Physical and Mechanical Properties of Pisha Sandstone with Different Corlors in Ordos Plateau

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Abstract: Pisha sandstone with different colors is widely distributed in Ordos Plateau, showing different engineering properties. Therefore, basic physical and mechanical properties of two kinds of common Pisha sandstones with different colors (purplish red and yellow) are studied through laboratory tests. Because of the capillary pressure in the soil, the shear resistance of Pisha sandstone will increase first and then decrease with the increase of water content; when the water content is nearly saturated, the shear strength indexes of two Pisha sandstones are significantly reduced.

1. Introduction
Arsenic sandstone is continental elastic rock widely distributed in Ordos Plateau. It mainly consists of mudstone and siltstone. It has certain particularities. Spalling and sliding which easily occur in the rock stratum are related to its physical characteristics. And the study on its physical properties will also be taken as reference for the protection of rock mass and infrastructure construction in the area of arsenic sandstone. Therefore, many scholars at home and abroad have studied physical and mechanical properties of arsenic sandstone. Among them, Tan et al. [1-2] analyzed the microstructure and material composition of mudstone and red sandstone by scanning electron microscope (SEM) and X-ray diffraction. Ren et al. [3-5] studied the microcosmic mechanism of soft rock softening and disintegration in details and found that soft rock disintegrated mainly due to the comprehensive functions from water absorption and expansion and disintegration mechanism of clay minerals, exchange and adsorption of ions, dissolution of soluble matters and formation of minerals, micromechanics mechanism of soft rock and water, non-linear chemical dynamics mechanism of the softening of soft rock, etc. The spalling and disintegration of rock mass are closely related to water content. A great number of studies show [6-15] that water content is the main factor affecting the mechanical strength of soil. This is similar to arsenic sandstone. Besides, the climate in the main distribution area of arsenic sandstone is changeable. Due to its features such as easy weathering, poor cementation and strong water sensitivity, it is necessary to master the basic physical and mechanical properties of the soil of arsenic sandstone along the infrastructure construction area and its influencing factors. Based on this, this paper has analyzed and studied the mechanical property at different water content and under different confining pressure of arsenic sandstone, which has certain reference value to the design and construction of subgrade and pavement of arsenic sandstone.
2. Analysis on characteristics of particle size and mineral elements of arsenic sandstone

The arsenic sandstone in this test is collected from the distribution area of arsenic sandstone, which is located in Hantai Town, Dongsheng District, Ordos City, Inner Mongolia. Yellow and purplish red arsenic sandstones are mainly distributed in this area.

2.1 Analysis on features of particle size of arsenic sandstone

As soil is formed when arsenic sandstone is weathered, the basic physical properties of two kinds of arsenic sandstone particles are tested according to GB/T 50123-2019 Standard for Geotechnical Testing Method [16]. The particle size distribution is analyzed through the sieving method and the natural density is derived through sealing with wax. The particle analysis curve of yellow and purplish red arsenite sandstone is shown in Fig. 1. Relevant particle size analysis parameters are shown in Table 1. The basic physical indexes of arsenic sandstone can be seen in Table 2.

![Particle size distributions](image)

**Figure 1.** Particle size distributions.

| Particle size range Type | d<0.1 | 0.1<d<0.25 | 0.25≤d<0.5 | 0.5≤d<1 | d≥1 | Uneven coefficient Cu | Curvature coefficient CC | Fineness module number MX |
|-------------------------|-------|-------------|-------------|---------|-----|-----------------------|-------------------------|--------------------------|
| Yellow                  | 8.5   | 21.9        | 35.2        | 25.2    | 3.5 | 5.41                  | 1.35                    | 1.83                     |
| Purplish red            | 5.1   | 47.2        | 36.2        | 10.1    | 0.6 | 3.11                  | 1.02                    | 1.24                     |

| Sandstone type          | Natural density ρ/(g•cm⁻³) | Natural water content ω₀/ % | Saturated water content ω₁/ % | Porosity n/ % | Permeability coefficient k/cm•s⁻¹ | PH |
|-------------------------|-----------------------------|-----------------------------|-----------------------------|---------------|-------------------------------|----|
| Yellow                  | 2.75                        | 7.65                        | 16.7                        | 36.15         | 6.5×10⁻³                      | 7.8|
| Purplish red            | 2.83                        | 8.54                        | 18.3                        | 31.86         | 5.2×10⁻³                      | 8.3|

