Evolutionary Characteristics of Weak Intercalation in Massive Layered Rockslides

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Abstract. Weak intercalation forms a sliding zone after long-term geological evolution and deterioration and plays an essential role in controlling massive layered bedrock landslides. In order to determine the formation process of such a sliding zone, the study took the Jiweishan Mountain landslide as an example. It analyzed the distribution and developmental regularities of the weak intercalation. Its three evolutionary stages were divided: the original soft rock, the interlayer shear zone, and the sliding zone. In addition, the study comparatively studied the evolutionary characteristics of weak intercalation through the laboratory test of the physical properties, physicochemical properties, and physical mechanics properties of three stages. The result indicated that, in terms of the evolution of mineral composition, the clay mineral content increased significantly, with the mean value up from 4.4% to 16.9%. In terms of the microstructure evolution, the inter-granular connection became weaker, the microstructure turned loose from dense structures, the porosity and joint fissures were increased, the density was decreased by 5%–6%, and the porosity was up by 108%. From the evolutionary process of the physicochemical properties, the total content of exchangeable salt was the highest in the original rock, followed by the sliding zone, whereas the interlayer shear zone exhibited the lowest value. The organic matter content was gradually increased, and the entire evolutionary environment was weakly alkaline. Concerning the evolutionary process of shear strength, the internal friction angle of the weak intercalation was decreased from 57.58° to 29.63°, and the cohesion, which had prominent creep characteristics, was reduced from 585 kPa to 96 kPa. Based on these data, the study also analyzed the residual sliding thrust of the largest main section of the driving block in the Jiweishan landslide. The residual sliding thrust increased as the long-term strength parameter decreased. When the internal friction angle $\phi < 25^\circ$ and cohesion $c < 129$ kPa, the residual sliding thrust was greater than zero and reached a maximum value of 9.7×104 kN/m. The conclusions of this study provided an essential reference for the further research on the development and mechanism of layered rockslides controlled by weak intercalations.

Keywords: layered bedrock landslide; weak intercalation; evolutionary process; shear strength; creep characteristics
1. Introduction

Long periods of intense tectonic activity and deep river erosion in the large folded mountains in southwestern China result in an alpine canyon topography. Several layers of weak intercalation of carbonaceous shale, which are commonly developed in the Permian hard limestone strata in this area, combined with a limestone mountain, form a structure of alternating layers of soft and hard rock controls the stability of large layered bedrock landslides. The properties gradually deteriorate to form a sliding zone under the internal and external dynamic actions following geologic evolution. Once the sloping rock is destabilized, the sliding zone is often formed along weak intercalation, and sliding occurs. Since the end of the 19th century, there have been dozens of large-scale landslide hazards associated with weak intercalations, both locally and abroad (Xu, et al., 2012), such as the Qianjiangping landslide in China (Liao, et al., 2005), Vaiont landslide in Italy (Müller, 1964, 1968, 1987), and Austin Dam Foundation instability in the Texas of United States of America (Wang, 1990). According to the statistics presented by Yin (2004) on collapses and landslides along 283 mainstream banks of the Three Gorges Reservoir area in China, about 90% of landslides occurred in the layered bedrock containing weak intercalations, and the sliding zones of these landslides developed mostly from these weak intercalations (Yin, 2004). Therefore, the evolutionary characteristics of the sliding zone formed by the weak intercalations are the key scientific issue in studying the causes of instability in massive layered rockslides.

