

## Postprint: Study on In-situ Mechanical Properties of Tuff Rock Mass

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**Date:** 2025-08-04T17:25:19+00:00

### Abstract

Tuff, as a type of pyroclastic rock, is widely utilized in construction and engineering applications due to its dense structure, high compressive strength, and excellent durability. This study investigates the in-situ mechanical properties of tuff from sites in Shunxi (Zhejiang), Fushun (Liaoning), and Emin (Xinjiang) through rigid bearing plate deformation tests and flat-jack direct shear tests, aiming to reveal the variation patterns of deformation and strength characteristics with respect to weathering degree. The results demonstrate that the mechanical properties of tuff are significantly influenced by weathering degree. For intact and fresh crystal-fragment welded tuff, the deformation modulus reaches as high as 20.36~44.40 GPa, with shear strength parameters of friction angle at 1.43~1.95 and cohesion at 1.53~3.05 MPa; whereas for strongly weathered tuff, the deformation modulus drops sharply to 0.10~0.31 GPa, and the shear strength parameters are also substantially reduced (friction angle 0.66, cohesion 0.14 MPa). Analysis indicates that the predominant role of weak minerals such as illite and muscovite during weathering leads to deterioration of the internal structure of the rock mass, consequently causing a precipitous decline in mechanical performance. This paper systematically examines the in-situ mechanical properties of tuff, providing an important reference for engineering applications of tuff, particularly for stability assessments of dam foundations, tunnels, and other engineering projects.

### Full Text

## Research on the In-Situ Mechanical Properties of Tuff Rock

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## Abstract

Tuff, as a volcanic clastic rock, is widely utilized in construction and engineering fields due to its dense structure, high compressive strength, and favorable durability. This study investigates the in-situ mechanical properties of tuff from construction sites in Shunxi (Zhejiang), Fushun (Liaoning), and Emin (Xinjiang) through rigid bearing plate deformation tests and direct shear tests using the push method, aiming to reveal the variation 规律 of deformation and strength characteristics with weathering degree. The results demonstrate that tuff's mechanical properties are significantly influenced by weathering. The deformation modulus of intact, fresh crystal-fragment welded tuff reaches 20.36–44.40 GPa, with shear strength parameters of friction angle 1.43–1.95 and cohesion 1.53–3.05 MPa. In contrast, strongly weathered tuff exhibits a sharp drop in deformation modulus to 0.10–0.31 GPa, accompanied by substantially reduced strength parameters (friction angle 0.66, cohesion 0.14 MPa). Analysis indicates that during weathering, the dominant influence of weak minerals such as illite and muscovite leads to deterioration of the internal rock structure, consequently causing a cliff-like decline in mechanical performance. This paper systematically examines the in-situ mechanical properties of tuff, providing an important reference for engineering applications of tuff, particularly for stability assessments of dam foundations and tunnel projects.

**Keywords:** Rigid bearing plate method; Push method; Deformation modulus; Shear strength parameter

## Introduction

Tuff is a fine-grained volcanic clastic sediment formed from volcanic ash and sand cementation. The glassy clasts within the rock are transparent with a slightly yellowish or brownish hue, appearing as tiny fragments or foam-like flakes, and additionally contain broken phenocrysts and solidified lava fragments. As a volcanic clastic rock, tuff is composed of over 50% volcanic clastic material with particle diameters smaller than 2 mm, primarily volcanic ash in composition, with appearance ranging from porous to dense. Layered varieties are termed stratified tuff, and the rock exhibits diverse colors including purplish-red, grayish-white, and grayish-green. Based on its volcanic clast composition, tuff can be classified into crystal-fragment tuff, glass-fragment tuff, and lithic-fragment tuff. Formed from magma that slowly cooled at great depth under substantial overburden pressure, tuff is characterized by its dense structure, high unit weight, high compressive strength, low water absorption, and excellent frost resistance, wear resistance, and durability. Tuff serves as a common building material and can also be used as raw material for cement production

and potassium fertilizer extraction.

Numerous scholars have investigated the mechanical properties of tuff. Wang et al. [?] studied the anisotropic characteristics of tuff as a dam foundation material; Zheng et al. [?] examined the internal structure and mineral composition of tuff; Li et al. [?] investigated the deformation and mechanical characteristics of tuff in high-altitude cold regions through monitoring methods; Jia et al. [?] studied the rock mechanical properties of tuff through laboratory tests; Li et al. [?] researched the rheological characteristics of tuff through laboratory creep tests; and Li et al. [?] examined the dynamic rock properties of tuff. Other scholars have also studied tuff properties as a concrete additive. However, no previous research has systematically investigated the in-situ mechanical properties of tuff. Through in-situ testing of tuff at multiple construction sites, this paper synthesizes the in-situ rock mass mechanical properties of tuff to provide comprehensive understanding and guidance for engineering construction.

