# Analysis of the engineering properties of Xigeda stratum in Lamaxi Gully, Sichuan Province, China

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**Abstract**

Attribution to the poor engineering properties of Xigeda strata, landslides easily occur in the areas where it is distributed widely. Taking the Xigeda strata in Lamaxi Gully, Sichuan Province, China as object, the characteristics of its particles, minerals and soluble constituents were studied to analyze the weathering process and the landslide features. It is indicated that the soft lithology of Xigeda strata is significantly important to induce the geological disasters.

**Keywords:** Xigeda strata, Engineering property, Landslide

## 1. Introduction

The late Cenozoic Xigeda strata are distributed widely in southwestern China, such as in the valleys of Jinsha River and Anling River, Dadu River and Yabi River and so on. Xigeda strata mainly consist of gray-black, gray-green and gray-yellow claystone, silty claystone and siltstone.

The study area Lamaxi gully is in the Xigeda strata district, where mainly distributes the Tertiary Pliocene (N2) lacustrine depositional semi-solid soft rock with poor geological engineering properties. The pale and light yellow and silty sandstone and shale has significant differences with the general rock soil mass in engineering properties. Under the influence of the Jiuxiang fault zone, there are ubiquitous crusher rocks and erosion gully caused by the long term slope surface erosion. The gully is with large longitudinal gradient and incision depth of 30~40 m. The sidewall soils are relative loose so that it is prone to result in instability in the process of the gully bed down-cutting erosion. The expand trend to the gully head and sidewalls year by year would induce the retrogressive erosion and slope instability. Therefore, it is necessary to conduct the research for the engineering properties of Xigeda strata. Under the consideration of the geological factors which could affect the property of the Xigeda strata, the grain size, chemical composition and soluble salt were experimental studied to discuss their influences on the rock's engineering properties.

## 2. Analysis of the geological factors of the Xigeda strata

For the bearing capacity of rock mass, the Xigeda strata are relatively good bearing layer of foundation. However, it is worth noted that there are also some harmful geological factors, which can be classified into the following aspects:

1. Though Xigeda strata have experienced early diagenesis, their strength is still relatively lower than that of the other rocks in the previous geological time. Especially under the action of water, the bearing capacity and shear strength will be reduced significantly.
2. Attribution to the well-developed beddings in shale and mudstone of the Xigeda strata, the rocks are ease to collapse under wetting and drying cycles.
3. Because the (silty) sandstone and

mudstone are interbedded in Xigeda strata, there are some weak sedimentary structure planes. These structure planes and the contact interfaces between the Xigeda strata and overlying and underlying strata are the main ill-structured surface which could trigger landslide and collapse.

4. As the strong neotectonic movement in Panxi district, there are many fracture planes mainly consisted of fault and structural fissures. This will seriously affect the slope stability in Xigeda district.

## 3. Methods

In the study area, Xigeda strata are mainly composed of three sections. The lower stratum are lacustrine sediments, which mainly consist of sets of sedimentary rhythm containing yellow-grey and livid silt clay or fleshy red interbedded clay; the middle stratum are mainly black muddy-silt and sandy clay with clear horizontal bedding; the top stratum are mainly ochre thick sand layer with mica sheet. According to the field investigation, three Xigeda soil samples with different colors (Lmx-1, pale yellow; livid, Lmx-2; fleshy red, Lmx-3) were collected to be analyzed.

The grain size analysis was conducted by the hydrometer method and diffusion method. The settling velocity was calculated by the Stokes' equation. Chemical analyses were conducted with an X-ray fluorescence spectrometer (ARL Advant' XP). The soluble salts were determined by the hydrochemical analysis of the leaching solutions. 50~100 g soil samples were weighed to place in a jar. The weight depends on salt content and test project. Then the water at the ratio of 5:1 was added and stirring for about 5 min. When the salt content is as high as dozens of grams, the ratio of water to soil can be higher, but not over 20:1. The leaching solution was obtained by filtration after 12 hours. The following indexes for the leaching solutions are tested: alkalinity, carbonate, bicarbonate, calcium, magnesium, potassium, sodium chloride and sulfate ions.