Weak intercalation is a product of geological history and is closely related to diagenetic conditions, tectonic action, and groundwater activity. Soft and hard interbedded rock mass with different strengths under tectonic action results in concentrated stress along with the interface between soft and hard rocks or inside soft rocks, which causes the phenomenon of interlayer displacement. Due to water’s long-term physical and chemical action, as the mineral composition of soft rock changes, the structure gradually becomes loose, weakening the inter-particle connection and moderately decreasing the intensities. Many scholars have studied the stability of landslides from the perspective of weak intercalations, such as Müller (1964, 1968, 1987), Broli (1967), and Voight (1982), who carried out a long-term systematic study of the Vaiont landslide. These authors believed that weak intercalation thickness and high clay content are causes of landslide occurrence. Tjong Kie et al. (1979) suggested that the creep behavior of weak intercalations in dam foundations is an important factor in dams’ long-term deformation. Fleming (1989) argued that the density of weak intercalations is lower than that of overlying strata, and loose weak intercalations occur due to expansion phenomena in the landslide movement process. Shuzui (2001) studied the resurrection landslides and found that the role of water-rock interaction promoted the formation of considerable montmorillonite within the sliding zone, resulting in an increase in the clay mineral content and a decrease in the sliding resistance force in the sliding zone. As a lot of research, a change in the weak intercalation in the rock mass is the root cause of forming a landslide sliding zone. So, far, the evolutionary process of the physical properties, mechanical properties, and microstructure of the weak intercalation still lack detailed systematic research, especially in thick layers of limestone regions. Therefore, it is necessary to study the evolution of weak intercalation properties for the layered bedrock landslide.

The Jiweishan massive layered bedrock landslide is used as an example in this study. It looked at the distribution and evolution of weak intercalation in the slope, divided the evolutionary stages, and compared the evolutionary process of the weak intercalation formed sliding zone in the lab. On this basis, the residual sliding thrust of the driving block’s variation trend was determined and analyzed. In addition, the sliding mechanism of the massive layered bedrock landslide controlled by weak intercalation evolution was further revealed.

2. Study area background

A massive mountain landslide occurred on June 5, 2009 in Jiweishan Mountain, Wulong District, Chongqing, China (hereinafter called Jiweishan landslide). Approximately 5 million cubic meters of limestone rocks slid down the weak intercalation of a gently tilted carbonaceous shale, forming a high-speed, long-distance landslide-debris flow disaster chain that killed 74 people and injured 8. In recent
In the past 3 years, there has been a rare and massive bedrock landslide event (Yin, 2010a, 2010b; Xu, 2010; Feng, 2012). (Fig. 1). The Jiweishan Mountain is an oblique inclined thick-layered limestone slope, and the east side of the slope is a cliff. The sliding rock mass of the Jiweishan Mountain is separated from the parent bedrock by two wide karstification fractures on the west and south containing small caves infilled with clay materials. And the filler age-dating showed that the two fractures were formed approximately 26 to 139 thousand years ago. The sliding rock mass is divided into a driving block in the rear and a key slide-stopping block in the front. The sliding bottom plane is weak intercalation of carbonaceous shale that developed along the bedding (Fig. 2). After a long geological evolution, the shear strength of the weak intercalation was continuously reduced; consequently, the residual sliding thrust of the rear driving block has continued to increase. Initially, material along the N15°W direction was prone to creep but was blocked by the stable mountain and tilted to N10°E as the inclination angle. As a result, the fundamental front block, which was continually squeezed, finally sheared and slid out.

Fig. 1 Location and Remote sensing map of the Jiweishan landslide. The dashed represents the driving and the key blocks of the sliding mass. The dot-dash line represents the accumulation area. The red arrows represent the direction of sliding mass movement.

Fig. 2 Photograph of the weak intercalation

There are several layers of weak intercalation in limestone. The lithology is carbonaceous shale, mainly distributed in the Permian Maokou and Qixia formations (Fig. 3). The formation of weak intercalation is the same as that of hard rock, which is mainly straight or slightly bend in general. The bedding plane of the weak intercalation is folded strongly by shearing action after the tectonization, even distorted into a curve with a certain fluctuation. According to field investigations and indoor analysis, the distribution of weak intercalation in the study area has the following characteristics:
(1) Well-developed weak intercalation with equidistant distribution (Fig. 4a). The thickness of the Maokou (P1 m) and Qixia (P1q) groups is approximately 180–255 m in total, covering seven well-developed weak intercalations. Weak intercalation was distributed at every 25–35 m along the cross-sectional direction perpendicular to the strata. The layer thickness is generally 0.3–0.6 m, and the extension length is 50–80 m. The well-developed weak intercalation has low strength, high fracturing, and strong weathering characteristics.

