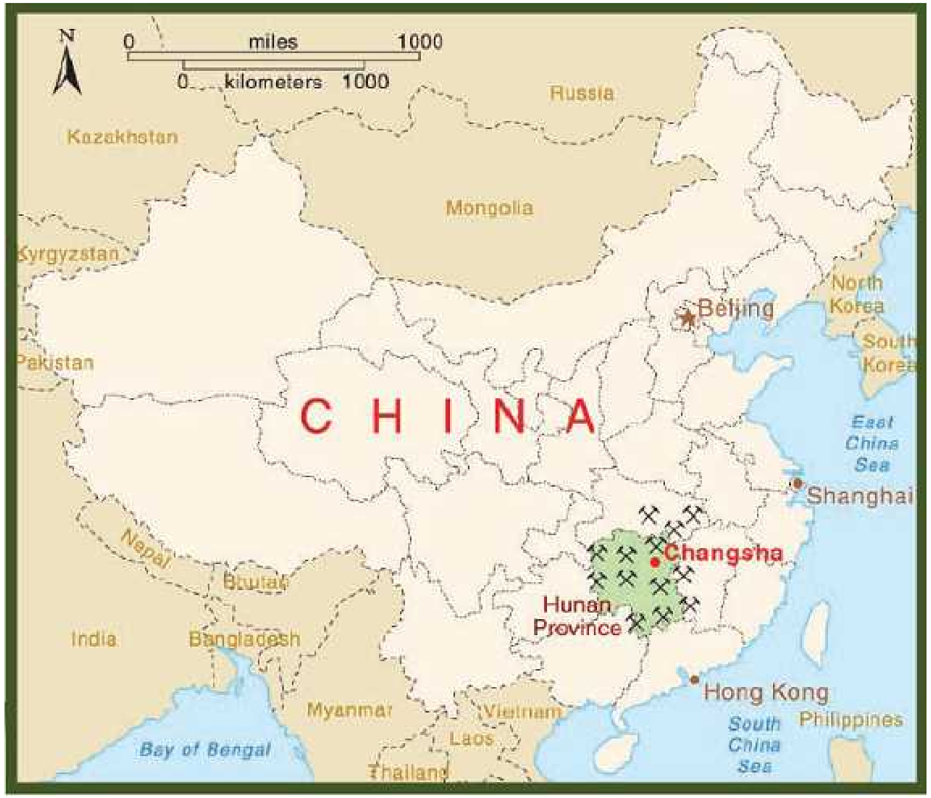
ISSMGE TC 202, 2nd Japan-China Mini Workshop on High Speed Railway Geotechnics

August 27-30 · Sapporo · Japan

Central South University (CSU)

中南大學
CENTRAL SOUTH UNIVERSITY



Central South University (CSU)

- Top ranked (Tier 1) comprehensive research university in China
- Top ranked engineering programs & medical school in the nation
  - Mining & Metallurgy
  - Civil Engineering
  - Railroad-related Programs
  - 3 large Grade-A affiliated hospitals
- Strong international joint education & research collaboration

School of Civil Engineering at CSU

- Top ranked programs in the nation
  - Geotechnical Engineering
  - Bridge Engineering
  - Tunnel Engineering
  - Railroad Engineering
  - Building Engineering
  - Construction Management
  - Engineering Mechanics
  - Fire Engineering
  - Construction Materials

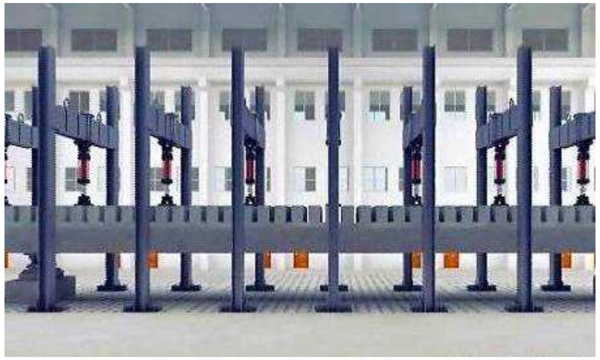
School of Civil Engineering at CSU

中南大學 CENTRAL SOUTH UNIVERSITY

- Research Centers
  - National Engineering Laboratory for High Speed Railway Construction
  - Ministry of Education Key Laboratory for Heavy Haul Railway Engineering Structures
  - International Cooperative Research Laboratory for Rail Transit Safety



School of Civil Engineering at CSU



School of Civil Engineering at CSU

Bio Sketch of Myself

- Education
  - Ph.D. in C.E., University of Illinois at Urbana-Champaign (UIUC), 2014
  - M.Sc. in Theoretical & Applied Mechanics, UIUC, 2013
  - M.S.C.E., Southeast University, Nanjing, China, 2008
  - B.S.C.E., Tongji University, Shanghai, China, 2005

- Research Interests
  - Transportation Geotechnics & Geomaterials in general
  - Testing & Modeling of Subgrade Soils, Base/Subbase Aggregates, & Railroad Ballast
  - Transportation Geodynamics
  - Subgrade Stability & Improvement (stabilization, geosynthetics)

Investigating Strength and Deformation Characteristics of Heavy-haul Railway Embankment Materials Using Large-scale Undrained Cyclic Triaxial Tests

Presenter **Dr. Prof. Yuanjie Xiao**

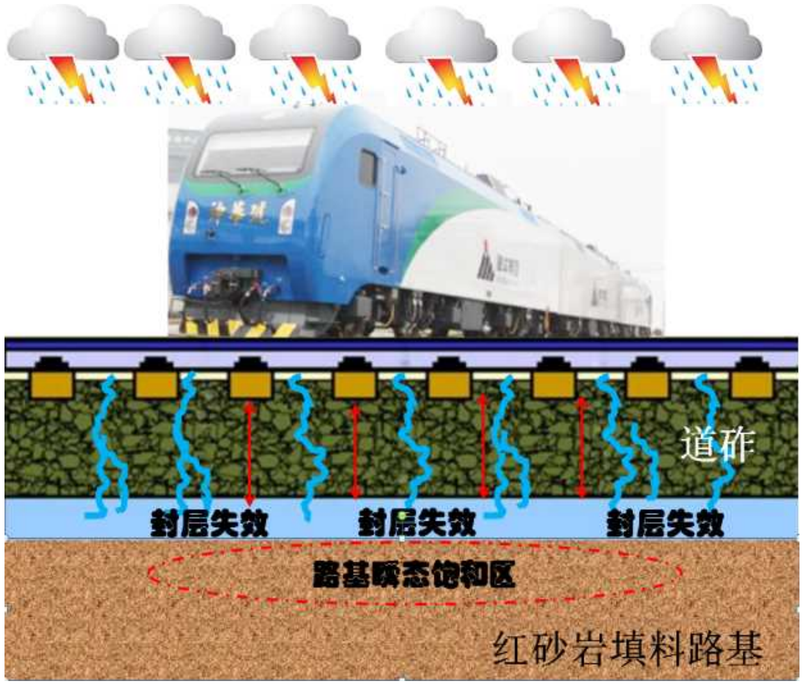
Affiliation **Central South University, Changsha, China**

Contact details **yjxiao@csu.edu.cn** or **xiao8@Illinois.edu**

中南大學
CENTRAL SOUTH UNIVERSITY

Outline

- Introduction
- Laboratory Test Procedures
  - Specimen Preparation
  - Testing Schemes
- Results & Discussion
  - Dynamic Strength
  - Elastic Deformation
  - Permanent Deformation
- Summary & Conclusions



Introduction

- Heavy-haul rail with increased axle load & speed is the new development priority in China
- About 70% of the heavy-haul railway lines are constructed over embankments of coarse-grained soil (CGS) filling materials, thus making the mechanical behavior of CGS critically important
  - Shear Strength
  - Elastic & Inelastic (permanent) Deformation
- Limited laboratory strength & deformation tests have been conducted on such CGS materials

A Selection of Previous Studies

中南大學
CENTRAL SOUTH UNIVERSITY

- The accumulation of excessive permanent deformation may cause a series of subgrade problems, such as settlement and instability, whereas excessive dynamic elastic (recoverable) deformation also reduces the train operating speed (Du et al. 2010; Liu et al. 2008; Zhou et al. 2000)
- The actual train loading applied relative to the coarse-grained embankment soils (CGS)' critical cyclic stress (CCS) level has a considerable influence on the plastic deformation accumulation characteristics (Boushehrian et al. 2011; Du et al. 2010; Liu et al. 2008; Stewart et al. 1986; Xiao and Tutumluer 2016)
- The influence of consolidation on CCS was studied and larger consolidation deviatoric stress was found to be attributable for greater CCS (Tang et al. 2003)
- The wet-dry cycles were also found to reduce the CCS of soils (Sun et al. 2004)

A Selection of Previous Studies

- Hirakawa et al. (2002) and Momoya et al. (2005) investigated through a model test the effect of moving wheel loads on cyclic plastic deformation of roadbed and railroad ballast
- The synergistic effects of principal stress axis rotation (PSR) & change in water content on the cyclic plastic deformation characteristics of granular base course materials were found important (Ishikawa & Miura 2015)
- Gräbe and Clayton (2003, 2009, 2014) concluded that PSR caused by moving wheel loads cause reduced resilient moduli and increased rate of permanent strain for certain types of road and track foundation materials
- The effect of the number of repeated-load applications on the dynamic shear modulus was investigated by Indraratna et al. (2005) and Flora and Lirer (2013)

