason for the slump occurrence.

(3) Gravity erosion is an important agent in the process of valley development. Gravity erosion has different intensity in different evolution stages of the gully, so it is possible to estimate the intensity of gravity erosion by the evolution stages of the gully.

8 References


The Numerical Simulation of a Coal Mining Based on the 3D Geologic Model

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Abstract: According to the geological drilling data of a mine area, established the 3D geological model of the mine area. Drawn the sectional view from the model and compared with the actual mining exploration line sectional view, verify the reliability of the model. Based on the multi-layer DEM 3D geological model, proceed simulation in the excavation of the tunnel using the method of advanced excavation. Got the initial gravity field, the calculate results of deferent work layer advance distance. The results showed: When the work layer advanced 200-975m, fault had no effect on mining. When advanced to 990m (from the fault F3 25m), the damage area caused by the mining has been through to the fault, if the working layer keep advance to the fault, it’s highly probable to happen roof fall, sudden water accidents. It can be inferred, to NO.9 coalbed first mining face, it should reserve 25 ~ 10m coal pillars at the F3 fault to prevent accidents.

Keywords: 3D geological model; fault; coal mining; numerical simulation

In the coal mining process, because of the faults, and other special construction collapse column, it may appear suddenly water, gas outburst, roof collapse and other dangerous. In order to avoid these dangerous, the exploration and mining are at the same time, or exploration prior to mining. Called "exploration" refers to various methods of physical exploration, such as drilling hole method, electric measurement and acoustic measurement method. However, the physical exploration can measured the range of anomaly zone only, the mining often need to find ways to circumvent the abnormal area to avoid danger, so the coal pillar must be reserved. But the reserved coal pillars are too many will cause waste of resources, and the too little reserved coal pillar will cause a series of danger such as tunnel fall and water inrush[1-2]. How to solve this problem effectively, may both to improve mining amount and avoid the occurrence of the roadway.
In this paper, using drilling information provided by Xiandewang Mine build multi-layer DEM model of the mine area. Build 3D finite element calculation model by obtaining sectional data in different locations, and with a combination of rock mechanics, elastic-plastic mechanics, fracture mechanics, NO.9 coalbed first mining face was carried out a numerical analysis.

1. Build 3D geological model based on drilling information of Xiandewang mine

3D geological modeling is one important part of digital mine. In recent years, some scholars have proposed a method of multi-layer digital elevation modeling DEM (Digital Elevation Model) modeling method[3-4].

1.1 Process original data

Original geological exploration data is generally based on drilling information unit, the drilling information includes the drilling hole number, the plane coordinates, and the corresponding histogram. Generate a 3D geological model need to deal with different geological layers information, so the original data structure based on the drill information only suitable as construction statistics, it can not as the data structure works to generate a 3D geological model. Processing original data is crucial to generate 3D geological model.

During processing original data, the data structure of drilling information units converted into the data structure of the geological layer units. The original data structure based on the drilling number, drilling 2D coordinates, and the corresponding histogram, reflected the geological information of each drilling. The processed data structure is based on drilling hole in each geological layer, reflected the geological information of various geological layers. Represents the plane coordinates of drilling k with k(x_k,y_k), z_ik, represents the elevation of k drilling belongs to the i soil layer. Proceed data is (x_k,y_k,z_ik,i), means location and elevation of all drilling in the i soil layer. The processed data structure reflected the plane information base on geological layer, according it the elevation models can be created for each geological layers.

1.2 Create single layer contour line

After the above processing of borehole data, on a separate layer is a group of discrete data points including the elevation. Apply these data points can be generated independent of level contours. These level contour line will be important data-source to generate DEM by the Kriging difference.

This paper used linear interpolation method to draw contour lines, this method is fast, Low data requirements, The accuracy is slightly lower. However, due to more intensive drilling in mining, the data more adequate, can make up for the manual error caused by the interpolation, so using the linear interpolation method can get same better results, the latter examples verified it too.

1.3 Divided stratum

Due to the spatial distribution of underground mudstone layer may be unevenly
and discontinuous, between different strata may be cross or strata missing, it is the key to deal with these special cases to build models.

First by drilling to split the mining into small area, the drilling data processing of small areas taken sequence from left to right, from shallow to deep. The relationship between these layers in small area may occur the following three situations:

1. Normal superimposed case (Fig.4), Two strata at neighboring borehole were exposed and in the same order, It can be seen the two strata between the two holes is not cross or no missing. Considering the limited distance between the two bore hole, the following case is extremely rare that the layers cross twice leading the layers vertical order unchanged (Fig. 5)

2. If the order of the expose strata at the two neighbor borehole is changed (fig.6), it is believed that the two soil layers occur cross one time between two bore holes. Generally two curved surface intersect will form one or more intersection line, may use these lines to divide the strata into many. The existence of many curved surfaces does not affect to establish multi-layer DEM. Only in using of multi-layer DEM to create an entity model, should pay attention to the topology relationships between the entity units at intersection.