(2) The weak intercalation between the rock strata with different properties is high in thickness, with the maximum thickness reaching 1.12 m. As a result, its shear action is more complete, often along with the mud intercalation (Fig. 4b). Therefore, after tectonic movement, stress concentration readily occurred in the contact surfaces of the soft and hard interbedded layers (such as the Qixia and Liangshan groups) with different properties, causing a shear fracture and bending folds, and consequently, fragmented rock.

(3) The development of the original weak intercalation was not continuous; pinching off or a sandwiched limestone lens was sometimes observed (Fig. 4c). The original soft rock was affected by the depositional environment during the deposition and diagenesis process. In the area where the terrain fluctuated, the rock gradually became thinner until there was no deposition. Alternatively, tectonic pressure or torsional effects formed a limestone lens during the deposition process, indicating the weak intercalation’s inconsistent development.

(4) In the process where the original weak intercalation formed an interlayer shear zone, the calcite veins were enriched and distributed in the interlayer shear zone (Fig. 4d). The parent rock of the original weak intercalation is shale; affected by interbedded shear, the rock became distorted and fractured. The calcium carbonate dissolved in the water penetrated the karst groundwater and was deposited in the cracks caused by the shearing action, thus forming striped calcite veins. Many calcite veins can be observed on the exposed cross-sections of the interlayer shear zone and the sliding zone of the Jiweishan landslide (Fig. 2).

(5) The muddy interlayer is generally formed on the surface where shear is violent, and groundwater runoff is smooth, such as the contact surfaces of the soft and hard interbedded strata or the weak surface inside the weak intercalation. Mud interlayer formation occurs under two conditions: broken rock fragments were produced by shear and squeeze, and sufficient groundwater needs to be present.
3. Methods

The sliding zone of the massive bedding bedrock landslide developed mainly in the weak intercalation. After tectonic movement and the long-term effects of groundwater, the parent rock of the weak intercalation became soft, forming weak intercalation, a softened interlayer, and a mud interlayer or weak layer (collectively referred to as the interlayer shear zone) (Xu et al., 2010). The mechanical strength of the interlayer shear zone deteriorated as the nature of the interlayer shear zone deteriorated, eventually developing into the landslide’s sliding zone. Therefore, the evolutionary process of the weak intercalation in Jiweishan can be divided into three sequential stages, including original soft rock, interlayer shear zone, and sliding zone (Fig. 5).
The following properties characterize the three evolutionary stages of the Jiweishan carbonaceous shale weak intercalation:

(1) Original soft rock stage. The study area is a Permian-era sea-and-land interactive deposition environment with a warm, humid climate, lush vegetation, and relatively flat ancient land that provided a small amount of shaly debris. Several layers of shale interlayer construction were deposited in the hard carbonate layer during the deposition process. The tectonic damage is minor, there is a layer structure, a small amount of carbon and calcium components, a poor degree of bonding, and a small number of gentle dip cracks in this type of original soft rock.

(2) Interlayer shear zone stage. This stage was mainly influenced by tectonic activities and other internal dynamic effects. During the initial formation period of the interlayer shear zone, the stress was concentrated on the contact surface of the hard rock and soft rock or inside the soft rock; small deformations occurred, characterized by high-density folds and cleavage. Later, impacted by the multi-period extreme tectonic action and sheared, the rock structural connections were damaged and fragmented, and the physical and mechanical strength decreased.

