# 短期滞在型共同研究（ 課題番号：29S-04 ）

課題名：中国三峡ダム貯水池におけるジュラ紀泥質軟弱層のせん断抵抗の低下および地すべり発生機構について
(Strength deterioration of muddy weak layer in Jurassic strata and initiation of landslide in the Three Gorges Reservoir, China)

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滞在場所：　防災研究所・斜面災害研究センター
共同研究参加者数：　3 名 (所外 1 名，所内 2 名)
・大学院生の参加状況： 4 名（修士 2　名，博士 2 名）（内数）
・大学院生の参加形態　[　実験の共同実施とデータ解析　　　　　]

研究及び教育への波及効果について

中国三峡ダム貯水池におけるジュラ紀泥質軟弱層のせん断抵抗の変化特性を調べて，ダム湛水位の変化に伴うその地すべりの発生・運動機構を明らかにした．このことは、山峡ダム地域だけではなく，他のダム貯水池における地すべりの防災に大いに資すると考えられる．また，大学院生と一緒に実験を実施し，実験データを解析するとともに，地すべりの運動機構についての検討をもおこなった．実験方法やデータ解析および論理的な分析などについて学ぶよい機会となったと思われる．

研究報告

(1)目的・趣旨

Deterioration of shear strength of weak layer in a slope is one of the primary reasons for landsliding. The causes of deterioration in shear strength of weak layer are keys to understand landslide mechanism. From the lithology structure of the Jurassic strata in the Three Gorges Reservoir (hereafter called TGR) in China, the interbedding layer of thick silty-sandstone and thin sandy-mudstone is an important reason for the development of weak layer with a high content of clay mineral like montmorillonite and illite in the long geological history (Jian et al., 2008). Investigating the mechanism of strength deterioration of muddy weak layer in Jurassic strata can provide an insight into the development of slip surface. Up to now, many studies had been performed on the landslides occurring in the Jurassic strata in the TGR area with focus on examining the geological basis (say, possible clay mineral in the weak bands of potential sliding surface) (Li et al., 2007; Wen et al., 2007; Jian et al., 2009). However, the mechanism of strength deterioration of muddy weak layer, especially in the case of changing of slope hydrological conditions caused by seasonal rainfall and periodic reservoir water level fluctuation, is not yet well understood. Therefore, our research findings may provide some evidence in the evolution of slip surface and also the initiation mechanism following the outside inducing factors.

(2)研究経過の概要

In the present research, we concentrate on the mechanism of strength deterioration of muddy weak layer from the perspective of drying-wetting cycle. We took the samples from rock outcrops of reservoir slope in Jurassic strata in the TGR and divided them into four parts. The first part is the sample without any wetting-drying cycle (hereafter initial sample), and the other three parts underwent 5, 13, and 21 times of cyclic wetting and drying. In each cycle the sample was soaked in the water for two days firstly and then was put into the oven for two days with a constant temperature of 105 ℃. After the cycles of drying-wetting, the sample was used to perform the ring shear tests including shear creep test, undrained shearing test and shear rate effect test in drained condition.

(3)研究成果の概要

- **Shear creep behaviors**

We performed the shear creep tests using the four samples above with the same shear stress of 140 kPa and normal stress of 300 kPa by means of No. 5 ring shear apparatus in DPRI. The applied shear stress and normal stress were calculated according to the location of the slip surface of the landslides in Jurassic strata in the TGR (Miao et al., 2014). The average depth of the slip surface is 15 m, the average gravity density is 22 kN/m$^3$, and the average slope angel is 25 degrees. Figure 1 plots the shear displacement of the four samples versus time in the shear creep tests in drained condition. As shown in figure 1 we can find that the initial sample has the largest creep displacement, whereas the sample with 21 cycles of drying-wetting has the smallest one. Due to the disintegration of the sample from muddy weak layer, many times of cyclic drying-wetting could make the initial sample into the sample with a lot of fine soil particles. Under the same applied shear stress and normal stress, the relative movement of soil particles determines the shear creep displacement. In general, the movement between coarse particles is easier than the movement between fine particles.

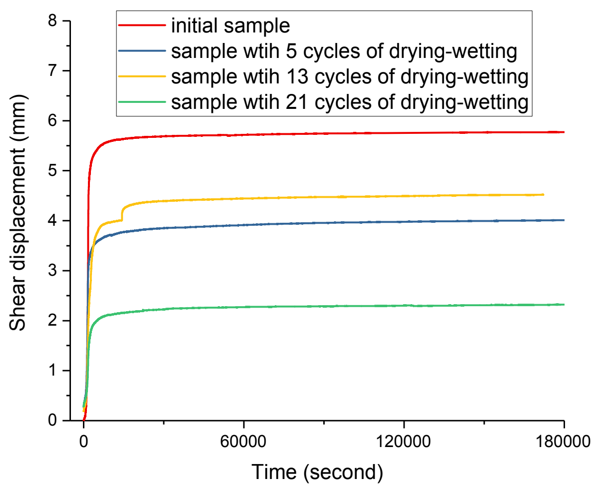


Figure 1 Shear creep displacment versus time for the samples with different times of cyclic drying-wetting with the shear stress of 140 kPa and normal stress of 300 kPa.