3. If two adjacent borehole, one does not expose a stratum drilling (fig.7), it’s be considered the no-exposed strata is missed between the two holes. To deal with this case, used to coincide the missing strata with the above or below strata at the drilling didn’t expose the strata. Specific to be considered of elevation difference between strata at the previous drilling, choose a small elevation difference strata to coincide with missing strata.

1.4 Establish multilayer DEM model
Using the above method, according to drilling data provided by Xiandewang mine, established multilayer DEM model and verified its reliability. There were 11 lines and 145 exploration drill holes. Distribution of drilling in Figure 8a.

Selected the following layers as three separate layers: the muddy surface, the No. 9 coal and the bottom of the ordovician limestone layer. Because the three layer relative easily to distinguish. Use borehole data processing raw data in accordance with the previous method of data processing. Then use the processed data and general interpolation to generate contour tracing algorithm to generate contour lines. Select layers cenozoic surface, No. 9 coal and ordovician limestone top as an independent three layers, and generate three separate levels of contour lines, fig 8b, c, d

(a) Drilling distribution (b) Cenozoic surface elevation contour map, (c) Nine coal elevation contour map (d) Ordovician limestone top elevation contour map

Fig.8 Contour maps generated by drilling data

Using the above three different levels contours, applied Kriging interpolation method, obtained different levels of digital elevation model (DEM), as shown in figure 9. Seasonal river flowing through the mine in Figure 9 (a), (b) is expressed as a light portion, Its formation process is sketched on the boundary surface model, covering the replacement, mainly to enhance the realism of the model.

(a) Separate strata superimposed renderings (b) Mine layered geological model, (c) An enlarged view of the fault (d) Two positions syncline

Fig.9 Different levels of digital elevation models

1.5 Get the data of any cross-sectional position

In the multilayer-DEM model, take a line coincident with the exploration of line as the section line, sectional view any profile can be obtained. Sectional view of the DEM model obtained in the two exploration lines shown in Figure 10

1.6 Use profile data to build three-dimensional finite element model

1.6.1 Determine the fault location

The section line is a continuous line. Fault location must have certain criteria to
judge. According to common sense, the fault occurs at the stratigraphic dramatic rise or fall, therefore could be considered \( \frac{dy}{dx} \geq 0 \) to determine, that is to say if the slope is greater than Section line at a certain value, the Department considers that a fault. With the above criteria, the approximate location of the fault can be obtained, as shown in Figure 10

![Fig.10 Two exploration line cross-sectional view and location schematic](image)

**1.6.2 Dimensional finite element model of the geological**

With cross-sectional data and the location of faults, build three-dimensional geological model using finite element modeling of the bottom-up approach. The three-dimensional finite element model can not only calculate the impact of various tectonic movements produced, but also simulate the destruction caused by the mining area and its extension given by the evolution of the relevant external loads and boundary conditions, and gives reasonable security pillar reserved distance.

Three-dimensional geological model is shown in Figure 11:

![Fig.10 Three-dimensional geological model diagram](image)

(a) Surrounding stratum chart of NO.9 coalbed first mining face, (b) Surrounding stratigraphic units graph partitioning NO.9 coalbed first mining face

2. Establishment of a two-dimensional plane strain finite element model

2.1 Model building

The actual mining working face is a three-dimensional. However, considering the length and width of the mining face far greater than the thickness of coal seam, the tendency of coal seam can be ignored, only consider the coal seam towards, then the plane strain model can be used to simulate.
According to the established model of multilayer DEM and extracting section methods, combined with the surrounding stratum chart of NO.9 coalbed first mining face, its cross-sectional can be established, and use this can build a two-dimensional cross-sectional plane strain finite element model to simulate the two-dimensional plane strain mining, shown in Figure 12.

Based on the engineering geological data, there are six stratigraphic model of NO.9 coalbed first mining face. From top to bottom were the cover soil, a mixed layer of mudstone sandstone, shale, sandstone mixed layer, coal, shale, sandstone mixed layer, limestone. For the mixed layer, such as the second, third, fifth layer of the material parameters obtained by averaging. Using bilinear strengthen elastic-plastic model, parameters of each formation are shown in Table 1.

<table>
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<th>stratum</th>
<th>Density(kg/m³)</th>
<th>Modulus of elasticity(GPa)</th>
<th>Poisson's ratio</th>
<th>Yield stress(MPa)</th>
<th>Strengthening modulus(GPa)</th>
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<td>40</td>
<td>0.23</td>
<td>55</td>
<td>10</td>
</tr>
</tbody>
</table>

2.2 Fault handling

There are two faults F3 and F18 in figure 12. Simplified handling for faults. In general, the fault should be established at the face - face contact. Considering the simulation is face mining, fault could not produce significant slip deformation. Therefore, using a soft elastic material to fill the gap between faults. In fact, due to the geological fault is the fracture zone, often be filled with mud, water, sand, and has a large amount of gaps, so this is a reasonable assumption. Enlargement at fault shown in Figure 13.

Fig.12 Two-dimensional plane strain finite element model      Fig.13 An enlarged view of the fault

2.3 Results and analysis

Mainly analysis the NO.9 coalbed first mining face on the left part of fault F3, The length of this part is about 1000m. Using advanced methods that used in
tunneling to simulate the excavation. Below given the calculation results of the the initial gravity field, working face go forward 200m, 400m, 700m, 950m, 975m, 990m.