(3) Sliding zone stage. This stage was mainly under the impact of gravity, groundwater, and other external dynamic effects. Under the condition of external dynamic geological actions, the interlayer shear zone was more conducive to groundwater activity. The groundwater infiltrated along the cracks or layers of the interlayer shear zone, which was further affected by water’s physical and chemical action. In addition, the fabric and mineral composition of soft rock under stress concentration changed further, the structure became loose, and debris particles emerged, showing a local phenomenon of a mud and plastic state, and its physical and mechanical strength was further reduced. Taking the Jiweishan landslide as an example, the sliding zone composed an interlayer shear zone and a thin muddy interlayer. Under the long-term effect of overburdening and groundwater, the shear strength of the sliding zone was gradually lost. Further, creep deformation occurred, and the sliding surface exhibited a mirrored and striated pattern, and the mineral particles were aligned in the same direction.

4. Results
The weak intercalation has special lithology, structure, and mechanical properties. The physical properties, microstructures, physicochemical properties, and physical mechanics properties of 72 samples of the three evolutionary stages of weak intercalation from Jiweishan Mountain in Chongqing were tested to determine the evolutionary process of the mineral composition. The lithology of weak intercalation samples is carbonaceous shale.

4.1. Evolutionary process of mineral composition
The mineral composition of the weak intercalation was determined using a D8 Advance X-ray diffractometer. The samples consisted of ten groups of the three stages (original soft rock, interlayer shear zone, and sliding zone). The average values of the experimental results are shown in Tab. 1.

| Evolutionary stage      | Quartz | Calcite | Dolomite | Pyrite | Jarosite | Talc | Montmorillonite | Chlorite |
|-------------------------|--------|---------|----------|--------|----------|------|-----------------|---------|
| Original soft rock      | 14.9   | 47.6    | 33.0     | 0.2    | -        | 2.3  | 0.9             | 1.2     |
| Interlayer shear zone   | 14.7   | 61.8    | 14.5     | 0.6    | -        | 3.6  | 3.2             | 1.5     |
| Sliding zone            | 15.3   | 53.6    | 5.5      | 0.5    | 8.2      | 5.8  | 7.3             | 3.8     |

It can be seen from Table 1 that in the evolutionary process of the weak intercalation, the quartz, because of its own nature, was stable, and there was a slight change in content; the calcite content was maintained at a high level because of dissolved calcium carbonate in the water in the process of karst groundwater infiltration, which was deposited in the weak intercalation cracks. In the formation process of the sliding zone later, the full participation of water caused hydrolysis and dissolution of calcite, resulting in a decrease in the calcium carbonate content. During the evolution, the dolomite content decreased significantly from 33.0% to 5.5%, indicating that it was involved in the evolution of the weak intercalation, in which Ca$^{2+}$, Mg$^{2+}$, and other exchangeable cations played a role in the chemical reactions with water and other minerals.

Fig. 6 shows the variations in the mean of clay mineral content during the evolution of the weak intercalation. (1) The clay minerals are mainly composed of montmorillonite, chlorite, and talc, of which the former two demonstrate strong hydrophilicity, swelling, and shrinkage. These minerals have a certain expansion pressure when they absorb water and swell. When the expansion pressure exceeds the overlying rock pressure, the weak intercalation’s structure is damaged, its strength decreases, and creep-slide occurs. The clay minerals shrink after dewatering, accelerating the mountain’s creep-slide deformation. Montmorillonite and chlorite also undergo particle rearrangement and form shear surfaces when subjected to shear forces. (2) Talc has a creamy texture and is very soft. This reduces the strength of the weak intercalation and is one of the factors that contribute to landslides and long-term creep-sliding. According to a large number of statistical experimental results, the clay mineral content in the original soft rock is less than 5%, 5% to 10% in the interlayer shear zone, and greater than 10% in the sliding zone.