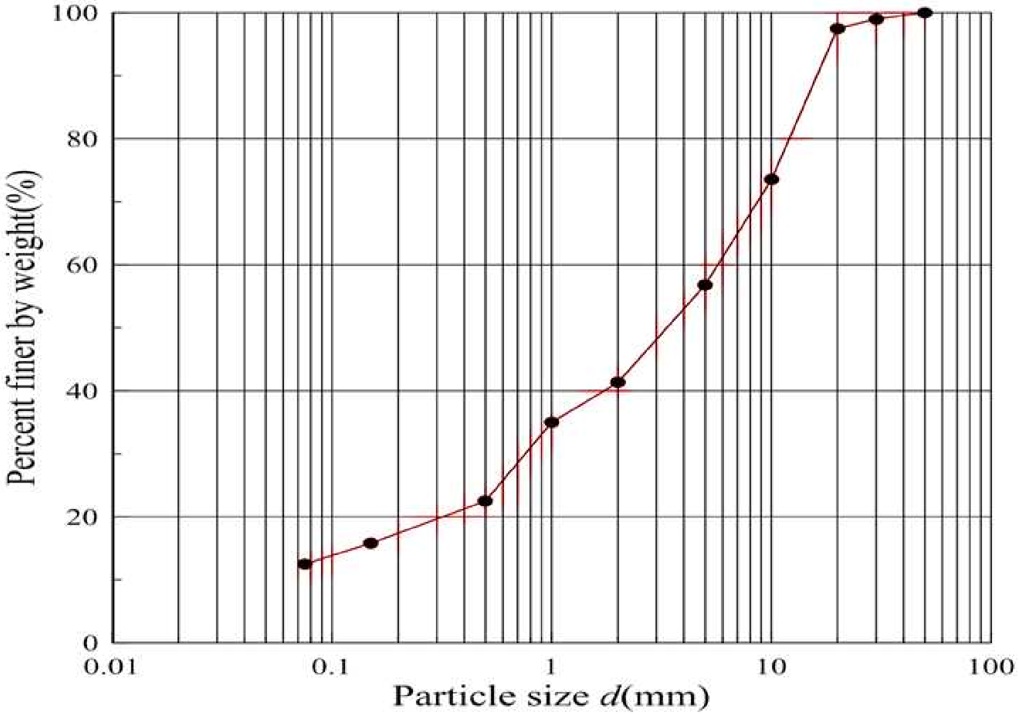
Research Objective & Scope

- To **present and analyze the permanent deformation and dynamic strength results** that were obtained from large-scale laboratory repeated load triaxial tests on over thirty CGS specimens
- To quantify the effects of **moisture content, degree of compaction, and deviatoric and confining stress levels** on the CCS of the tested CGS
- To utilize a **customized large-scale laboratory repeated load triaxial apparatus** recently developed at the Central South University

Tested Materials

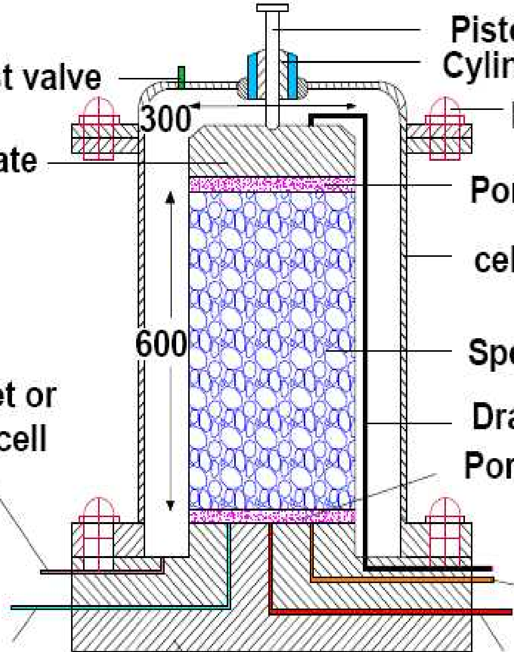
Table 1. Physical Properties of Tested CGS Embankment Material

Parameter	Value
Maximum dry density, $\rho_{d\max}$ (g·cm^{-3})	2.21
Water content of saturated specimen, ω_{sat}, (%)	9.3
Void ratio	0.248
Coefficient of uniformity C_u	80
Coefficient of curvature C_c	1.25
Effective shear-strength parameters	
φ' (%)	41
c' (kPa)	69