## 4. Test results and discussion

### 4.1 Grain size

The results of grain size are shown in Table 1 and Fig. 1. It shows the grain sizes of three soil samples are mainly distributed in the scope of 0.075-0.005 mm, whose proportion is about 66%~85%; followed is the scope of 2-0.075 mm, whose proportion is about 10%~20%. The remaining grain sizes are all less than 0.005 mm.

Table 1 Result of the grain size

| sample number | 2-0.075（mm） | 0.075-0.005（mm） | <0.005（mm） |
|---|---|---|---|
| Lmx-1 | 10.7 | 84.1 | 5.2 |
| Lmx-2 | 19.6 | 66.3 | 14.1 |
| Lmx-3 | 12.1 | 84.5 | 3.4 |
| Average | 14.1 | 78.3 | 7.6 |

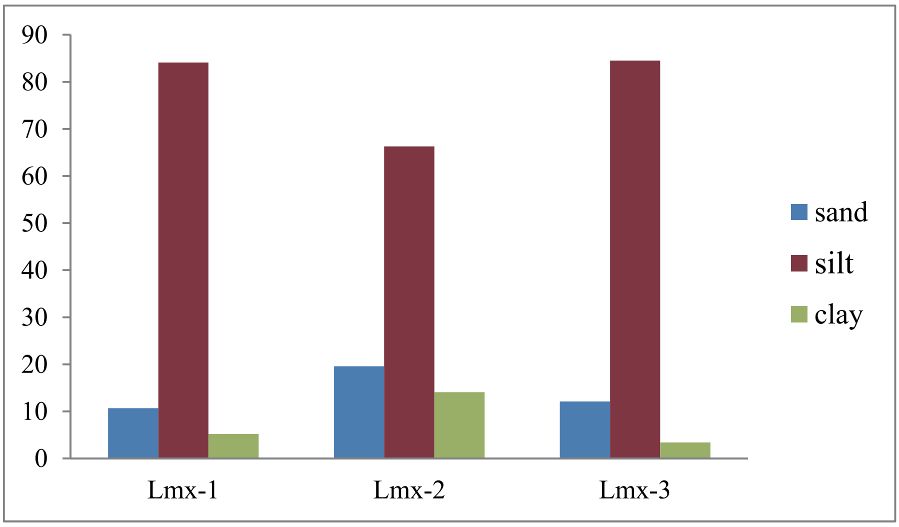


Fig. 1 The contrast of the grain size content

**4.1.1 Granularity and corrosion resistance**

It is reported that the resistance will increase with the grain size decreasing. As the grain size is homogeneous, the stability of the soil will be worse, vice versa. For the soils with more than 30% ~ 35% clay content, the cohesion is relatively higher and it could form stable soil crumb structure. This kind of crumb structure occupied higher resistance to raindrops hit and splash erosion (Kirkby and Morgan, 1987).

The average content of the sand of the Xigeda soil in the Lamaxi Gully is about 14.1%, while that of the silt is about 78.3% and that of the clay is about 7.6%. It is indicated the soil composition is mainly silt and relatively homogeneous. Thus, the loose structure will result in the weak anti-erosion capability.

**4.1.2 Mechanical properties of the grain**

The grain size has influence on the soil strength. Generally, the soil strength can be represented by the coulomb's law:

general soil: $\tau = c+\sigma \cdot tg\varphi$

sandy soil : $\tau = \sigma \cdot tg\varphi$

From the above equations, it shows the soil strength is not only relevant to the internal friction angle φ, but also to the cohesive force C at the condition of constant stress. The intensity curve is a line with intercept C on vertical axis (Fig. 2). When the grains become coarser, the cohesion value decreased gradually and the intensity curve (b) moves down along the vertical axis trending to the curve (a). When the cohesion value decreases to zero, curve (b) and curve (a) are overlap and their strength become equal. Meanwhile, the soil turns to be loose dry sand with low strength. It will be eroded and disintegrated immediately once being saturated with water.