2.3.1 Simulate initial ground stress in gravity field
In order to simulate the mining process, initial ground stress must be simulated, in order to facilitate the release of the follow-up exploration step to simulate the stress. Failure criterion is used to achieve a certain degree plastic strain on behalf of damage. Initial ground stress analysis results shown in Figure 14 (a), (b).

![Fig.14](image1)

It can be seen from Figure 14. under the gravity, there have been some plastic strain upper and lower ends of the softer seams and faults. This is consistent with the actual

2.3.2 Numerical simulation and analysis when working face moving forwards
(1) Numerical simulation

![Fig.15](image2)

![Fig.16](image3)
(a) y-direction displacement cloud  (b) plastic strain cloud
Fig. 17 Working Face Moving Forwards 700m (Fault F3 300m away)

(a) y-direction displacement cloud  (b) plastic strain cloud
Fig. 18 Working Face Moving Forwards 950m (Fault F3 50m away)

(a) y-direction displacement cloud  (b) plastic strain cloud
Fig. 19 Working Face Moving Forwards 975m (Fault F3 25m away)

(a) y-direction displacement cloud  (b) plastic strain cloud
Fig. 20 Working Face Moving Forwards 990m (Fault F3 10m away)

(2) Analysis

The paper used life and death method of the units to simulate the processing of the mining, kill the been mined coal unit to simulate the advance of working face. When the work face advance 200 meters (Fig. 15), the strata above the mined-out...
area appears to sink, because he node stress of the mined-out area didn’t be released, upper part of the mined-out area has not plastic strain. In fact, this state is similar with supporting to counteract the ground stress. However, the soil layer of the mined-out area appeared to sink due to didn’t simulate alone support system. Also the top and floor near the working face appeared a certain degree of plastic strain, but it not yet reached the degree of broken damage.

When the working face advanced 400m-950 meters, shown as Fig.16-18, with the advancing of the working face, the plastic strain progressively became larger. The plastic strain is concentrated in front of the working face, the strata on the bottom and top of the working face had a certain degree of plastic strain. Damage region concentrated in the upper and lower rock of working face and the limited distance from the coal seam, it was safe of mining, so the destruction of these areas did not the focus.

When the working face advanced 975 meters (Fault F3 25 meters away), shown as F19, y-direction displacement and plastic strain had increased further, the plastic strain region has been extended to through to the fault, but the plastic strain of the through area was little, did not reach the damage judgment criterion of coal rock. Damage region concentrated in the upper and lower rock of working face and the limited distance from the coal seam. So at this time there was no fault impact on mining yet, the likelihood of accidents was still low.

When the work face advance 990 meters (Fault F3 25 meters away), shown as Fig.20b, can be seen by the plastic strain cloud figure, that the damage area by the mining has through to the fault, and the remaining coal have all over the destroyed limit, at this time the reserved pillar could not resist the stress concentration caused by faults. Due to damage area has through to the fault, the damaged rock will release stress at the fault, if the working face kept continue advance to the fault direction, it was highly likely to occur roof fall and sudden water accidents. So in the case of NO.9 coal-bed first mining face, should reserve 25 ~ 10m of coal pillar at fault F3 to prevent accidents.

3. Summaries

(1) Based on the existing mine borehole data, established multi-layered geological model DEM. According to the borehole data and geological model multilayer DEM, established a finite element model.

(2) Combined with rock mechanics, elastic-plastic mechanics, using fracture mechanics, two-dimensional plane strain elastoplastic damage model, Simulated the actual coal exploitation Xiandewang of NO.9 coalbed first mining face.

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engineering

References:
Design and Application of Pressure Dispersed Anchor Cable in High Soil-like Slope

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Abstract: Reinforcement of high soil-like excavation slope as an example, this paper introduces the stress mechanism, design and calculation, application effect for pressure dispersed anchor cable. It has reference value for similar projects.

Key words: high soil-like slope, pressure dispersed anchor cable, design and calculation

0 Foreword

Although the soil-like slope retains some characteristics of the parent rock, it is with loose structure, joint development and the soil property. When the original soil-like slope is excavated, the mechanical equilibrium is destroyed. Then the stress in the slope is changed and adjusted. If there is water into the slope during the period and the slope has not be reinforced, the slope can not reach the new mechanical equilibrium. Therefore landslide will occur, and the high soil-like slope should be reinforced in advance.

As a light retaining structure, the prestressed anchor cable has the advantages of little disturbance, large anchoring force, and it is applied widely.

1 Stress Mechanism and Characteristics of Pressure Dispersed Anchor Cable

1.1 Stress Mechanism

At present, the common type of cable in the project can be divided into tension type and pressure type. The characteristics of tension type anchor cable is to use interface friction between injecting cement paste and cable, and between injecting cement paste and the soil, to provide anchoring force for the retaining structure.

But a lot of experiments prove that bond stress of tension type cable along the anchorage section is extremely uneven.