According to GBJ145-90 Standard for Classification of Soil [17] and SL 237-1999 Code for Soil Tests [18], two kinds of arsenic sandstone are fine-grained soil sand (SF). These two soil samples are poor-graded materials. In the engineering application, an appropriate amount of sticky particles are added into two kinds of arsenic sandstone so that the fine particles are more adequately filled in the gap formed by coarse particles, the particle size of rock and soil is more evenly distributed and filled materials among particles are more dense, so as to reduce the compressibility of particles of arsenite sandstone and improve the compactness and permeation stability.
2.2 Analysis on mineral elements of arsenic sandstone

X-ray diffraction (XRD) is used to analyze the mineral composition of yellow and purplish red arsenite sandstone in order to study it, and XRD data are processed by Jade software. K-value method is applied for phase semi-quantitative analysis. The diffraction results are shown in Fig. 2 and Fig. 3 and the mineral composition is shown in Table 3. It can be seen that the mineral composition of arsenic sandstone in Fig.2 is consistent. The main primary minerals are quartz and feldspar, and the content of feldspar, chlorite and montmorillonite is very approximate. The content of calcite, illite and ferrodolomite in purplish red arsenic sandstone is much higher than that in yellow arsenic sandstone. And the content of quartz in yellow arsenic sandstone is much higher than that in purplish red arsenic sandstone. The grading curve of arsenic sandstone in Fig.1 indicates that one of the reasons that fine sand of purplish red arsenite sandstone is more than that of yellow arsenite sandstone is that purplish red arsenite sandstone lacks original mineral, compared with yellow arsenite sandstone. However, the research on the arsenic sandstone by some scholars [19] shows that the content of quartz of mature sandstone is commonly more than 75%. Thus, it can be judged that the maturity of arsenic sandstone in this area is relatively low.

![Diffraction Patterns](image)

(a) Yellow  (b) Purplish red
1. calcite 2. quartz 3. clinochlore 4. albite 5. potassium feldspar 6. montmorillonite 7. illite 8. Ferridolomite

Figure2. diffraction pattern of Pisha sandstone.

| Mineral composition type | Quartz | Calcite | Albite | Potassium feldspar | Chlorite | Illite | Montmorillonite | Ferridolomite |
|-------------------------|-------|--------|-------|-------------------|---------|-------|----------------|--------------|
| Yellow arsenite sandstone | 34.75 | 11.80 | 19.79 | 2.01              | 4.45    | 12.93 | 7.87           | 4.52         |
| Purplish red arsenite sandstone | 9.58 | 30.76 | 18.06 | 3.19              | 3.84    | 16.34 | 7.88           | 10.19        |

Moreover, the diffraction pattern of arsenic sandstone in Fig. 2 indicates that the diffraction intensity of purplish red arsenic sandstone quartz is far higher than that of yellow arsenic sandstone, so the crystallinity of its quartz is higher and the development is better. As other minerals are not crystallized, it is difficult to present it on the XRD graphics, so except above mineral elements, the peaks of other minerals are not obvious [20]. In the tested mineral elements, quartz is a mineral resource with stable physical and chemical properties. Calcite is active in chemical property. Due to the role of water erosion, calcite reacts with H2O and CO2 in cracks and pores of rock mass, which can generate soluble Ca (HCO3)2. Then, it dissolves and loses, which damages rock structure. However, when weathering and erosion occur in the area of arsenic sandstone, the fine particles formed by weathering and decomposing...
rock are selectively taken away by rainwater runoff. Although there are still large quartz particles, it is possible that the runoff on the surface of earth can directly wash away the loose arsenic sandstone particles due to the gradual reduction of vegetation coverage. And under the influence of local climate and natural conditions, the feldspar which is easily weathered will make the arsenic sandstone become weaker, whose cementing property is originally poor. Rock mass is collapsed and decomposed, and then it completely loses the capacity to resist the current scour, which will further lead to the loss of water and soil. This is also the main reason that in the lower and middle reaches of the Yellow River, coarse sediment is accumulated and the riverbed is deposited and lifted, which causes barren land and floods. However, due to high content of calcite and low content of quartz whose chemical property is stable in purplish red arsenite, natural disasters such as landslides and collapses occur more easily, compared with yellow arsenite sandstone mass. In addition, the engineering practicability is not strong in the construction application.