## 2.1 Rigid Bearing Plate Method Deformation Test

The rigid bearing plate method for rock mass deformation testing employs a bearing area of 2000 cm<sup>2</sup>, with increased plate thickness for rock masses with higher deformation modulus. At selected test sections, deformation test points are arranged. Professional stonemasons manually remove the surface loose layer and carve a 2 m × 2 m horizontal plane, with the central Φ60 cm range meticulously carved to meet specification requirements for the test point surface, followed by geological sketching of the point surface. Photographic documentation is conducted for the geological conditions of various rock mass deformation test points. The test installation is shown in [Figure 1: see original paper]. Loading is applied in five stages using a progressive cyclic loading method, with deformation readings taken every 10 minutes before and after each loading increment.

## 2.2 Push Method Direct Shear Test

The push method for rock mass direct shear testing involves preparing rock specimens with dimensions of 50 cm × 50 cm × 35 cm (length × width × height). A concrete protective jacket is cast around the specimen or a steel mold is used to encase the sample, with a 2 cm shear gap reserved between the protective jacket/steel mold bottom and the rock mass (structural plane). Testing proceeds after the protective jacket achieves sufficient rigidity and strength. The test installation is shown in [Figure 2: see original paper].

## 3.1 Deformation Data Processing

The average effective surface deformation of the plate is calculated, and the pressure P versus deformation W relationship curve is plotted. The rock mass deformation modulus  $E_0$  and elastic modulus  $E_e$  are calculated using the following formula:

$E$ —rock mass deformation modulus or elastic modulus, MPa; when total deformation is substituted into the formula, it represents the deformation modulus  $E_0$ ; when elastic deformation is substituted, it represents the elastic modulus  $E_e$ ;  
 $\mu$ —rock mass Poisson's ratio;  
 $P$ —pressure calculated per unit area of bearing plate, MPa;  
 $D$ —bearing plate diameter, cm;  
 $W$ —rock mass surface deformation, cm.

### 3.2 Direct Shear Data Processing

For direct shear tests using the push method, normal stress and shear stress under each normal load are calculated using the following formulas:

$\sigma$ —normal stress acting on the shear plane (MPa);  
 $\tau$ —shear stress acting on the shear plane (MPa);  
 $P$ —total normal load acting on the shear plane (N);  
 $Q$ —total shear load acting on the shear plane (N);  
 $A$ —shear plane area ( $\text{mm}^2$ ).

$AP = AQ =$

For each specimen, curves of shear stress versus shear displacement  $\mu_s$  and normal displacement  $\mu_n$  are plotted based on test results. The shear failure peak and shear peak under each normal stress are determined from these relationship curves. For a set of test data, the shear stress  $\tau$  versus normal stress  $\sigma$  relationship curve is plotted based on normal stress and its corresponding shear failure peak, and the Coulomb expression is used to determine the corresponding shear strength parameters as the rock mass shear strength parameters. Similarly, rock mass shear strength parameters can be determined.

### 4.1 Deformation Test Results and Analysis

Comprehensive test results from various construction sites are listed in . The table shows that the deformation modulus of tuff is higher when the rock is fresher, and decreases with increasing weathering, exhibiting a cliff-like drop that may be related to internal composition and structure. According to research by Zheng et al. [?], tuff contains minerals such as quartz, illite, and muscovite. As weathering progresses, the weak minerals like illite and muscovite play a dominant role, causing increased rock deformation and rapid reduction in deformation modulus.

### 4.2 Synthesis of Rock Mass Direct Shear Test Results

Rock mass direct shear test results exhibit characteristics consistent with the deformation modulus—that is, the more weathered the rock mass, the more significantly its strength parameters decrease, particularly the internal friction angle  $C'$  value.

**TABLE 1** Comprehensive Deformation Test Results

Rock Type	Deformation Modulus (GPa)
Crystal-fragment welded tuff (intact fresh)	20.36–44.40
Crystal-fragment welded tuff (weathered)	10.28–19.50
Strongly weathered tuff	0.10–0.31
Crystal-fragment welded tuff (slightly weathered)	5.80–14.62
Crystal-fragment welded tuff (moderately weathered)	1.07–4.00

**TABLE 2** Comprehensive Direct Shear Test Results

Shear Strength Parameters	Value Range
Friction angle	1.43–1.95
$C'$ (MPa)	1.53–3.05

## 5 Conclusions

When tuff is intact and fresh, it exhibits dense structure, high unit weight, high compressive strength, high deformation modulus, and high strength parameters. As weathering progresses, the internal structure rapidly changes due to the presence of weak minerals, leading to a sharp decline in deformation and strength parameters. The systematic study of in-situ mechanical properties of tuff provides crucial guidance for engineering applications, particularly for stability evaluation of dam foundations and tunnel engineering.

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*Note: Figure translations are in progress. See original paper for figures.*

*Source: ChinaXiv — Machine translation. Verify with original.*