There is serious stress concentration at the proximal end of the anchorage section, and effective tension length of anchorage section is limited. When the anchorage length is more than 8 ~ 10 m, it is not usefull to improve anchoring force through...
increasing the anchorage length. Therefore, the traditional tension type cable can not get higher anchoring force [1].

Pressure dispersed anchor cable is multiple anchor system of single bore, which is composed of multi-anchoring units. Firstly, it transmits tension to the separate bearing carriers. Then tension force is converted into pressure, pressure reached in the vicinity of the cement mortar. Cement mortar under pressure produces micro compression expansion and compression deformation.

Finally, the pressure is transmitted to the rock and soil mass, so that it withstands the shear.

1.2 Stress Characteristics

(1) The concentrated force is dispersed into several smaller pressure zone by pressure dispersed anchor cable, which make the bond stress value of anchorage section greatly reduced, and well-distributed. Stress concentration is decreased, and the formation strength around the anchor is fully mobilized.

Then anchoring ability is improved, so as to compensate the shortage of tensile type anchor.

(2) For pressure dispersed anchor cable, injecting cement paste is not easy to crack, which is subjected to compression not tension. It is beneficial to be waterproof and anticorrosion for the cable body.

Pressure dispersive anchor cable for weak rock, especially for the soil permanent reinforcement of low bearing capacity has an irreplaceable role [2].

Pressure dispersed anchor cable structure, see figure 1. The stress distribution of the friction around the anchorage section, see figure 2.

![Figure 1](image)

Figure 1  Pressure dispersive dispersed anchor cable structure (unit:mm)
2 Engineering Situation

A factory is located in the hilly area. Leveling way of the site is "digging the mountain to fill out the ditch", and in the factory on the eastern side of the slope is cutted to backfill gully to form the platform. After the excavating, the two parts of slope (A, B) are formed.

Main features of slope A:
(1) The excavation height is large, and the field is narrow. The maximum excavation height is about 40m, but due to the land boundary, only about 40m is available for the horizontal distance.
(2) Strict safety requirements for the slope are needed. The traffic flow and people flow are large at the foot of slope. Once the landslide occurs, consequences will be unbearable.
(3) The project is located in the southern region, with annual rainfall of more than 1900mm.
(4) Seismic fortification intensity vi is not considered in the design.

3 Engineering Geological Conditiona & hydrogeology condition

3.1 Engineering Geological Conditiona

According to the drilling exposure, formation of the site from top to bottom as follows:
(1) ②-2 Silty clay (Q4el+ dl), thickness of 8.5m, brown-yellow, containing iron oxide stripes and Fe-Mn nodules, lots of gravel, and clay interlayer.

Natural moisture content(w): 19.0%~33.9%, natural void ratio(e): 0.616~0.945, liquid index( I L ): 0~0.45, compression coefficient (a1-2): 0.11~0.33MPa-1, waxiness to hard plastic state, medium compressibility.

(2) ④-1 Fully weathered shale (T3r-J1), thickness of about 24m, yellow-brown, the whole structure has been unable to be identified, soil-like.
Natural moisture content \( w \): 15.6% ~29.6%, natural void ratio \( e \): 0.506 ~ 0.835, liquidity index \( I_L \): 0.02 ~ 0.42, extremely soft rock, rock basic quality level \( V \).

(3) 

④-2 Strongly weathered shale \( (T_{r-J1}) \), yellow-brown ~gray-brown, strongly weathered, calcareous cementation, sandy and lamellar structure, shiver chunky and soil-like, extremely soft rock, rock basic quality level \( V \).

Some drilling has dolomitic limestone \( (5-1) \) and \( (5-2) \), weathered dolomitic limestone \( (C_{1m}) \), separately belonging to extremely soft rock and hard rock, and a small amount of karst cave is found.

3.2 Hydrogeological Conditions

There are no groundwater in the slope A and slope B, so the influence of groundwater is considered.

4 Slope Reinforcement Scheme

Comprehensive consideration, reinforcement scheme of slope A is anti-slide pile, slope cutting + pressure dispersed anchor cable. The typical section of the slope stability calculation and reinforcement design, see figure 3.

![Figure 3](image)

Figure 3  The typical section of the slope stability calculation and reinforcement design (unit:m)

5 Design and Calculation of Pressure Dispersed Anchor Cable \[^{[3]–[6]}\]

5.1 Choice of Bond Strength of Anchorage Section

Generally, the selection of calculation parameters has indoor test, field test method, empirical parameter method and index back calculation method. The selection of the calculation parameters for the project is mainly based on the basic test of anchor cable.
in the field, and combined with the engineering experience and the recommended data of the exploration units. The parameter is very important for anchor cable design, so it should be carefully chosen. It is recommended bond strength of anchorage section should be determined by field test.

As the anchoring section is mainly in the fully weathered shale, eventually the standard value of the bond strength between the grout body and the rock-soil layer is 120kPa.

5.2 Design and Calculation of Anchoring Force

design anchoring force $P_t$:

$$P_t = \frac{F}{\lambda \sin(\alpha + \beta) \tan \phi + \cos(\alpha + \beta)}$$

Among them:

- $P_t$: design anchoring force;
- $F$: downslide strength (by calculation): 200kN/m;
- $\phi$: internal friction angle of sliding surface: 24°;
- $\alpha$: inclination of anchor cable and sliding surface intersection: 31°;
- $\beta$: Angle between the cable and the horizontal plane: 15°;
- $\lambda$: reduction factor, for soil slope 0.5;

design anchoring force by calculation: $P_t = 234$kN/m.