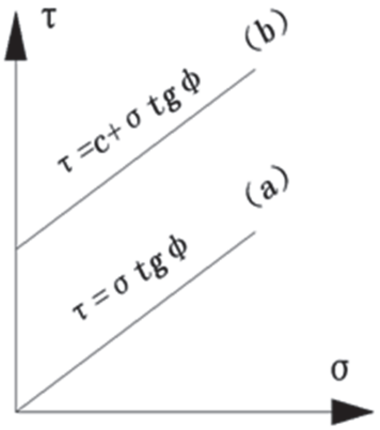


Fig. 2 Soil strength curve

In consequence, as the grain size is coarser it will cause smaller natural porosity and lower interparticle cohesion. Correspondingly, the stability and anti-erosion capability of the silty particles in the Xigeda soils are relatively weak in water.

**4.2 Chemical component**

Table 2 lists the analytical results of chemical composition. It shows the contents of each element oxides are similar in different samples. The content of SiO2 is in the range of 52.94%～62.98%, Al2O3 is 12.16%～15.22%, Fe2O3 is 4.78%～6.24%, MgO is 1.46%～2.87%. In Xigeda strata, the sum of instable chemical component contains Na2O, K2O and CaO occupied 3.64～10.82% of the total. Due to the active chemical properties of the soil, some soluble chemical compositions can migrate to cause local mineral enrichment or be taken away with water under a special hydrological and climatic conditions, such as Ca2+, Na+, K+ and so on. It will gradually enlarge the void among rock mineral and aggravate the intensity of chemical weathering, eventually lead to the destruction of the rock mass structure. The content of instable chemical compositions is relatively lower in Lmx-3 sample, presumably due to the result of the eluviation loss of the soil samples near the surface.

**4.2.1 Chemical weathering degree**

The chemical weathering degree is controlled by many factors, such as geographic and geomorphic conditions, lithology, climate features (rainfall), etc. Generally, it is identified by the CIA value and Na/K index of acid non-soluble substance. The bigger the CIA value is, the higher lever rock chemical weathering occupied, which suggests that feldspar corrosion is being gradually altered into clay minerals. CIA value is expressed as (Nesbitt and Young, 1982):

$$CIA = [Al_2O_3 / (Al_2O_3 + CaO + K_2O + Na_2O)] \times 100$$

Formula above is the mole ratio of the oxides. CaO represents the content in silicate minerals, but not include the content in carbonate and phosphate. It shows the average CIA value of Xigeda strata is 63.4, which is within the range of the quaternary glacial clay (Table 2). This value is slightly lower than that of shale (70-75), and far lower than that of residual soil (85-100). It indicates that the overall weathering resistance degree of Xigeda strata is relatively weak. But compared to the quaternary loess and paleosol, there are no significant differences among them, which reflecting that the Xigeda soil is still in the process of strong chemical weathering.

Na/K ratio is an index to evaluate the plagioclase weathering degree. It can also be used to represent chemical weathering degree of sediment. Because weathering rate of plagioclase is faster than potassium feldspar, Na/K ratio is inversely proportional to weathering degree and is on contrary of the changing characteristics of the CIA parameters. The Na/K value is close to loess and paleosol indicating the strong chemical weathering of Xigeda soil as well.

Table 2 Chemical composition comparisons among the Xigeda soil, Loess and Paleosoil (Chen et al, 2001)