Large-scale Triaxial Apparatus

► **Customized for testing CGS:**



Large-scale Triaxial Apparatus

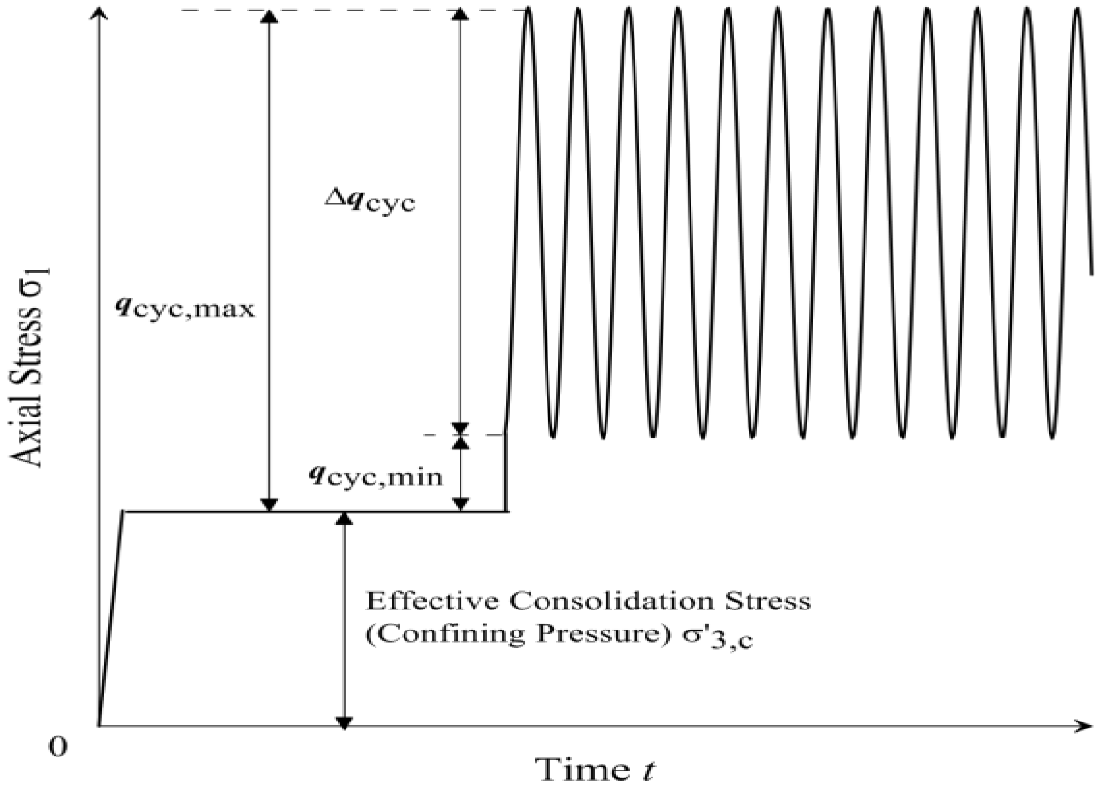
中南大學
CENTRAL SOUTH UNIVERSITY

► **Customized for testing CGS:**

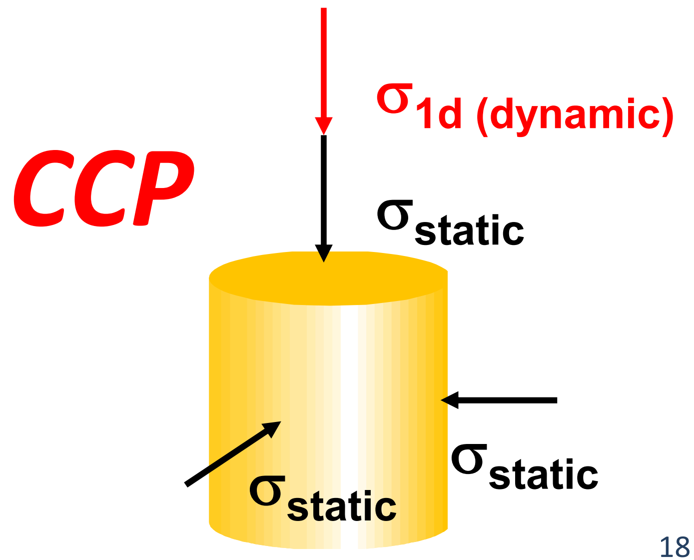
(a)MTS控制系统 (b) 变形测试系统 (c) 孔隙水压测试系统

(d)大型围压室 (e) 围压和饱和水箱 (f) 抽真空系统

Dynamic Stress Scheme Applied

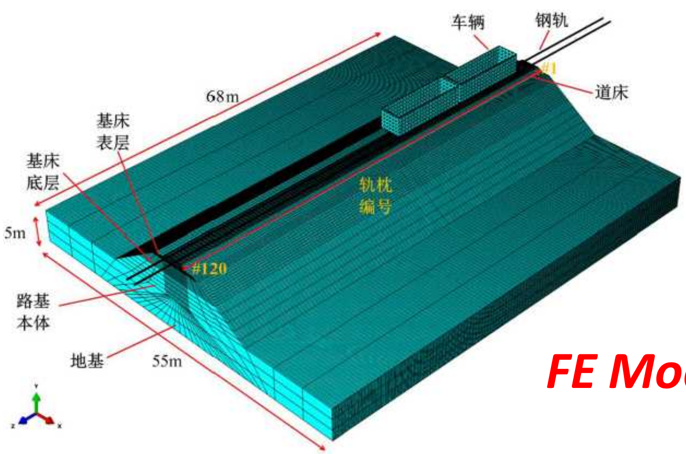


- **Constant Confining Pressure (CCP) Tests**



Dynamic Stress States

Field Instrumentation



FE Modeling

Table 3. Testing Program

Name	Water content [ω (%)]	$\sigma'_{3,c}$ (kPa)	Δq_{cyc} (kPa)
15050S	9.3	15	50
15100S	9.3	15	100
15125S	9.3	15	125
15150S	9.3	15	150
15200S	9.3	15	200
15250S	9.3	15	250
30050S	9.3	30	50
30100S	9.3	30	100
30125S	9.3	30	125
30150S	9.3	30	150
30200S	9.3	30	200
30250S	9.3	30	250
60050S	9.3	60	50
60100S	9.3	60	100
60125S	9.3	60	125
60150S	9.3	60	150
60200S	9.3	60	200
60250S	9.3	60	250
15100U	6	15	100
15150U	6	15	150
15200U	6	15	200
15250U	6	15	250
30250U	6	30	250
30275U	6	30	275
30300U	6	30	300
60250U	6	60	250
60300U	6	60	300
60350U	6	60	350
60400U	6	60	400
60250U	7.5	60	250
60350U	7.5	60	350
45350U	7.5	45	350

Lab Testing Process

(a)分层装土击实

(b) 卸下两瓣式对开模

(c)制备完成后的试样

（试样编号 9730200B）试验完成后的外形照片

Results & Discussion

中南大學 CENTRAL SOUTH UNIVERSITY

- Static Shear Strength

Table 2. Static Shear-Strength Properties (Total Stress) of Tested CGS Specimens at Different Conditions

Test conditions	Apparent cohesion [c' (kPa)]	Angle of internal friction [φ' (degrees)]
$K = 0.97$, $\omega = 9.3\%$	58	33
$K = 0.97$, $\omega = 7.5\%$	61	35
$K = 0.97$, $\omega = 6.0\%$	62	36
$K = 0.95$, $\omega = 9.3\%$	45	31
$K = 0.95$, $\omega = 6.0\%$	50	32

Note: K = degree of compaction (i.e., achieved dry density divided by maximum dry density); ω = gravitational moisture content.

Results & Discussion

- Permanent Axial Deformation Accumulation

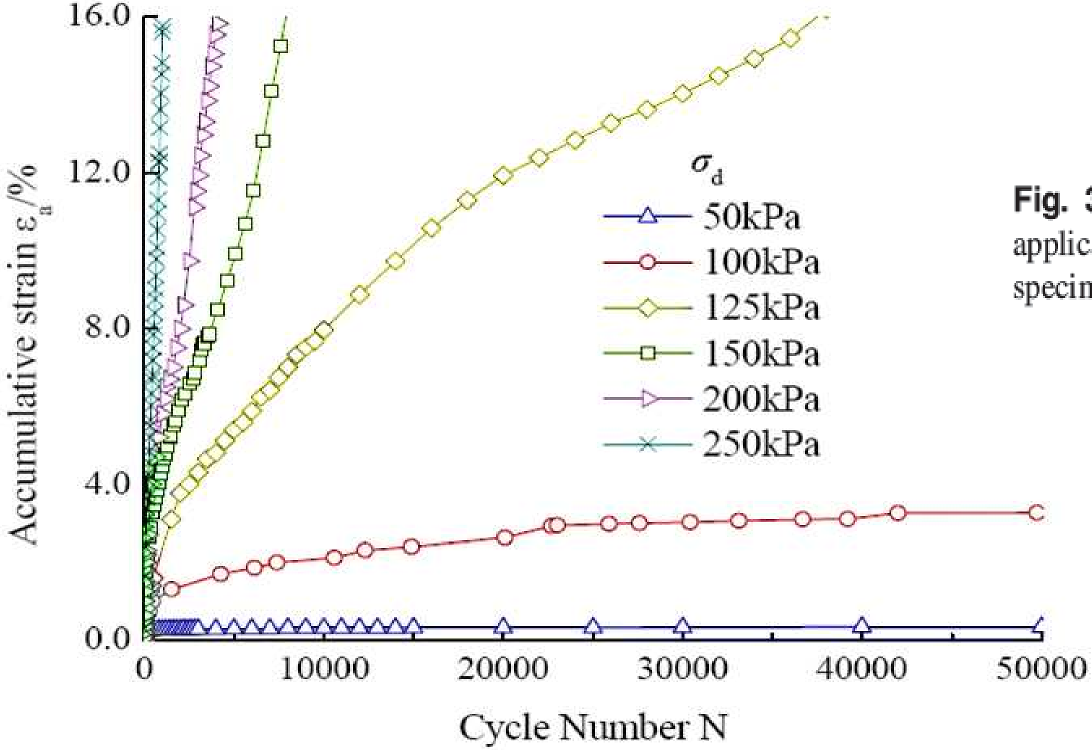


Fig. 3. Permanent axial strain accumulating with number of load applications under varying cyclic-stress combinations for saturated specimens with $\sigma'_{3,c}$ of 15 kPa

Results & Discussion

- Permanent Axial Deformation Accumulation

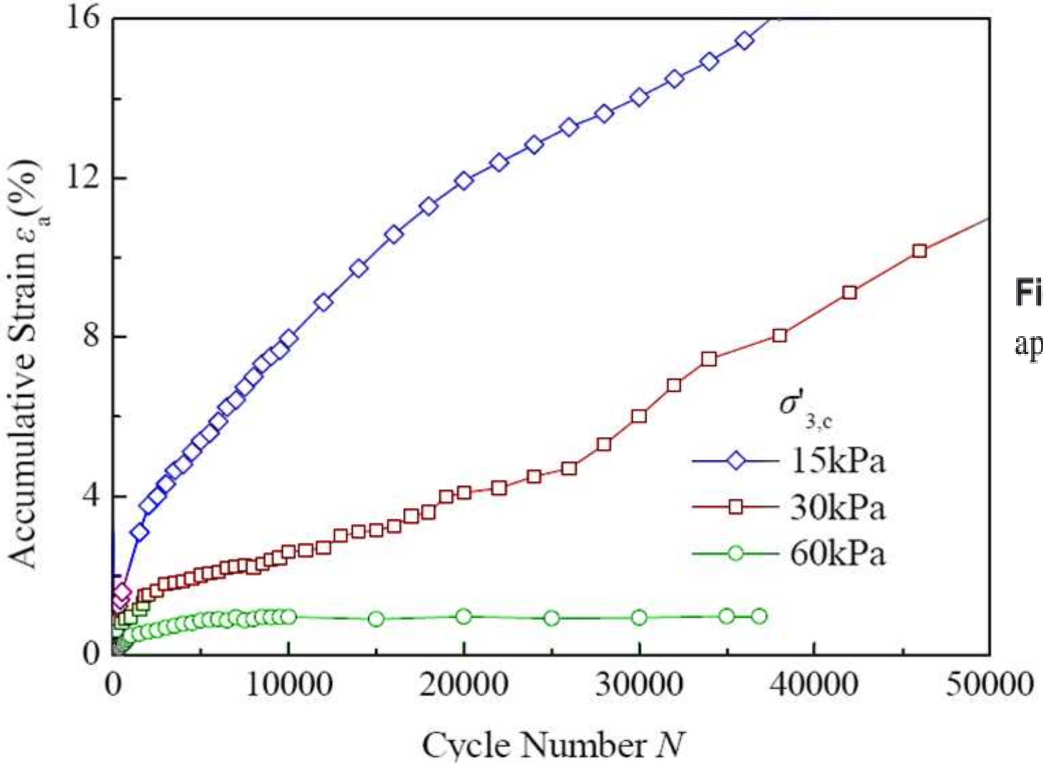


Fig. 4. Permanent axial strain accumulating with the number of load applications under varying confining stress levels ($\sigma_d = 125$ kPa)