5.3 Determination of Anchor Spacing

horizontal spacing of anchor cable: 4.0m

The design of anchoring force within the 4m width

$P_T = 234$kN/m $\times$ 4.0m = 936kN

effective anchorage force each bundle of anchor cable : $[F] = 300$kN

line number:

$$n = \frac{P_T}{[F]} = \frac{936}{300} \approx 3.1 \approx 4$$

5.4 Anchor Cable Structure Calculation

5.4.1 Design and calculation of anchorage section

The grouting material adopts M30 unmixed cement mortar.

According to the following two kinds of method to calculate bond strength, and choose the maximum value.
(1) according to the bond strength of cement paste (bond strength between cement paste and steel strand is far greater than between mortar and the borehole wall), so it don't be calculated.

(2) according to the shearing strength between the anchorage body and borehole wall.

\[ L_s = \frac{F_{s2}[F]}{\pi \cdot d_h \cdot \tau} \]  

Among them:

- \( F_{s2} \): anti-pulling safety factor of the anchorage body, 2.5;
- \( d_h \): diameter of anchorage cable hole, 150mm;
- \( \tau \): bond strength between the grout body and the rock-soil layer, 120kPa.

As a result, the anchor length \( L = 14 \) m, the length of free section of anchor cable have to pass through the depth of the slip surface greater than 1.0 m, so anchor cable have to pass through the length of the sliding surface not less than 15.0 m.

The number of bearing carriers: 2, each anchorage length: 7 m

5.4.2 The Choice of the Number of Steel Strand

Considering two bearing carriers, each bearing carrier adopts two steel strands. Each bundle of anchor cable is with 4-\( \Phi 15.2 \) mm unbonded steel strand.

\[ P_u = 4 \times 259kN = 1036kN \]  

safety factor: \( F_{s1} = 2 \), effective pull:

\[ \frac{P_u}{F_{s1}} = \frac{1036}{2} = 518kN > 220kN \]

So steel strand won't be pulled apart.

5.5 Total Length of Anchor Cable

The total length of the cable=the length of the anchorage section + the length of free section+ the length of tension section

5.5.1 The Length of Free Section

Determination principle: in order to prevent the pre-tension of anchor cable from significant attenuation due to anchor head loosen and soil creep, and to increase the stability of anchoring formation, the length of free section of anchor cable should be no less than 5 m, and pass through the sliding surface of slope.

5.5.2 The Length of Tension Section

The length of tension section should be determined according to tension machine, and exposed length of anchor cable is generally about 1.5m.
6 Reinforcement Effect of Pressure Dispersed Anchor Cable

The construction of slope A has been completed in April 2012, and has experienced the test of the south rainy season. The displacement of the slope A is in the standard range, which indicates that the reinforcement measures are safe and feasible.

Reinforcement effect diagram of pressure dispersed anchor cable, see figure 4.

![Figure 4  Reinforcement effect diagram of pressure dispersed anchor cable](image)

7 Conclusions

(1) Pressure dispersed anchor cable used in soil-like slope of overburden being thicker, can fully mobilize the formation strength around the anchor, and significantly improve the anchor bearing capacity. It is a very effective way for the loose and broken rock and soil mass, for which anchoring force is insufficient.

(2) In the design, the standard value of the bond strength between the grout body and the rock-soil layer should be determined by the basic test when there is no enough experience of the project.

8 References

Study on the Phase Characteristics of the Collocation Relationship Between Runoff and Sediment in the Slop-Gully System

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Abstract: Slope-gully system is the basic unit to study the erosion regularity and arrange the soil and water conservation measures. The study on the phase characteristics of the collocation relationship between runoff and sediment is very important for arranging soil and water conservation measures of adaptation to local condition. Based on the Key Laboratory of Yellow River Sediment Research of Ministry of Water Resources, the paper analyzed the process of runoff and sediment production in the slop-gully system of the soil erosion and the phase characteristics of the collocation relationship between runoff and sediment in the 3 different rainfall intensities by using the artificial rainfall simulation test method. The results showed that:

1) Under the condition of a certain underlying surface, there is a critical point in the process of soil erosion in the slope-gully system. Less than the certain rainfall intensity, the runoff and sediment yield increased greatly with the increasing rainfall intensity. Over the certain rainfall intensity, the increasing degree of runoff and sediment yield and the velocity of erosion evolution slowed down.

2) The rainfall intensity and rainfall are important factors for affecting the process of erosion and sediment yield. And the effect of rainfall intensity on runoff and sediment yield is even greater than the rainfall.

3) The collocation relationship between the runoff and sediment in the slop-gully system of the quasi shallow gully erosion stage was significantly different from that of sheet erosion stage and rill erosion stage. And with the same runoff yield, sediment yield increased significantly. Therefore, the soil and water conservation measures should be arranged according to the erosion development stage and the rainfall characteristics.