| Lithology | Xigeda strata | | | | Loess | | Paleosoil | |
|---|---|---|---|---|---|---|---|---|
| NUM | Lmx-1 | Lmx-2 | Lmx-3 | Ave. | scope | Ave. | scope | Ave. |
| $SiO_2$ | 59.38 | 52.94 | 62.98 | 58.43 | 63.83～69.47 | 66.4 | 63.20～67.97 | 65.18 |
| $Al_2O_3$ | 12.16 | 13.635 | 15.215 | 13.67 | 13.14～15.04 | 14.2 | 13.96～15.51 | 14.79 |
| $Fe_2O_3$ | 4.775 | 5.98 | 6.24 | 5.67 | 4.18～5.50 | 4.81 | 4.66～5.54 | 5.12 |
| CaO | 6.7 | 6.905 | 0.68 | 4.76 | 0.87～1.22 | 1.02 | 0.57～0.95 | 0.83 |
| MgO | 2.195 | 2.87 | 1.46 | 2.18 | 1.99～2.60 | 2.29 | 1.86～2.60 | 2.21 |
| $K_2O$ | 2.255 | 2.58 | 2.565 | 2.47 | 2.62～3.23 | 3.01 | 2.56～3.35 | 3.15 |
| $Na_2O$ | 1.51 | 1.33 | 0.395 | 1.08 | 1.32～2.03 | 1.66 | 1.03～1.79 | 1.41 |
| $TiO_2$ | 0.665 | 0.765 | 0.9 | 0.78 | 0.67～0.79 | 0.73 | 0.72～0.78 | 0.75 |
| MnO | 0.0855 | 0.12 | 0.11 | 0.11 | 0.05～0.09 | 0.07 | 0.06～0.09 | 0.08 |
| $P_2O_5$ | 0.165 | 0.21 | 0.04 | 0.14 | 0.12～0.18 | 0.15 | 0.09～0.14 | 0.11 |
| CIA | 53.75 | 55.77 | 80.69 | 63.40 | 62.93～68.56 | 65.46 | 65.99～69.71 | 67.99 |
| Na/K | 66.96 | 51.55 | 15.40 | 44.64 | 50.38～62.85 | 55.15 | 40.23～53.43 | 44.76 |
| $SiO_2/R_2O_3$ | 1.95 | 1.54 | 2.28 | 1.89 | 2.26～2.56 | 2.38 | 2.21～2.48 | 2.29 |

#### 4.2.2 The stability of anti-erosion

$SiO_2/R_2O_3$ index is commonly used to indicate the anti-erosion stability of the soil (Wang et al, 2001). $R_2O_3$ represents the oxides except $SiO_2$. The bigger the value of $SiO_2/R_2O_3$ is, the weaker the stability of anti-erosion is. From the result in Table 2, the value of Xigeda soil is 1.54~2.28; the loess is 2.26~2.56; the paleosol is 2.21~2.48. It is suggested that the anti-erosion stability of the Xigeda soil is similar to that of the loess and the paleosol. Thus, we can apply some scientific research achievements of loess erosion to the study of Xigeda soil.

#### 4.2.3 The relationship between the chemical composition and the shear strength

The ability of the rock to bear the shearing force is called the shear strength. The shear strength of the rock consists of two parts, the cohesion (*C*) and the internal friction resistance ($\sigma \cdot tan\varphi$), which are related to the strong connection of rock. When the gravity or its component imposed to the rock mass in a slope is greater than the residual shear strength, the gravitational erosion phenomenon like collapse occurs.

(1) Analysis of the rock mass stress

Collapse is one of the main gravitational erosion type. Gravitational erosion occurs when different weathering degree leads to different erosion rate, and the overlying strata is hanging. For the gravitational erosion of sandstone, there are two different directional forces on the rock mass before collapsing: one is the vertically gravity and the other is shearing force. Under this circumstance, $\tau = C + \sigma \cdot \tan\varphi$, $\sigma=0$. It indicates there is no stress upon the free face. So, T=C. When C is greater than the gravity of rock mass, collapse won't happen. On the contrary, collapse occurs. Therefore, based on the force analysis, the gravitational erosion is related to value of the rock's cohesion.

(2) The relationship between the chemical composition and cohesion

The data from the factor correlation analysis of the chemical composition and the cohesion suggested that cohesion increases with the increase of $Fe_2O_3$ .MgO, MnO ,$Na_2O$ and FeO in the rock mass, and decreases with the increase of $K_2O$, CaO and $SiO_2$ (Ye et al, 2006). The characteristics of correlation analysis show that different chemical composition has different effect degree on the cohesion. The correlation has significant difference in linear correlation or non-linear correlation, which shows that different chemical composition has independent effect on cohesion. Although the test result only denotes the total content of certain chemical compositions, the result reflects the relationship between the cohesion and the chemical composition of the rock to a certain extent. The content of $Fe_2O_3$, MgO, MnO, $Na_2O$ of Xigeda soil comprised 8.02%~10.3% of the total amount of chemical constituents while the content of $K_2O$, CaO and $SiO_2$ comprised 62.43～68.34, which indicates the cohesion of Xigeda soil is comparatively low.