- **Undrained shear behaviors**

Figure 2 presents the undrained shear behaviors of the four samples with the total normal stress of 300 kPa in undrained condition. Figure 3 reveals the relationship between the number of drying-wetting cycles and the shear strength ratio for the four samples. Here the peak or residual shear strength ratio is defined as the ratio of peak or residual shear strength to effective normal stress respectively. We can find that both the peak shear strength ratio and residual shear strength ratio have a small increase with the increasing of the number of cycles of drying-wetting.

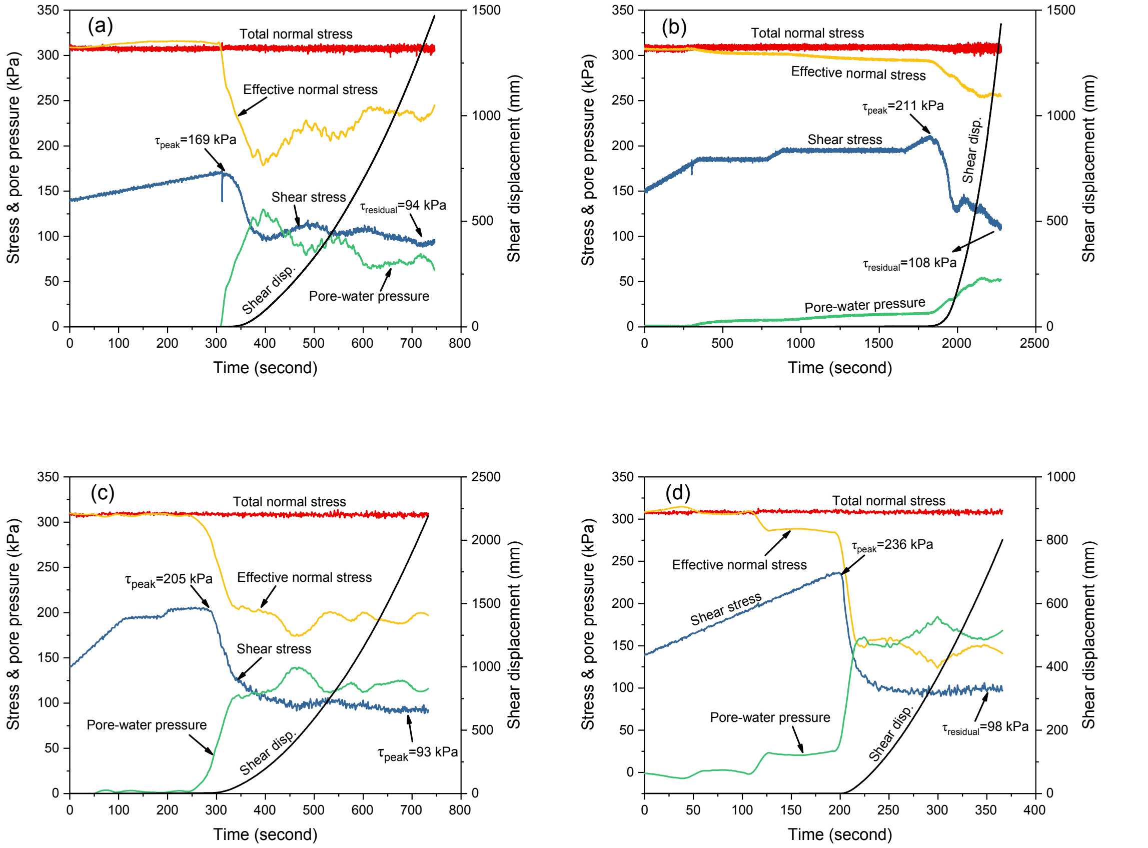


Figure 2 Undrained shear behaviors for the samples with different times of cyclic drying-wetting with the total normal stress of 300 kPa. (a) initial sample, (b) sample with 5 cycles of drying-wetting, (c) sample with 13 cycles of drying-wetting and (d) sample with 21 cycles of drying-wetting.

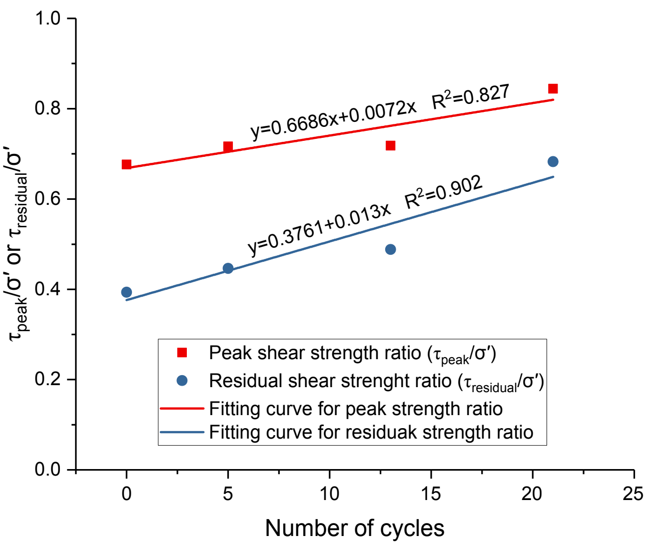


Figure 3 Shear strength ratio for the samples with different times of cyclic drying-wetting