Key words: slop-gully system, runoff and sediment yield, the collocation relationship between the runoff and sediment, phase characteristics

1 Introduction

The surface soil on slope would be stripped away from the original surface by the
rainfall runoff, which ends up with soil and water loss. Soil and water loss not only caused the ecological environment deterioration and declining agricultural productivity, but also seriously restricting the sustainable development of social economy. Slope-gully system is the main source of erosion sediment in small watershed, and it’s also the basic unit to control soil erosion, restore and reconstruct ecological environment. The erosion process and mechanism research can not only provides scientific basis for arranging soil and water conservation measures, but also has important significance for the restoration and reconstruction of ecological environment.

The study on the relationship between rainfall and sediment yield of slope-gully system originated from the debate about the key controlling region in 1950s, which reflects the weakness of soil erosion researching. With the constant development of soil erosion process, people gradually realized that slope and gully is an indivisible whole in the soil erosion process(Chen,1993, Chen et al.,1999). And the study of soil erosion mechanism has obtained high-quality results(Wei et al.,2010, Xiao et al.,2009, Ding et al.,2005, Yao et al.,2011, Xiao et al.,2007, Wei et al.,2012). Xiao PeiQing et al. (2009)quantitatively analysised the characteristics of slope runoff and hydraulic parameters in slope-gully system by means of rainfall simulation. They pointed out that with the increasing rainfall intensity, the runoff changed from the slow flow into the rapids, runoff Reynolds number and Froude number increased markedly, the Darcy-Weibach decreases, and the sediment yield was significantly increased eventually. Wei Xia et al.(2010) studied the erosion process of slope-gully system by artificial water scoured experiment and showed that the runoff and sediment yield increased exponentially with the growth of water inflow rates.

During the transformation process of sediment stripped away from the original surface by the rainfall runoff, runoff and sediment yield were constantly changing. But during the process of soil erosion in the slope-gully system, the collection relationship between the runoff and sediment has a certain phase characteristics. In the existing research results, the qualitative and quantitative research about this field is rare, which is not conducive to arrange the water and soil conservation measures. For that reason, in this paper, the phase characteristics of runoff and sediment yield in slope-gully system are studied quantitatively and qualitatively through the artificial rainfall simulation method.

2 Material and methods

The experiment was conducted in the Key Laboratory of Yellow River Sediment Research of Ministry of Water Resources. According to the actual situation of the Loess Plateau and the laboratory’s facilities, the experimental soil box of slope-gully system was designed, as shown in Figure 1. The experimental model is composed of
two parts (the slope and gully slope), which is 10 meters in length, 1 meters in width. Based on the previous research results and the investigation of the degrees of hill slope and gully slope, determined the degrees of hill slope and gully slope (20° and 35°). As for the geometrical features of the model, it’s projection area are 9.60m², and it’s total height is 4.59m.

![Sketch map of experimental soil bed of slope-gully system](image)

Fig.1 Sketch map of experimental soil bed of slope-gully system

The soil material used in this study is the loess from Mangshan Mountain located at the north of Zhengzhou City, Henan Province, China. This paper sifted them through sieves with 5 mm aperture first, and then layered and patted strictly into the soil box. The depth of fill was 45cm. And the Soil bulk density was controlled in 1.22~1.25g/cm³. After filling, the soil was made to reach the saturation state through a drizzle initiated by artificial rain, and then natural settling for 24h in order to control the soil moisture content in 14%~15%, which can eliminate the influence of different water content in the early stage. The percentage of the soil grain size is shown in Table 1.

<table>
<thead>
<tr>
<th>Grain size/mm</th>
<th>1.0</th>
<th>1.0-</th>
<th>0.25-</th>
<th>0.05-</th>
<th>0.01-</th>
<th>0.005-</th>
<th>&lt;0.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>percentage</td>
<td>0.05</td>
<td>34.45</td>
<td>43.40</td>
<td>3.20</td>
<td>6.40</td>
<td>10.50</td>
<td></td>
</tr>
</tbody>
</table>

The rainfall equipment used in the experiment is the automatic artificial rainfall system of the test chamber. The rainfall system (TSJY-1) is composed of sprinkler, pressure pipe, water system, etc. Through setting the nozzle size, the length of time, pressure and other parameters on the visual interface of the rain water system in the control room, can simulate different rainfall intensity and rainfall duration. The height of nozzle is 22m, can ensure that more than 95% of the rain drops reach to the...
uniform fall state, which has a high degree of similarity with the natural environment. In this experiment, the rain intensity (66mm/h, 42mm/h, 85mm/h) were determined by parameters setting and direct measuring, and the uniformity of rainfall was 85%, 89.5% and 86.8% respectively. Parameter setting of rainfall simulation system is shown in table 2.