Results & Discussion

- Permanent Axial Deformation Accumulation

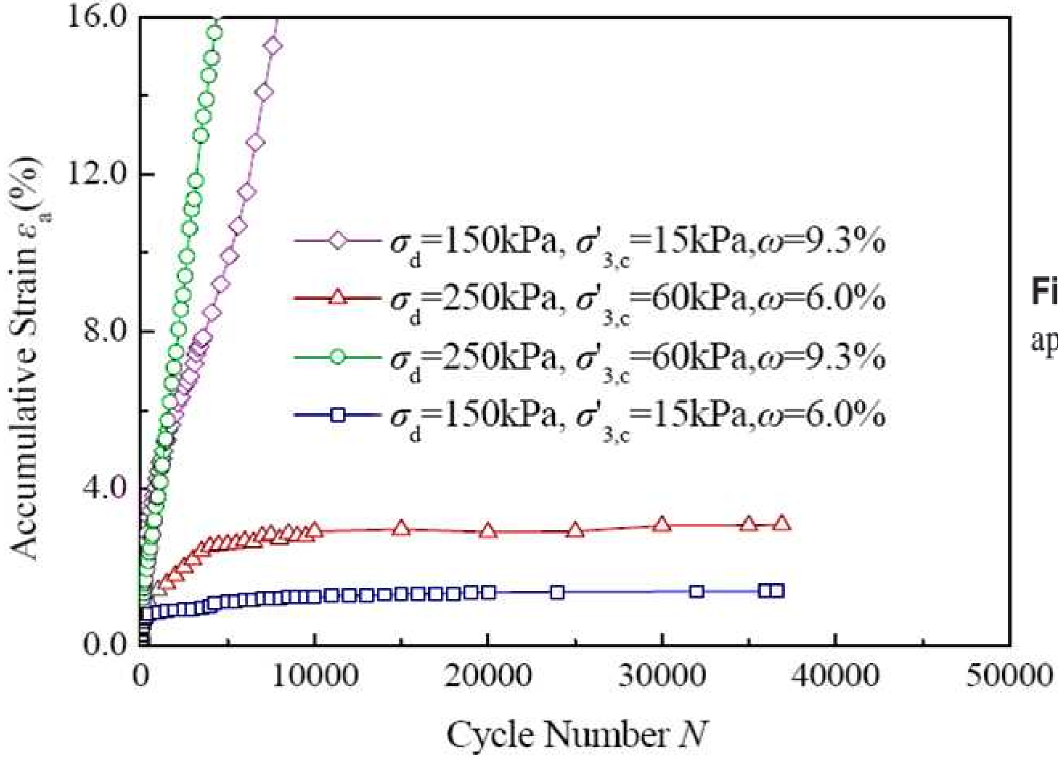


Fig. 5. Permanent axial strain accumulating with the number of load applications for different moisture contents

Results & Discussion

中南大學
CENTRAL SOUTH UNIVERSITY

- Permanent Axial Deformation Accumulation

Table 4. Method for Classifying the Specimen Patterns

Name of pattern	Description
Attenuation	ε_a increases slowly, does not exceed 4% after 50,000 cycles
Criticality	ε_a increases, sometimes quickly, sometimes slowly, and can reach 15% after 20,000 cycles
Failure	ε_a increases quickly and can reach 15% before 20,000 cycles