**Fig.6** Mean values of clay mineral content

4.2. *The evolutionary process of physical properties*

Fig. 7 shows the mean curve of the weak intercalation’s main physical properties during the evolution. It can be seen that during the evolution of the weak intercalation, the structure of rock was damaged by the shear effect, and cracks and pores increased. Compared with the original soft rock, the natural
and saturated density of the sliding zone decreased by 6% and 5%, respectively, and the porosity, natural moisture content, and saturated ratio increased by 108%, 224%, and 195%, respectively.

Fig.7 Evolutionary process of physical properties

4.3. Evolutionary process of microstructure

A Quanta250 SEM was used to determine the microstructure of the weak intercalation. The samples consisted of ten groups each from the three stages. The representative test results were analyzed as shown in Fig. 8.

Fig.8 Evolutionary process of the microstructure

The test results indicate the following: (1) The microstructure of the original soft rock is a layered structure, the interlayer connection is compact as thick as 1–5 μm, and the stretching effect forms ragged cracks and fractures. (2) The microstructure of the interlayer shear zone is a skeleton structure,
the connecting force of the loosening frame between the particles is weak, and the amount of micropores has increased. Since the calcite veins formed by the karst process were deposited in the joints and fissures, there were some directional scratches on the layer’s surfaces with a 40–60 scratches/cm frequency. (3) The microstructure of the sliding zone in the Jiweishan landslide is a skeleton honeycomb structure. The particles are loose with a weak connecting force, and there are many micropore cracks filled with floc clay particles. The sliding zone shows mechanical characteristics of shear fracturing and tensile fracturing, and the frequency of scratches on the layer’s surface is higher than that seen in the interlayer shear zone \( \backslash \), which is about 80–120 scratches/cm. The size of the debris particles in the sliding zone is different, and they exhibited an apparent directional arrangement. This microstructure provides favorable conditions for rock creep deformation and failure.

4.4. The evolutionary process of physicochemical properties

Through a series of tests, the chemical parameters, including the cation content, organic matter content, and pH value, were measured, and the results are shown in Table 2.

| Evolutionary stage       | Exchange cation concentration \((\text{meq/100g})\) | Total exchangeable bases \((\text{meq/100g})\) | Organic matter (%) | pH |
|--------------------------|-----------------------------------------------|-----------------------------------------------|-------------------|-----|
| Original soft rock       | K\(^+\) 2.323, Ca\(^{2+}\) 0.085, Na\(^+\) 0.918, Mg\(^{2+}\) 0.011, Al\(^{3+}\) 0.003 | 3.390                                           | 1.32              | 9.12|
| Interlayer shear zone    | K\(^+\) 1.477, Ca\(^{2+}\) 0.088, Mg\(^{2+}\) 0.630, Na\(^+\) 0.019, Al\(^{3+}\) 0.009 | 2.330                                           | 1.37              | 9.04|
| Sliding zone             | K\(^+\) 1.835, Ca\(^{2+}\) 0.084, Mg\(^{2+}\) 0.819, Na\(^+\) 0.015, Al\(^{3+}\) 0.004 | 2.810                                           | 2.31              | 8.74|

From Table 2, the physicochemical properties of the weak intercalation exhibited the following characteristics in the evolutionary process: (1) The total content of exchangeable cation was the highest in the original rock, followed by the sliding zone, whereas the interlayer shear zone had the lowest content. Ca\(^{2+}\) and Mg\(^{2+}\) were consistent with the change of the total content of exchangeable salt, and Ca\(^{2+}\) accounted for the largest share of the exchangeable cations, indicating that the following in the weak intercalation evolution; mainly Ca\(^{2+}\) exchange, highest K\(^+\) content in the interlayer shear zone, and the contents of Na\(^+\), Al\(^{3+}\), and Fe\(^{3+}\) were lower in the other two stages. (2) Organic matter is mainly carbon, and carbon was directionally distributed in the rock; its content gradually increased from 1.32% to 2.31%. The higher the carbon content, the lower the degree of rock cementation, and the more developed the foliation, resulting in weathering and a lower mechanical strength of the rock.