2.3 Analysis on chemical components of arsenic sandstone

X-ray fluorescence emission spectrum analyzer (XRF) whose emission target is Cu Kα is used to analyze oxide components of 2 soil samples in order to further study the probable influence of chemical components of arsenic sandstone on its physical and mechanical properties. The analysis results are shown in Table 4.

| Arsenite sandstone | SiO2 | Fe2O3 | Al2O3 | CaO | Na2O | K2O | MgO | TiO2 |
|--------------------|------|-------|-------|-----|------|-----|-----|------|
| Yellow             | 64.04| 4.33  | 20.08 | 3.82| 2.98 | 1.56| 1.96| 0.23 |
| Purplish red       | 58.62| 12.73 | 17.27 | 3.9 | 2.02 | 1.95| 2.65| 0.89 |

It can be seen from Table 4 that there is no difference in the oxide components between yellow and purplish red arsenite sandstone, of which the mass percentage of SiO2 is the largest, followed by the mass percentage of Al2O3. The mass percentage of the rest oxide components are mostly below 10%. The obvious difference is the content of Fe2O3. The mass percentage of Fe2O3 in the purplish red arsenite sandstone is far higher than that in the yellow arsenite sandstone. According to the diffraction results in Table 3, the content of ferrodolomite in the purplish red arsenite sandstone is also higher than that in the yellow arsenite sandstone. Among them, ferrodolomite is the mineral in the isomorphous series, which is formed when Fe2+ in the components of dolomite is more than Mg2+. Its structure is basically composed of calcium carbonate and different amounts of iron, magnesium and manganese [21]. Most of the Fe ions in arsenic sandstone exist in the form of FeO. The proportion of the content of Fe is more or less directly related to the colors of soil sample. The larger the content of Fe is, the darker the soil particles will be. Therefore, different content of Fe2O3 is the main reason for the color difference between the two kinds of arsenic sandstone. The low-valence chemical components of Fe2+, Mg2+, etc. can easily become high-valence ionic elements under the condition of acid medium, e.g. turning from Fe2+ to Fe3+. Due to the change of chemical elements, it can also lead to the instability of arsenic sandstone easily, which makes the weathering and balling of rock mass even worse [22]. Although the content of CaO, K2O and Na2O in arsenic sandstone is low, their properties are active and they extremely easily react with water and other substances, which leads to the change of internal structure. This is one of the influencing factors of weak weathering and erosion resistance for arsenic sandstone. As the weathering and erosion in the natural environment are further aggravated, arsenic sandstone will be semi-weathered into rock debris, and the content of organic matters and nutrient elements in the soil decreases sharply, leading to the loss of soil fertility [23]. Therefore, the existence of active oxides in the arsenite sandstone has changed the mechanical property of arsenite sandstone, resulted in the decline of its strength and rigidity. Thus, arsenite sandstone cannot be directly applied to the actual construction project.
3. Study on mechanical properties of arsenic sandstone

3.1 Compaction property of arsenic sandstone
According to the Test Methods of Soils for Highway Engineering (JTG E40-2007)[24], indoor light compaction method is adopted to carry out compaction test on two kinds of arsenic sandstone. The small compaction cylinder is selected for the test, and the arsenic sandstone soil sample which is prepared in advance is divided into five layers and filled into the compaction cylinder. Each layer is filled and compacted for 27 times. Refer to Table 2 for basic physical property indexes of arsenic sandstone and Figure 3 for compaction curve.

![Compaction curve of Pisha sandstone.](image)

From Fig.3, it can be concluded that the maximum dry density of yellow and purplish red arsenic sandstone is 1.95 g/cm³ and 1.83 g/cm³ respectively, and the corresponding water content is 12.6% and 13.7% respectively. The content and distribution of coarse particles in arsenite sandstone have a great influence on the compactability of arsenite sandstone. During the compaction process, the coarse particles contact with each other and the gap is filled by fine particles. Besides, the gap is filled by the coarse particles which are crushed during the test or fine particles produced when particles squeeze and wear each other during the compaction. Therefore, it can achieve high dry density. According to the analysis parameters of grading curve and particles, the particle size distribution of purplish red arsenic sandstone is too centralized and the distribution of particle size of yellow arsenic sandstone is relatively even, so it is difficult to compact it. Then it can achieve larger dry density.