Table 2  Parameter setting of rainfall simulation system

<table>
<thead>
<tr>
<th>Rainfall intensity (mm/h)</th>
<th>Nozzle</th>
<th>Pressure (Pa)</th>
<th>Rainfall duration (min)</th>
<th>Uniformity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>5#</td>
<td>0.1</td>
<td>140</td>
<td>85</td>
</tr>
<tr>
<td>66</td>
<td>5#</td>
<td>0.2</td>
<td>100</td>
<td>89.5</td>
</tr>
<tr>
<td>85</td>
<td>4#</td>
<td>0.04</td>
<td>62</td>
<td>86.8</td>
</tr>
</tbody>
</table>

During the experiment, the critical time that runoff and sediment beginning were recorded, and all the runoff and sediment samples were collected every two minutes using a big bucket. In the course of the experiments, monitored dynamically the width and depth of the gully of slope-gully system by the thin steel ruler and digital camera. After the experiment, weighed the runoff and sediment quality, and determined the runoff volume, and finally calculated the runoff and sediment yield data by the replacement method.

3 Results and discussion

3.1 The process of runoff and sediment yield in slope gully system

In this artificial rainfall simulation tests, 142.5min after the rainfall, intensity 45mm/h, the slope in the model was scoured out many small ditch whose depth was less than 3cm by the dispersive small runoff, or appeared surface layer of soil loss, and the process of gully development was slow. As for 65mm/h and 85mm/h, 100min and 62min after rainfall, respectively, the slope was scoured out many shallow grooves whose depth was about 15cm by the big runoff collected from the dispersive small runoff, and the gully slope was constantly washed lead to collapse of the local soil. Therefore, the rainfall intensity was stronger, the rainfall duration was shorter, the gully development in the soil erosion process of slope-gully system was faster, and the surface land was incised more fiercely.

According to the test record, the initial runoff time of 42mm/h, 66mm/h, 85mm/h was 2.5min, 2min, 1min, respectively, which proved that the initial runoff time of high rainfall intensity was earlier than the low rainfall intensity. It means that the rain was infiltrated and absorbed by soil for the reason that the initial infiltration capacity of soil was greater than that of rainfall intensity at first. With the rainfall, soil infiltration capacity decreased with the increased of soil water content. When the soil infiltration
capacity was less than the rainfall intensity, the slope-gully system started to flow.

With the generation of surface runoff, the sand of slope-gully erosion was output. The process curve graph of runoff and sediment yield in 3 kinds of rainfall intensity is plotted according to the runoff and sediment sample data (figure 2, figure 3). From the figure we can found that the effect of rainfall intensity on runoff and sediment yield of slope gully system was very obvious. The process curve of rainfall runoff and sediment yield of 42mm/h was significantly lower than that of 66mm/h and 85mm/h. Under the same rainfall condition, the increasing trend of runoff yield with the runoff time was greater than that of sediment yield with the increase of runoff time, which was consistent with the relationship between runoff and sediment yield in slope-gully system \(y=ax^b\) based on rainfall simulation experiments by Xiao Peiqing et al.(2007).

![Fig 2](image-url)  The process of runoff of 3 kinds of rainfall intensity

![Fig 3](image-url)  The process of sediment yield of 3 kinds of rainfall intensity

20min after rainfall, with the formation of overland runoff in the slope-gully system, the water content of the soil reached saturation state, and soil infiltration rate tended to be stable. Based on the above reasons, the difference of later runoff process was caused by rain intensity. Under the premise of same rainfall duration, compared with the rainfall intensity of 42mm/h, the rainfall intensity of 66mm/h is 1.57 times as high.
as that of 42mm/h, but the cumulative runoff and sediment yield of 66mm/h is respectively 5.20 times and 14.76 times as much as that of 42mm/h; the rainfall intensity of 85mm/h is 2.02 times as high as that of 42mm/h, but the cumulative runoff and sediment yield of 85mm/h is respectively 6.27 times and 36.27 times as much as that of 42mm/h. Compared with the rain intensity of 66mm/h, the increasing degree of rainfall intensity of 85mm/h was about same as that of cumulative runoff and sediment yield (Rain intensity increased by 0.29 times, and the cumulative runoff and sediment yield increased respectively by 0.31 and 2.27 times). These analytical data showed that, with the increase of rainfall intensity, the cumulative runoff and sediment yield had the tendency of accelerates increase, but when rainfall reaches a certain intensity, the trend of cumulative runoff and sediment yield increased with the increasing rainfall intensity would weaken.

3.2 The phase characteristics of runoff and sediment yield in slope-gully system

In the time scale, the development period of soil erosion in slope-gully system were different under the different rainfall conditions. The soil erosion process in slope-gully system was divided into surface erosion stage (before rill formation), rill erosion stage (rill formation to fine deep groove width within 20cm) and quasi shallow channel (Yao et al. 2011) erosion stage (deep gully erosion stage were greater than 20cm) under the experimental conditions. These erosion forms appeared in succession and usually concomitantly exist in erosion development process of slope-gully system. The time of next erosion forms appeared and became the main erosion forms in the erosion process would be regarded as the boundary between different erosion stages. The process curve graph of runoff and sediment yield in 3 kinds of rainfall intensity and the record data from the soil erosion process observation were combined to analysis the phase characteristics of runoff and sediment yield in slope-gully system (table 3). Under the condition that the rain intensity was 42mm/h, the whole development process of soil erosion was divided into surface erosion and rill erosion stage, and didn’t reach the quasi shallow gully erosion stage. But under the condition that the rain intensity was 66mm/h and 85mm/h, the soil erosion developed to the quasi shallow gully erosion stage, and the stronger the rain intensity, the earlier the erosion stage occurred. For the same erosion stage, the velocity of runoff and sediment generation and the average sediment concentration in runoff increased with the increasing rain intensity and the development of erosion stage. It can be seen that the rainfall intensity and rainfall are the important factors that affect the process of erosion and sediment yield.