During the evolution of the weak intercalation, the mean pH value decreased from 9.12 to 8.74, i.e., weakly alkaline. A weak alkaline environment is conducive to montmorillonization and illitization.

4.5. The evolutionary process of creep mechanics

Changes in rock mineral composition, microstructure, and physicochemical properties directly affect physical and mechanical strength during evolution. Weak intercalation strength decrease is the root cause of the landslide sliding zone formation. The creep characteristics of the interlayer shear zone and argillaceous fillings in the hard rock mass have been highly significant by numerous on-site monitoring and laboratory tests(Sun 1999, 2007). Based on the rock creep mechanics tests in the laboratory, the evolution of the creep mechanics of the weak intercalation was analyzed. The shear creep tests scheme of the weak intercalation is shown in Table 3, where \( \sigma \) is the normal stress; \( A \) is the shear surface area, and \( q \) is the graded shear stress.

| Evolutionary stage       | \( \sigma \) \((\text{MPa})\) | \( A \) \((\text{cm}^2)\) | \( Q \) \((\text{MPa})\) |
|--------------------------|--------------------------|------------------|------------------|
| Original soft rock       | 0.7                      | 361              | 0.496, 0.870, 1.305, 1.725, 2.176, - |
The shear creep test of the weak intercalation was completed in a year and a half. The shear creep time-displacement curve of three evolutionary stages when the normal stress was 1.5 MPa (Fig. 9). The rock samples had significant creep deformation characteristics. The deformation of the rock specimen increased gradually with the evolutionary process under the same normal stress level, while the shear stress decreased gradually. The weak intercalation’s creep deformation can be divided into three stages: (1) When shear stress was applied at all stages, the initial creep stage occurred. The stage was brief, but it contained a significant amount of displacement, and the creep rate decreased rapidly over time. (2) The steady-state creep stage began after the end of the initial creep stage, lasting for a long time; the displacement remained essentially constant or exhibited slow uniform growth, and the creep rate was zero or remained at a small constant value. (3) The accelerated creep stage was short, the displacement was large, the creep rate increased sharply with time, and finally, the rock specimen was destroyed.
Long-term shear strength refers to the shear strength of rock that has been damaged due to long-term creep deformation. The shear stress-displacement isochronal curve method was used to determine the strength of each rock specimen (Fig. 10). It can be seen that long-term shear strength gradually decreased during the evolution of the weak intercalation. In the stage of original soft rock to the interlayer shear zone, the internal friction angle was reduced by 27.04%, and the cohesion was decreased by 45.64%. In the stage from the interlayer shear zone to the sliding zone, the internal friction angle was reduced by 29.47%, and the cohesion was reduced by 69.81%.

5. Discussion

5.1. Evolutionary mechanism of weak intercalation

Weak intercalations are affected by regional tectonic movement or the overburden load in the process of evolution; the stress is most concentrated on the contact surface of soft rock and hard rock or the inner bedding plane of soft rock. There are differences in the physical mechanics’ properties between the contact surface and bedding plane, which form a coupling effect, resulting in a stress field parallel to the layer and shear deformation under the action of the upper and lower rock stress and forming a displacement surface. As a result, the interlayer shear and displacement occur once or twice on the soft rock, destroying the original rock structures and interlayer and vertical joint fractures; consequently, the rock becomes fragmented or even turns into mud (Deng, 2016).

In the evolutionary process, the weak intercalation underwent dissolution due to karst water, groundwater and rainfall, etc. Soluble saline minerals in the rock dissolved in water, creating more Ca²⁺ and Mg²⁺. The resultant solution turned alkaline, conducive to mineral montmorillonitization, and increased the clay mineral content. At the same time, there was a constant and strong ion
exchange between groundwater and rich Ca$^{2+}$, Mg$^{2+}$, Al$^{3+}$, K$^+$, and Na$^+$ ions in the detrital minerals and clay minerals, which aggravated the muddy degree of the weak intercalation. In addition, water molecules penetrated into the crystal frame of rock minerals under hydration and were attached to the soluble ions, which destroyed the original microstructure of the rock and reduced the cohesion of the rock. In the process of seepage, water not only removed tiny debris from the rock but also dissolved and removed the easily dissolved components. Hence, the integrity and density of the rock were gradually destroyed and lost (Ling, 2015).