Results & Discussion

中南大學
CENTRAL SOUTH UNIVERSITY

- Permanent Axial Deformation Accumulation

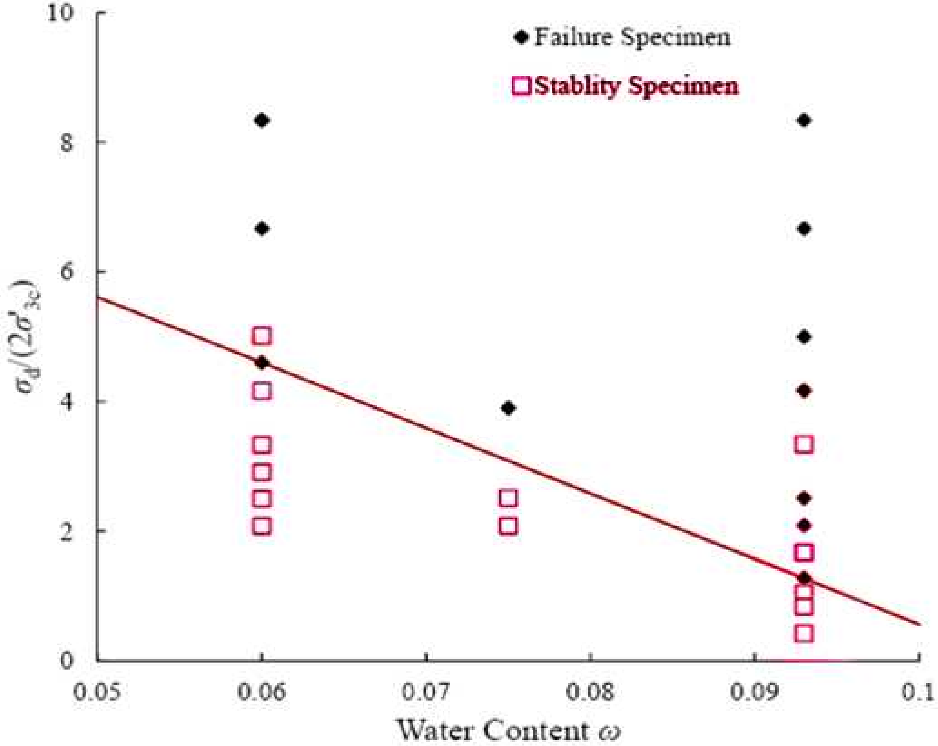


Fig. 6. Cyclic stress ratio versus moisture content for the CGS specimens tested

Results & Discussion

- Permanent Axial Deformation Accumulation

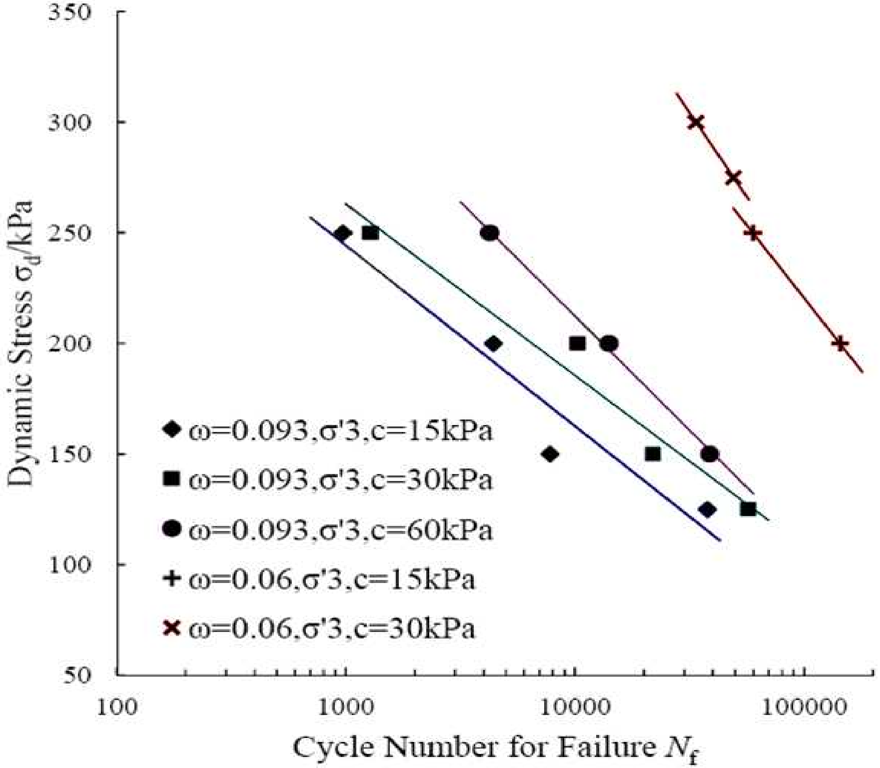


Fig. 7. Variation in dynamic strength with moisture content and confining stress

Results & Discussion

- Permanent Axial Deformation Accumulation

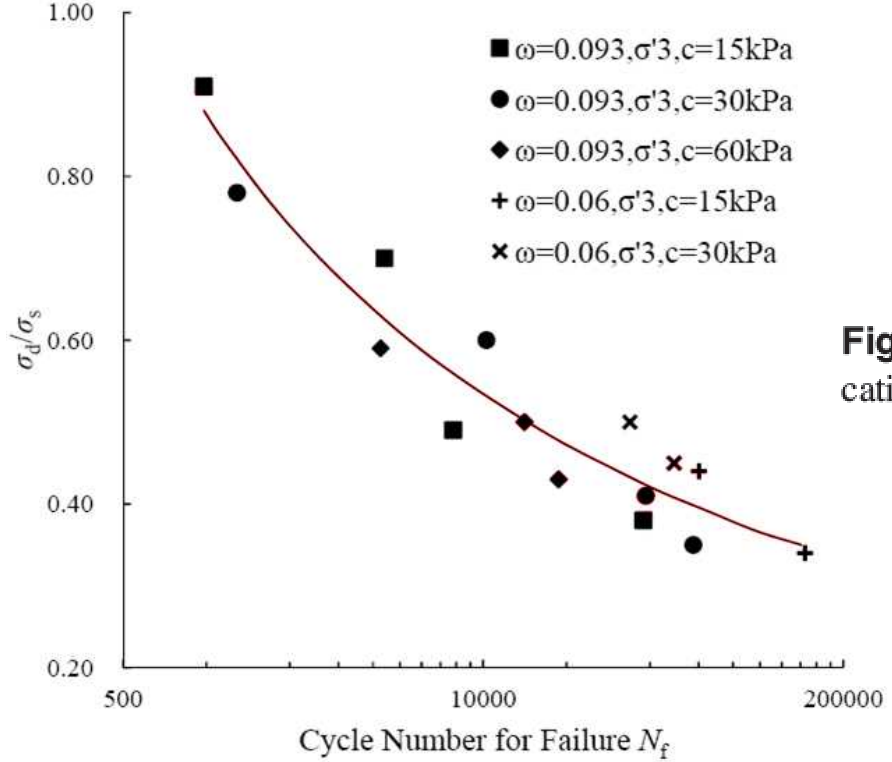
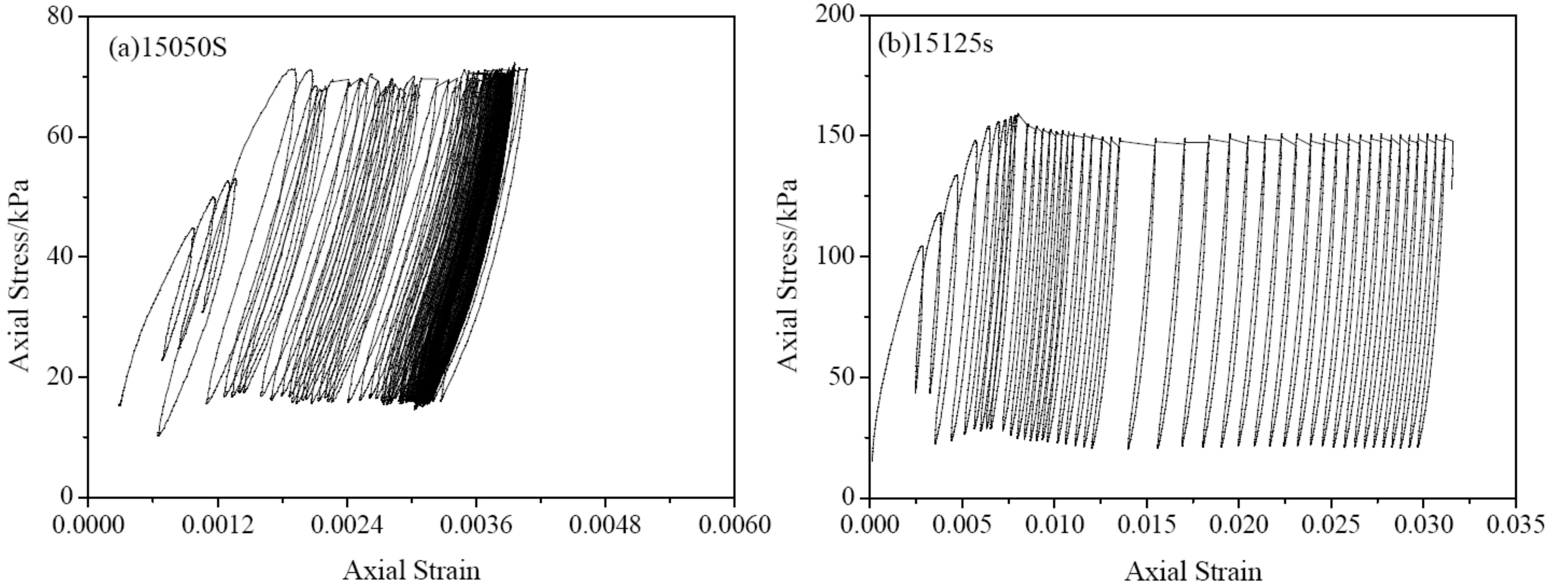


Fig. 8. Normalized dynamic strength versus the number of load applications to failure, N_f

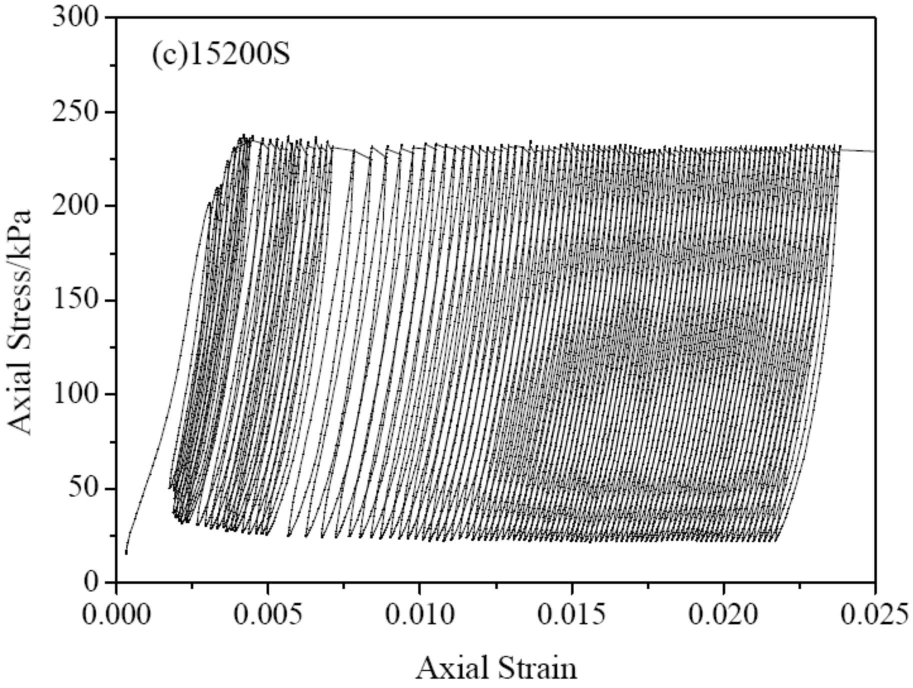
Results & Discussion

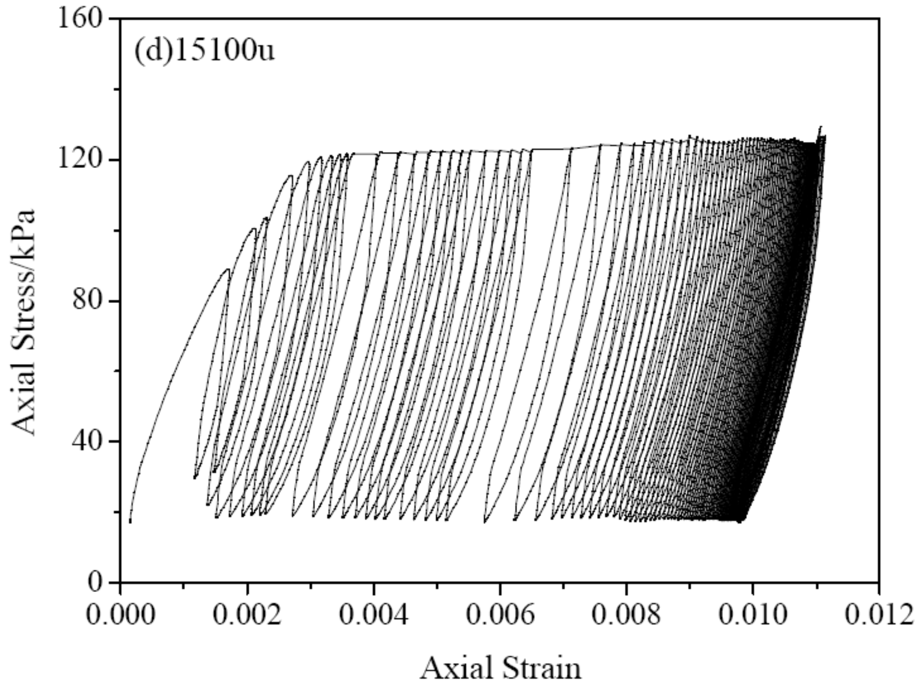
- Permanent Axial Deformation Accumulation



Results & Discussion

- Permanent Axial Deformation Accumulation





Results & Discussion

- Permanent Axial Deformation Accumulation

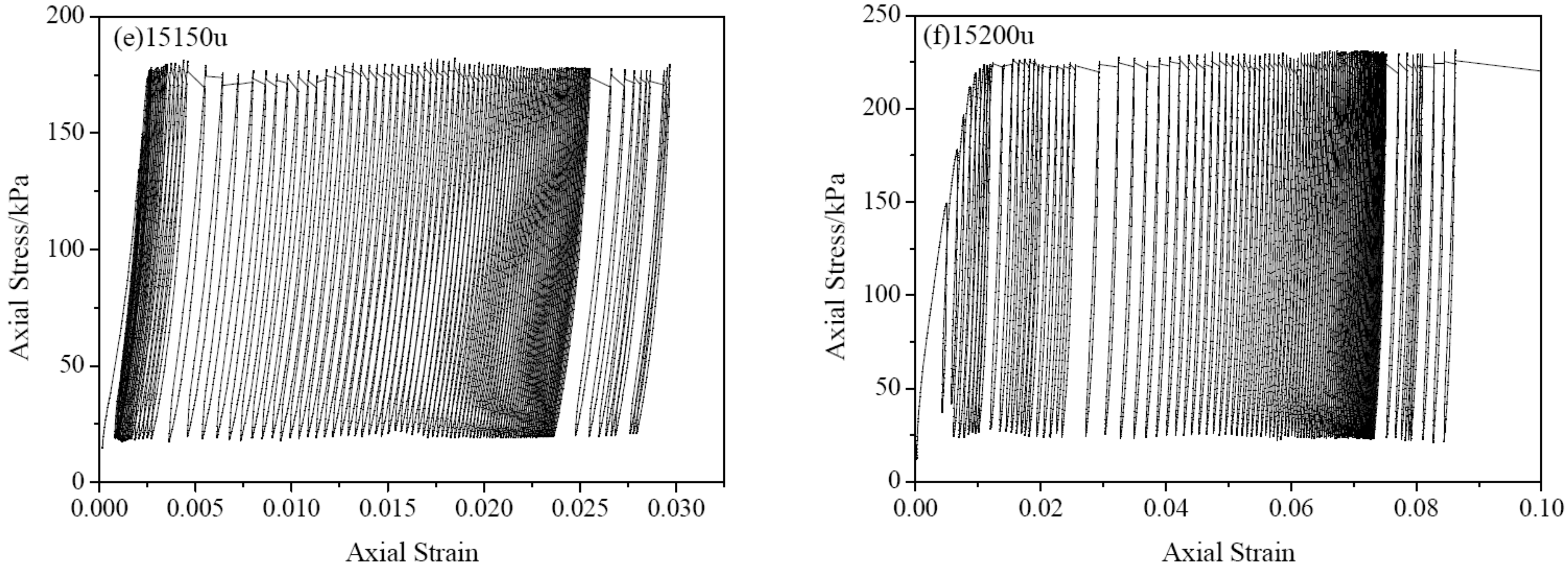


Fig. 9. Cyclic axial stress-strain loops for (a) through (c) saturated and (d) through (f) unsaturated specimens subjected to representative stress states: (a) 15050S; (b) 15125s; (c) 15200S; (d) 15100u; (e) 15150u; (f) 15200u