<table>
<thead>
<tr>
<th>Item</th>
<th>Stage</th>
<th>42mm/h</th>
<th>66mm/h</th>
<th>85mm/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (min)</td>
<td>surface erosion</td>
<td>0~40</td>
<td>0~24</td>
<td>0~16</td>
</tr>
<tr>
<td></td>
<td>rill erosion</td>
<td>40~140</td>
<td>24~60</td>
<td>16~40</td>
</tr>
</tbody>
</table>

Table 3  Phase characteristics of runoff and sediment yield in slope-gully system

Journal Website: http://ijgsw.comze.com/
You can submit your paper to email: Jichao@email.com
Runoff and sediment yield were the result of the combined effects of rainfall and rain, but the two showed the different effect on runoff and sediment yield. The regression analysis of cumulative rainfall (P) of each stage and the corresponding rainfall intensity (I) derived that an inequality had to be met in the relationship of the velocity of sediment generation (Sq), velocity of runoff generation (Wq) and the accumulated rainfall (P), rainfall intensity (I):

\[ S_q = 108.32P + 238.65I - 16474.1 \quad (R=0.7854) \quad (1) \]
\[ W_q = 135.46P + 281.81I - 16232.6 \quad (R=0.8178) \quad (2) \]

From the regression coefficient of formula (1) and (2), it could be found that the effect of rain intensity on velocity of runoff generation was 2.1 times as much as that of rainfall, and the effect of rain intensity on velocity of sediment generation was 2.2 times as much as that of rainfall. This suggested that the effect of rainfall intensity on velocity of runoff and sediment generation was stronger than rainfall. The results were consistent with the conclusion of Wei Wei et al. (2012) - rain intensity is the most major factor affecting soil and water loss in all characteristic value of rainfall.

3.3 The collocation relationship of runoff and sediment yield in different erosion stage

The law of collocation relationship of runoff and sediment yield is a very complicated problem, and that is different in different erosion stages. Under different rainfall conditions, the relationship of runoff and sediment yield in the slope-gully system at different erosion stages is shown in Fig 4.
Fig 4  The scatter diagram of runoff and sediment yield at different erosion stages

Further analysis the distribution characteristic of the data points in figure 4, in the sheet erosion stage, the collocation relations of runoff and sediment yield under the 3 kinds of rain intensity condition were basically the same, which satisfied the formula \( y=ax^b \) (y is the sediment yield, and x is runoff); In the rill erosion stage, the runoff and sediment yield data of 85mm/h is slightly higher than that of 66mm/h, but still satisfied the above formula; when the erosion developed to the quasi shallow gully erosion stage, the collocation relations of runoff and sediment yield under the 2 kinds of rain intensity condition tended to satisfying the linear relationship which is \( y=ax+b \) (x, y ditto). It specifically demonstrated that under the condition of same volume of runoff, the stronger the rain intensity, the higher the content of the sediment (see Table 4).

Table 4  The collocation relationship of runoff and sediment yield in different erosion stage

<table>
<thead>
<tr>
<th>Erosion</th>
<th>Rainfall intensity (mm/h)</th>
<th>Formula</th>
<th>Correlation coefficient</th>
<th>Sample number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface erosion</td>
<td>42, 66, 85</td>
<td>( y = 0.0028x^{1.4806} )</td>
<td>0.934</td>
<td>34</td>
</tr>
<tr>
<td>Rill erosion</td>
<td>42, 66, 85</td>
<td>( y = 0.0021x^{1.5279} )</td>
<td>0.901</td>
<td>80</td>
</tr>
<tr>
<td>Quasi shallow gully erosion</td>
<td>66</td>
<td>( y = 1.2776x - 28544 )</td>
<td>0.818</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>( y = 1.3323x - 15879 )</td>
<td>0.948</td>
<td>11</td>
</tr>
</tbody>
</table>
4 Conclusions

(1) With the increase of rainfall intensity, the cumulative runoff and sediment yield had the trend of accelerates increase, but when rainfall reached a certain intensity, the trend of cumulative runoff and sediment yield increased with the increasing rainfall intensity would be weaken.

(2) Under the conditions of same underlying surface, the stronger the rain intensity, the earlier the erosion stage occurred. For the same erosion stage, the velocity of runoff and sediment generation and the average sediment concentration in runoff increased with the increasing rain intensity and the development of erosion stage. Rainfall and rainfall intensity are the important factors that affect the process of erosion and sediment yield, and the effect of rainfall intensity on velocity of runoff and sediment generation was stronger.

(3) The relationship of runoff and sediment yield was different in different erosion stages. In the quasi shallow gully erosion stage, under the condition of same volume of runoff, the stronger the rain intensity, the higher the content of the sediment.

5 References


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