5.2. Analysis of residual sliding thrust on the main section of the driving block

The top surface of the slope was assumed to be parallel to the sliding surface based on the shape characteristics of the Jiweishan landslide’s driving block; this was generalized as an isosceles trapezoidal. The sliding body’s top surface AD was 462 meters, the sliding surface BC was 508 meters, the height H was 60 meters, and the dip angle was 30 degrees. The mechanics model of the main section for the driving block was established using the two-dimensional limit equilibrium analysis method (Fig. 11). (the main section refers to the longest sliding section in the dip direction and also the section with the largest residual sliding thrust). The variation trend of the residual sliding thrust on the main section of the driving block was analyzed during the evolution of the weak intercalation.

![Fig.11 Mechanics model of the main section for the driving block](image)

The driving block was mainly subject to its own gravity W, the effective reaction force of the sliding surface W·cosa, and the sliding thrust of the block W·sina. Therefore, the residual sliding thrust P of the main section of the driving block was calculated as follows:

$$P = W \cdot \sin \alpha - (W \cdot \cos \alpha \cdot \tan \varphi + c) \quad (1)$$

where P is the residual sliding thrust, $\varphi$ is the internal friction angle of the weak intercalation, c is the cohesion of the weak intercalation, and l is the length of the sliding surface BC.

According to the above evolutionary rule of the weak intercalation’s long-term strength, we substituted the values of $\varphi$ and c into equation (1). As a result, we obtained the residual sliding thrust of the largest main section of the driving block (Fig. 12). It can be seen that, with the decrease in the weak intercalation $\varphi$ and c values, the residual sliding thrust gradually increased. When $\varphi > 25^\circ$ and c > 129 kPa, the resistance was greater than the sliding force; the residual sliding thrust P was 0, the safety factor was greater than 1, meaning the rock was stable. When $\varphi < 25^\circ$ and c < 129 kPa, the resistance was less than the sliding force, and the residual sliding thrust gradually increased, up to 97000 kN/m. At this time, the safety factor was less than 1, indicating the rock stability loss and sliding occurred.
Fig.12 Trend image of the residual sliding thrust of the main section for the driving block during the evolution process

6. Conclusion
According to the above analysis, the conclusions are drawn as follows:

(1) The weak intercalation distribution and development in Jiweishan Mountain is fairly regular, and it can be divided into three evolutionary stages: original soft rock, interlayer shear zone, and sliding zone.

(2) The clay mineral content gradually increased during the evolution of the weak intercalation, from less than 5% in the original soft rock to between 5% and 10% in the interlayer shear zone to greater than 10% in the sliding zone. Because it had been compacted, the microstructure had become loose. The number of pores and joint fissures increased as the bonding force between the particles decreased.

(3) The internal friction angle and cohesion of weak intercalation declined further in the evolutionary process of the interlayer shear zone to sliding zone as compared to the evolution from the original rock to the interlayer shear zone. Therefore, in the landslide disaster research, attention should be paid to landslides of an interlayer shear zone and targeted prevention and control measures should be adopted.

(4) After a long geological evolution, the long-term shear strength of the weak intercalation was continuously reduced. As a result, the residual sliding thrust of the driving block increased along with the decrease in the long-term strength parameter of the weak intercalation. When $\phi < 25^\circ$ and $c < 129$ kPa, the residual sliding thrust is greater than zero; at this point, the safety factor is less than 1, indicating the rock mass failure, resulting in sliding.

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