Results & Discussion

- Permanent Axial Deformation Accumulation

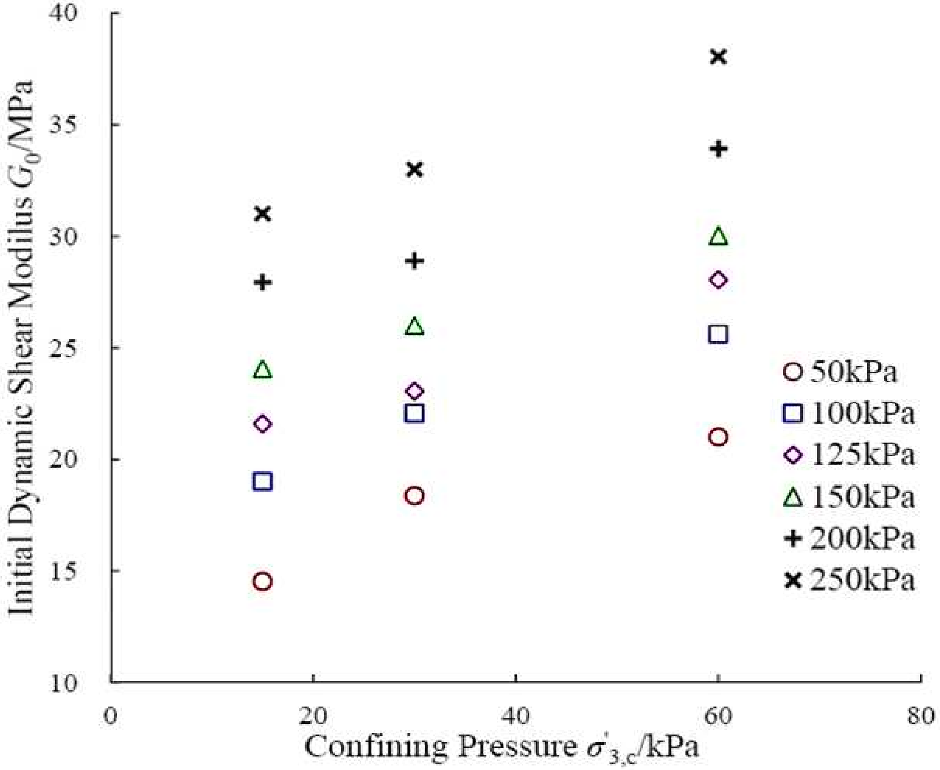


Fig. 10. Variation in initial dynamic shear modulus with cyclic deviator stress and confining stress

Results & Discussion

- Permanent Axial Deformation Accumulation

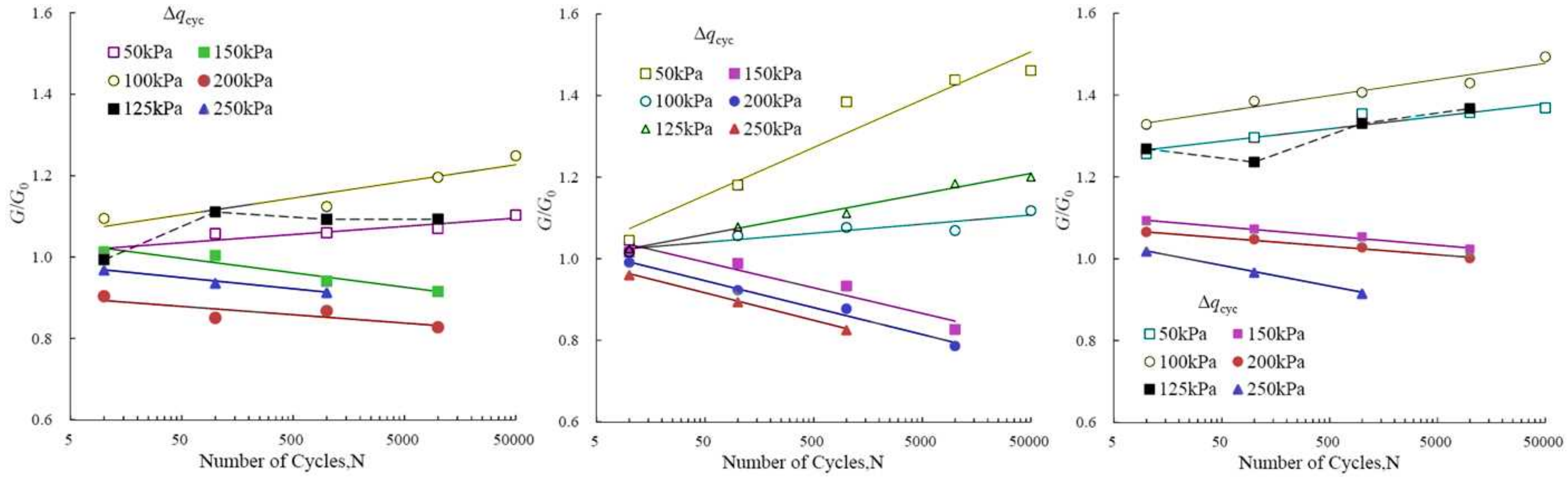


Fig. 11. Relationship between the G/G_0 of saturated specimens and the number of load applications, N (open marker: stable specimens; solid marker: failed specimens): (a) $\sigma'_{3,c}$ of 15 kPa; (b) $\sigma'_{3,c}$ of 30 kPa; (c) $\sigma'_{3,c}$ of 60 kPa

Results & Discussion

- Permanent Axial Deformation Accumulation

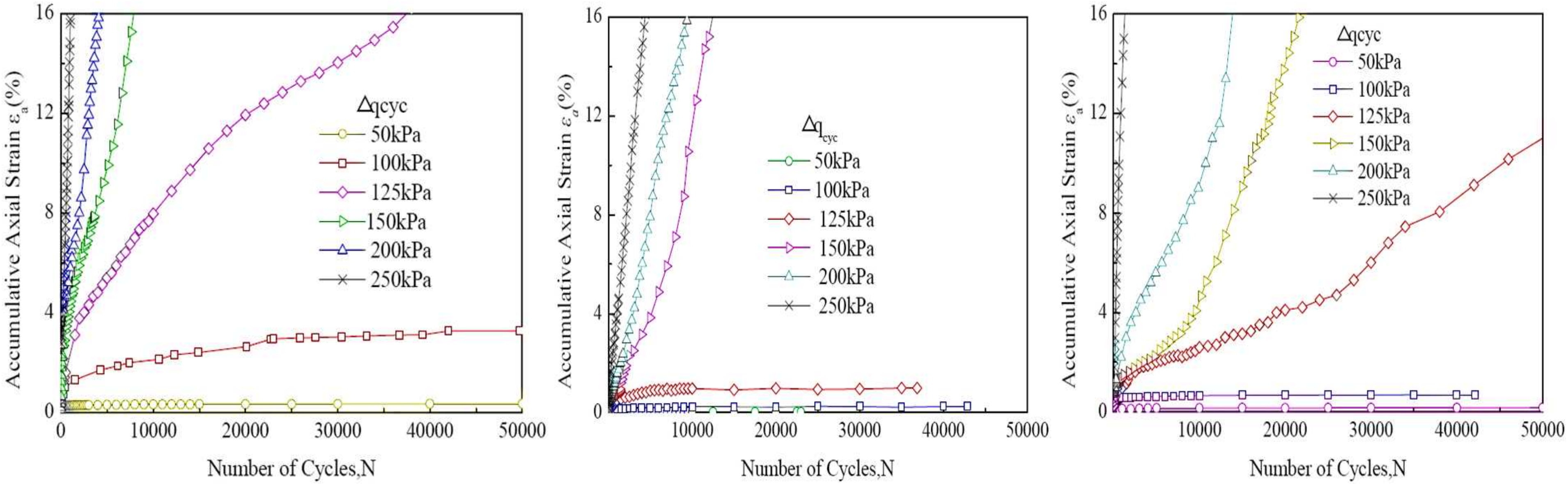


Fig. 12. Permanent axial strain accumulating with the number of load applications, N, for saturated specimens: (a) $\sigma'_{3,c}$ = 15 kPa; (b) $\sigma'_{3,c}$ = 30 kPa; (c) $\sigma'_{3,c}$ = 60 kPa