3.2 Shearing character of arsenic sandstone
In order to measure the shearing resistance of remolding specimens of two kinds of arsenite sandstone, the paper adopted the strain-controlled direct shear apparatus to carry out equal strain shearing experiment and analyzed the change rule of shearing strength of the specimens under the influence of different normal pressure and different water content. The dry density of specimens of two kinds of arsenite sandstone is controlled at 1.85g/cm³ according to practical projects. The influence of water content on shearing strength and its parameters is shown in Fig. 4 to Fig. 6.
Figure 4. Effect of vertical stress on shear strength of Pisha sandstone under different water cuts

Figure 5. Shear strength of water content on purplish Pisha sandstone under different vertical stresses

Figure 6. Curve of water content on shear resistant criteria of Pisha sandstone.
As can be seen in Fig. 6, as water content increases, the shearing strength indexes of two kinds of arsenic sandstone increase at first and then decrease in the form of parabola, because when arsenic sandstone is not saturated, there is water and air existing in the interstice of particles at the same time, and there is capillary tension at the interface between water and air. The arsenic sandstone is pressed, which leads to the increase of friction among particles and then the increase of friction. And the function of capillary tension makes arsenic sandstone particles stick together temporarily. Then cohesion increases. The cohesive action is different from that of sticky soil. As the space of arsenic sandstone particles is filled with water or the moisture is evaporated and dried, arsenic sandstone becomes granular mixtures. The capillary tension among particles will disappear as capillary water reduces, because there is certain cohesion function among slightly wet sandstone particles. Due to the softening effect of water to the arsenic sandstone particles, the shearing resistance of arsenic sandstone specimen decreases. The water has an obvious lubricating effect on arsenic sandstone particles which exist as cementing substance. Along with the increase of water content, the softening and lubricating effect becomes more and more obvious. Water will change the original cementation bond among arsenic sandstone particles into hydrogel bond, so that the connection force among arsenic sandstone particles is weakened and mutual friction is reduced. Therefore, the internal friction angle and cohesive force continue to decrease as water content increases. Moreover, due to the physical characteristics of the purplish red arsenolite sandstone itself, there are more mineral elements that easily produce chemical reaction. Therefore, the shearing resistance of the purplish red arsenolite sandstone decreases more quickly under higher water content. Under the same test conditions, the internal friction angle of arsenic sandstone is similar to that of other different types of sandy soil, the influence of which on its shearing resistance is basically identical [25].

Based on the above experimental study, it can be found that the arsenic sandstone at Hantai Town in Dongsheng Diamond can achieve larger shearing strength when the water content falls between 11% and 13%. Therefore, if the arsenic sandstone is directly used as subgrade filler, it is suggested to ted arsenic sandstone at first, so that its water content can reach the optimum moisture content. And then compact subgrade soil, which can improve the strength of arsenolite sandstone. However, Wu [26] found that the compressive strength and frost resistance of arsenic sandstone increased significantly when it was maintained by mixing less than 20% cement in the arsenic sandstone for 28 days. Li [27] found during his study on composite materials of arsenic sandstone that when arsenic sandstone was mixed with fly ash and mineral powder under alkali environment, its shearing strength was significantly enhanced. Therefore, appropriate amount of cement, fly ash and mineral powder can be added in arsenolite sandstone to enhance its engineering property.

4. Conclusion
(1) The yellow arsenic sandstone in Ordos area belongs to rock soil with good gradation, the purplish red arsenic sandstone is rock soil with poor gradation and the yellow arsenic sandstone is the rock soil with good gradation. Its particle size is even distributed, so it can achieve larger dry density and compactness.

(2) XRD and XRF diffraction results indicate that the main primary minerals of the two kinds of arsenic sandstone are quartz and feldspar. Due to the lack of primary minerals in the purplish red arsenic sandstone, there are more fine sand grains. The difference of the content of Fe2O3 leads to the difference of the color of two kinds of arsenic sandstone. In addition, the existence of active oxides in properties is an important factor that leads to the decrease of strength and rigidity of arsenic sandstone.

(3) The results of direct shearing test indicate that the shearing strength of two kinds of arsenic sandstone increases linearly as normal pressure increases, and increases in the form of a convex parabola as water content increases. When water content is nearly saturated, the shearing strength of two kinds of arsenic sandstone both decreases significantly.
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