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# Cyclic response and modeling of saturated silty clay due to fluctuations in reservoir water level of the Three Gorges Dam, China

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**Abstract**

The deformation characteristics of soil obtained from landslides at the Three Gorges Dam Reservoir have been examined. Due to the annual fluctuation in the water level of the reservoir, landslides around the Three Gorges Dam Reservoir are subjected to cyclic loading. Laboratory triaxial tests have been carried out on silty clay specimens subjected to cyclic changes in pore water pressure. The test results indicate that when the soil is subjected to repeated unloading–reloading with constant deviatoric stress in an overconsolidated state, the silty clay material shows inelastic deformation with the accumulation of irrecoverable strain. To capture this behavior, a constitutive model has been developed to simulate the deformation induced by changes in pore water pressure. This model is based on a modification of Yao et al. (2009)'s model to include the effect of cyclic loading. The model has been used to calculate the shear strain during cyclic loading and for a comparison with the laboratory test results. It has been shown that the proposed model is capable of capturing the deformation response of landslide soil subjected to changes in pore water pressure caused by the fluctuating water level of the reservoir.


*Keywords:* China Three Gorges Dam; Landslides; Reservoir water level fluctuations; Cyclic loading; Constitutive modeling of soil; Mechanical behavior of soil

## 1. Introduction

The effects of fluctuations in reservoir water levels on the stability of partially submerged slopes have long been the subject of investigation in landslide studies, especially under rapid drawdown conditions (Morgenstern, 1963; Desai, 1997; Lane and Griffins, 2000). Field observations have indicated that changes in pore water pressure comprise the main factor influencing slope stability (Rinaldi et al., 2004; Wang et al., 2008). Extensive studies using scale model experiments and numerical simulations have been carried out to examine and identify the controlling variables, such as the soil permeabilities under saturated and unsaturated conditions, the soil strength, the slope geometry, the rate of water level drawdown, and the initial pore-water pressure distribution (Zhang et al., 2005; Jia et al., 2009; Viratjandr et al., 2006; Berilgen, 2007; Zhou et al., 2012; Paronuzzi et al., 2013; Liu and Li, 2015).

The Three Gorges Dam is located in Yichang, China. It is the largest water conservation and power generation project in China. Under the normal operation of the dam for flood control of the Yangtze River and optimum power generation, the reservoir water level fluctuates annually between elevations of 145 m and 175 m. Since the completion of the dam and the commissioning of the power generators in 2003, more than 5,000 km along the banks of the reservoir have been affected by these changes in water level, including the tributaries of the Yangtze River. There

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are about 2,000 partially submerged landslides among the 4,600 landslides which have been identified by geologists, the risk of more than 550 of which have been studied in further detail with geotechnical engineering assessments. Residents from about 600 landslide-affected areas have been relocated, and 255 other high-risk landslides are being monitored continuously.

Field data collected for the reservoir landslides indicates that the movement of most of the landslides occurs under rapid drawdown conditions due to the outward seepage of water on the face of the slope generating destabilizing forces in the soil. On the other hand, some landslides have shown rapidly increasing movements under the condition of a rising water level, for example, the Tanjiahe landslide. The increase in water level in the soil results in a decrease in the mean effective stress which leads to slope movement. These two mechanisms are typical to many landslides around the Three Gorges Dam Reservoir. In order to provide appropriate and effective mitigation measures for the landslides in this area, it is necessary to understand the sliding mechanism and the responses of the soil under the fluctuating water level.

Landslides around the Three Gorges Dam can be broadly classified into two categories according to their movement response due to changes in the water level of the reservoir, as seen in Fig. 1. In Category 1, accelerated movement occurs during the falling of the water level, while in Category 2, accelerated movement occurs during the rising of the water level. The mechanism associated with the movement of Category 1 landsides is normally attributed to the seepage force inside the landslide when a rapid drawdown occurs. Moreover, the stabilizing force provided by the water is removed due to the falling of the water level. This usually occurs in soil with relatively low permeability. For Category 2 landslides, the rising of the water level results in higher pore water pressure in the sliding zone and a reduction in effective stress in the soil. This reduction in effective stress results in lower shearing resistance, and therefore, has a destabilizing effect on the landslides. Therefore, accelerated movements occur during the rising of the water level. Many landslides around the Three Gorges Dam Reservoir belong to Category 1. However, there are a few landslides that belong to Category 2.

Although the stability of the Category 2 landslides can be explained using the Principle of Effective Stress on the sliding surface, the repetitive movement of the slide under the periodic variation in water level cannot be explained

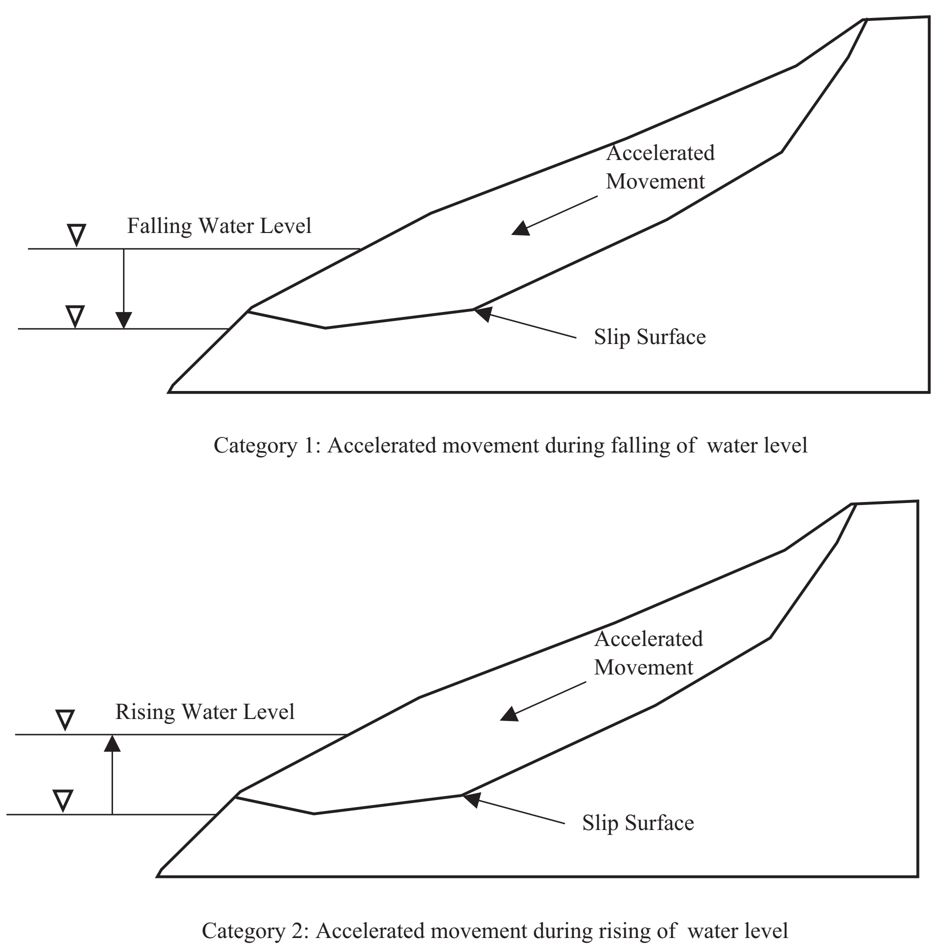


Fig. 1. Mechanisms of movement of slopes due to fluctuation in reservoir water levels.

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