Results & Discussion

- Cyclic Stress Ratio (CSR)

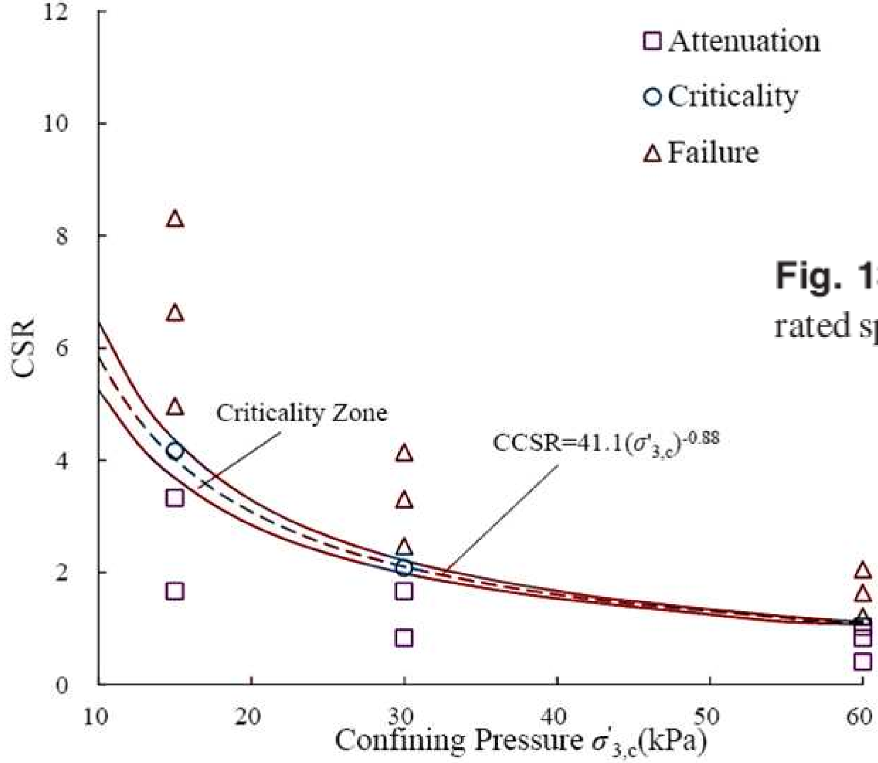


Fig. 13. Cyclic stress ratio versus confining pressure, $\sigma'_{3,c}$, for saturated specimens

Results & Discussion

- Permanent Axial Deformation Accumulation

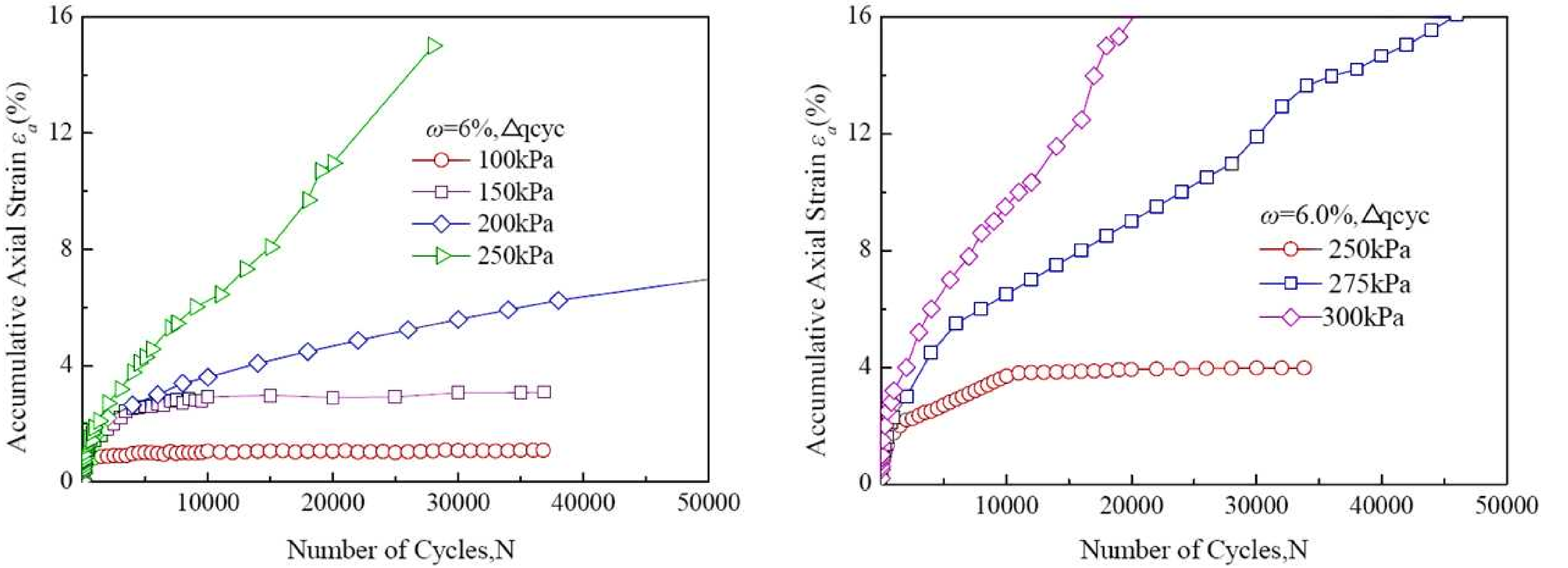


Fig. 14. Permanent axial strain accumulating with the number of load applications, N, for unsaturated specimens: (a) $\omega = 6\%$, $\sigma'_{3,c} = 15$ kPa; (b) $\omega = 6\%$, $\sigma'_{3,c} = 30$ kPa; (c) $\omega = 6\%$, $\sigma'_{3,c} = 60$ kPa; (d) $\omega = 7.5\%$

Results & Discussion

- Permanent Axial Deformation Accumulation

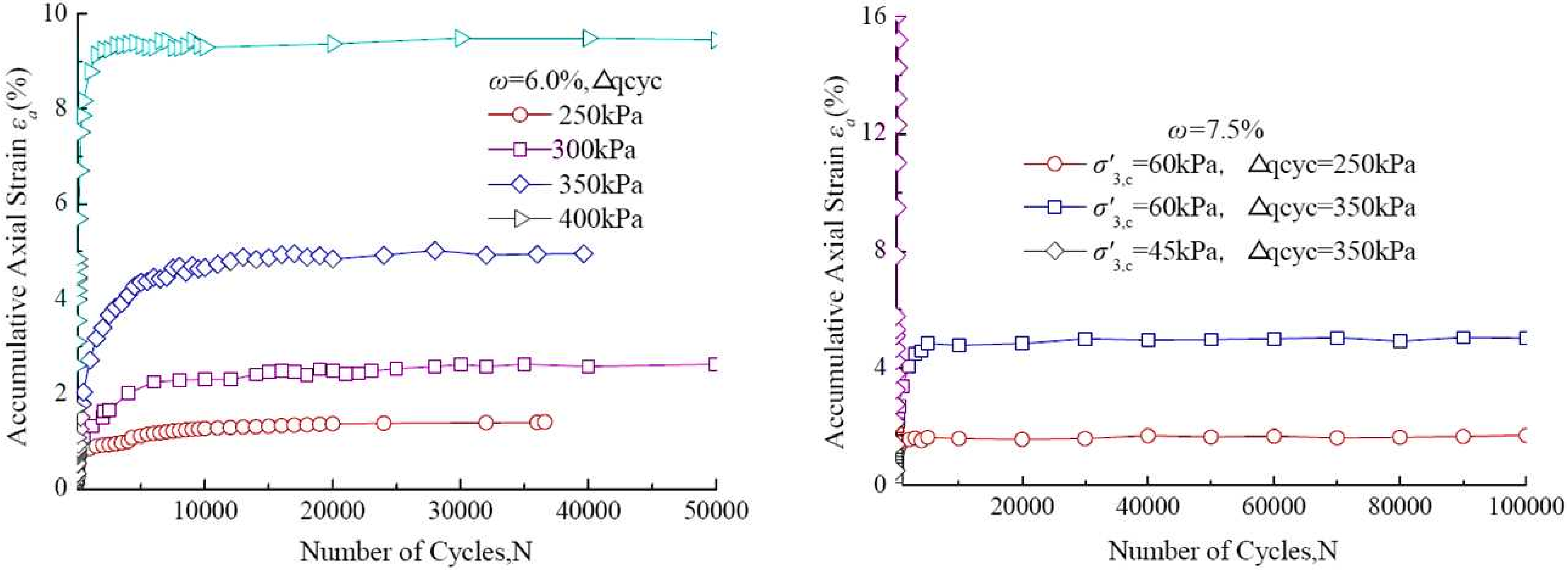


Fig. 14. Permanent axial strain accumulating with the number of load applications, N, for unsaturated specimens: (a) $\omega = 6\%$, $\sigma'_{3,c} = 15$ kPa; (b) $\omega = 6\%$, $\sigma'_{3,c} = 30$ kPa; (c) $\omega = 6\%$, $\sigma'_{3,c} = 60$ kPa; (d) $\omega = 7.5\%$