- **Residual shear strength envelope**

We performed the ring shear tests on three samples, i.e. sample with 5, 13 and 21 cycles of drying-wetting, to get the residual shear strength envelope. All the three samples were in drained condition at the same shear rate of 0.001 cm/s. Figure 4 presents the shear stresses of the three samples above at the normal stress of 300 kPa, 350 kPa, 400 kPa and 450 kPa. The linear fitting curves show that with the increasing of number of drying-wetting cycles the cohesive force increases whereas the internal friction angle decreases. There is a significant increase of the cohesive force for a large number of cycles of drying-wetting. Cyclic drying-wetting on the muddy weak layer of Jurassic strata can make the large particle to a smaller one, which further causes a stronger cohesive force between soil particles due to the electrification of clay minerals (Di Maio et al., 2015). Meanwhile, the smaller soil particles bring the smaller interparticle friction during the shearing. However, as a whole the residual shear strength increases after a large number of cycles of drying-wetting.

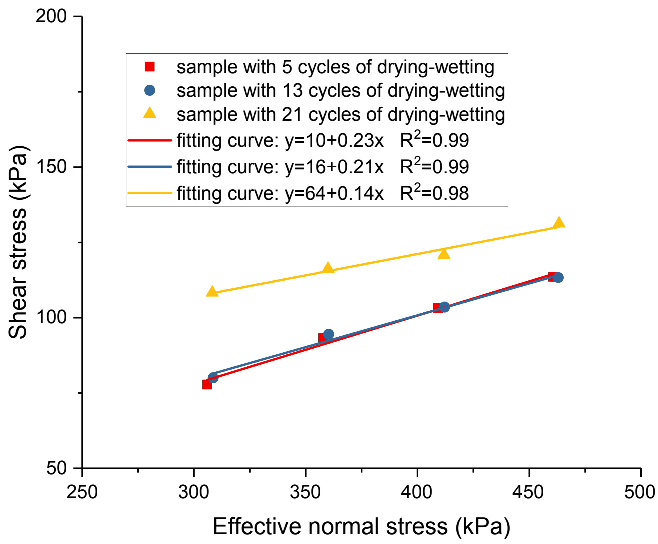


Figure 4 Residual shear strength envelope for the samples with different times of cyclic drying-wetting

- **Shear rate effect on the residual shear strength**

The test of shear rate effect on the residual shear strength was not conducted for the initial sample without cyclic drying-wetting. Figure 5 plots the residual shear strength at different shear rate for the sample with 5, 13 and 21 cycles of drying-wetting in drained condition with the same normal stress, respectively. The results show that there is a negative effect on the residual shear strength when the shear rate is less than 0.01 cm/s, whereas a positive effect when the shear rate is more than 0.01 cm/s. For the same shear rate the residual shear strength of the sample with 21 cycles of drying-wetting is significantly larger than the other two samples. That means it is impossible for the landslide in Jurassic strata in the TGR have a large sliding speed after the failure. This inference can provide the evidence for a lot of slow moving landslides in Jurassic strata in the TGR (Miao et al., 2014).

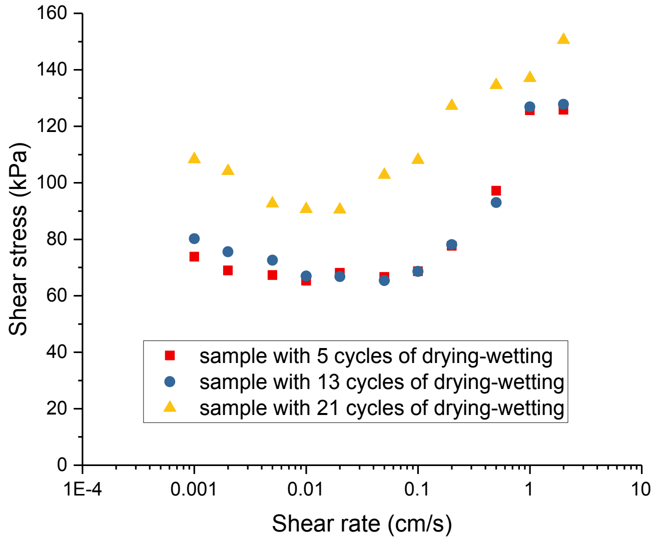


Figure 5 Shear rate effect for the samples with different times of cyclic drying-wetting at the normal stress of 300 kPa in drained condition

(4)研究成果の公表

Now the relevant paper is in writing.