### 4.3 Composition of soluble salt

Soluble salt refers to the salt easily dissolved in water, including all chloridum, potassium sodium sulfate and potassium sodium carbonate. This test is applicable to various types of soil whose grains are less than 2 mm. The soil with grains greater than 2 mm must be sieved out before, and parallel determination should be adopted. The analytical results of soluble salt test are shown in Table 3:

Table 3 Analytical results of the soluble salt

| Samples | pH | $CO_2$ | $HCO_3^-$ | $CO_3^{2-}$ | $Cl^-$ | $SO_4^{2-}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^++K^+$ | total hardness | total salinity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lmx-1 | 8.90 | 0.21 | 1.54 | 0.00 | 0.06 | 0.86 | 0.42 | 0.13 | 0.20 | 54.79 | 203.00 |
| Lmx-2 | 8.63 | 0.10 | 2.23 | 0.00 | 0.09 | 0.25 | 0.46 | 0.40 | 0.19 | 86.39 | 148.59 |
| Lmx-3 | 8.56 | 0.21 | 1.34 | 0.00 | 0.06 | 0.90 | 0.20 | 0.22 | 0.16 | 42.14 | 196.81 |

Note: The unit of ion concentration is mmol/L; the unit of hardness and salinity are mg/L.

In general, leaching deformation is closely related to the long-term immersion of soluble salt in soil. The results in Table 3 show that the contents of soluble salt are low, with a value of about 4.01 mmol/L. The positive ion content is about 0.79 mg/100g, of which $Ca^{2+}$ and $Mg^{2+}$ occupy the major content which indicates them the main loss of ions in Xigeda soil. Referring to previous study (Kong and Li, 2001), the leaching deformation is small when the content of soluble salt is less than 90 mg/100g. As the content of soluble salt is greater than 90 mg/100g, the leaching deformation will increase significantly. Based on the test data, Xigeda soil has leaching deformation in a certain extent.

Table 4 Substituted quantity computation sheet of the cations

| Samples | $Ca^{2+}$ | $Mg^{2+}$ | $Na^++K^+$ | Cation exchange capacity | ESP（%） |
|---|---|---|---|---|---|
| Lmx-1 | 0.042 | 0.013 | 0.020 | 0.075 | 27 |
| Lmx-2 | 0.046 | 0.040 | 0.019 | 0.105 | 18 |
| Lmx-3 | 0.020 | 0.022 | 0.016 | 0.058 | 28 |

Note: the unit is cmol/kg. ESP is potassium and sodium percentage of the exchanged cations.

The soil with an ESP value ≥ 15% is called high dispersal soil, which leads to erosion easily. Encountering with water, this kind of soil is easily to be dispersed and taken away. The exchanged amount of the cations can be calculated from unit conversion in the dilute solution. The Table 4 shows the ESP value of Xigeda soil is 18%～28%, which belongs to high dispersal soil. The poor physicochemical property further illustrates the weak erosion resistance.

In brief, the content of soluble salt has significant effects on soil loss. The Xigeda soil in Lamaxi valley contains a certain amount of soluble salt, which is easily to be dissolved and decrease the cohesion under the influence of water. Thus, the amount of soluble salt is a significant factor in soil erosion and soil loss on slope surface.

## 5. Conclusion

The serious headward erosion is closely associated with the geotechnical characteristics of the Xigeda strata in our study area. The shearing resistance is affected by the mineralogical and chemical compositions as well as the rock structures in the erosion process. The grain size and chemical compositions of the rocks are the internal factors impact on the rock's strength. Furthermore, the soluble salt and clay mineral are the primary cause of strength reduction.

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