Results & Discussion

- Permanent Axial Deformation Accumulation

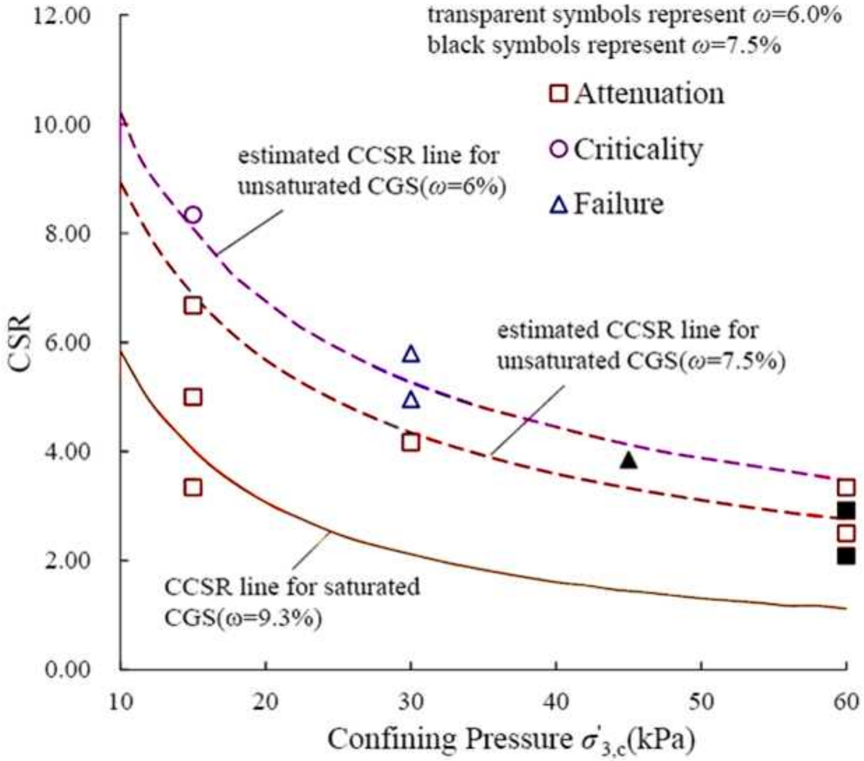


Fig. 15. Cyclic-stress ratio (CSR) versus confining stress, $\sigma'_{3,c}$, for unsaturated specimens

Results & Discussion

- Permanent Axial Deformation Accumulation

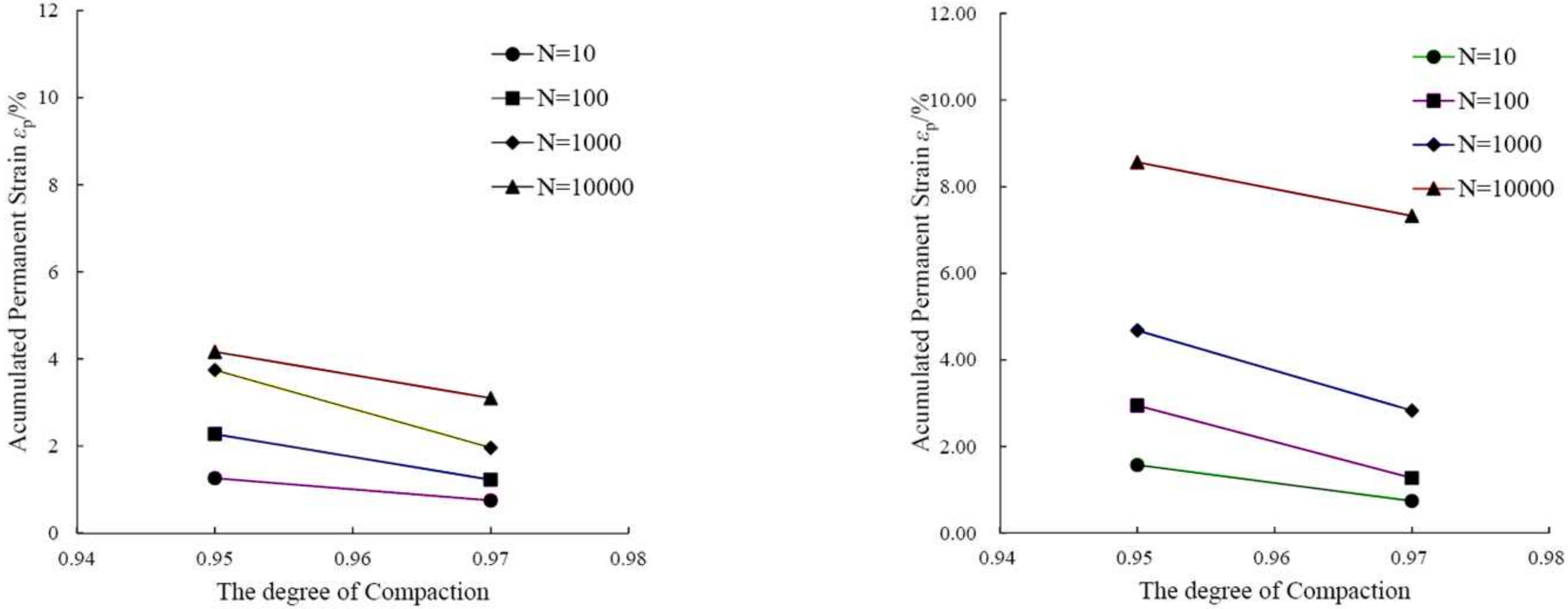


Fig. 16. Effect of degree of compaction on accumulated permanent axial strain: (a) σ_d of 100 kPa and σ_3 of 15 kPa; (b) σ_d of 125 kPa and σ_3 of 15 kPa

Summary & Conclusions

- **The CGS's permanent axial strain induced by cyclic stress accumulates with the number of load applications; the confining stress could hinder the accumulation, whereas moisture content could accelerate the accumulation**

- **The concept of the critical cyclic stress (CCS) was proposed and further defined as the threshold cyclic stress that causes the occurrence of criticality. It was then successfully employed as one of the key criteria to ensure the dynamic stability of CGS embankment layers by controlling the stress level imposed by train loading below the limit of the CCS**

Summary & Conclusions

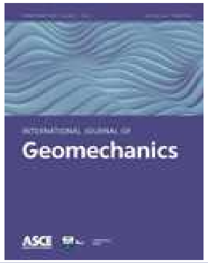
中南大學
CENTRAL SOUTH UNIVERSITY

- The critical dynamic stress increases with larger confining stress and lower moisture content. One of the key measures for maintaining the CGS embankment stability is to control the in-situ dynamic stress levels imposed by train loading to be within the limiting range of the critical stress level
- The higher cyclic deviator stress and confining stress were found to contribute to better specimen compaction and particle interlocking and thus increased initial elastic stiffness of the CGS embankment material, especially within a small number of load applications
- The elastic stiffness degradation is associated with permanent deformation failure of the specimen

Acknowledgement

- Financial support by the National Natural Science Foundation of China (NSFC) under Grant No. 51508577 & U51408613
- Collaborators: Prof. W. Leng, Prof. R. Nie, Dr. W. Liu, and Dr. W. Zhou at Central South University
- The staff and research engineers at National Engineering Laboratory for High-speed Railway Construction for their assistance

To be published in an issue of the
International Journal of Geomechanics



Thank you!..

中南大學
CENTRAL SOUTH UNIVERSITY

SAVE THE DATE! CALL FOR ABSTRACTS OPENNING SOON!

The 8th International Symposium on Environmental Vibration and Transportation Geodynamics

October 27-28 2018

The 2nd Young Transportation Geotechnics Engineers Meeting

October 26 2018

Under the auspice of ISSMGE TC202 Transportation Geotechnics

Xiandai Gloria Grand Hotel, Changsha, China

Paranomic View of Changsha City

FIRST ANNOUNCEMENT & CALL FOR ABSTRACTS OPEN SOON! **www.isev2018.cn**

GLORIA
Hotels & Resorts

CONFERENCE THEMES

- Dynamic interaction of vehicle and transportation infrastracture (pavement, railway and airfield)
- Wave propagation and traffic induced structure and ground vibrations
- Soil-structure dynamic interaction problem in transportation
- Analysis and testing on environmental vibration
- Vehicle, machine and human induced vibrations
- Monitoring, evaluation and control of traffic induced vibrations
- Cyclic deformation of soils and transportation foundation settlement
- Structural safety and serviceability of railway, metro, roadway and bridges
- Application of geosynthetics in transportation infrastructure

CONFERENCE CO-CHAIRS

Erol Tutumluer, Ph.D.
University of Illinois at Urbana-Champaign

Zhiwu Yu, Ph.D.
Central South University; National Engineering Laboratory for High-speed Railway Construction

8th ISEV & 2nd YTGE Secretariat

Central South University
School of Civil Engineering
22 South Shaoshan Road
Changsha, Hunan 410075
China

E-mail: ISEV2018@yahoo.com
Tel.:(+86) 731-8265-5177
Website: http://www.isev2018.cn

FIRST ANNOUNCEMENT & CALL FOR ABSTRACTS OPEN SOON! www.isev2018.cn