

SHEAR BEHAVIOUR OF COHESIONLESS MATERIALS
UNDER GENERALISED CONDITIONS OF STRESS AND STRAIN

PRAKASH C. RAWAT

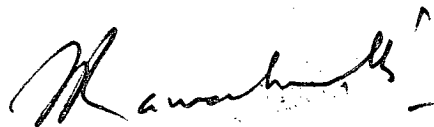
THESIS SUBMITTED TO THE
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
FOR THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
AUGUST, 1976.

CERTIFICATE

This is to certify that the thesis entitled "SHEAR BEHAVIOUR OF COHESIONLESS MATERIALS UNDER GENERALISED CONDITIONS OF STRESS AND STRAIN" being submitted by Mr. Prakash C. Rawat to the Indian Institute of Technology, Delhi for the award of the degree of DOCTOR OF PHILOSOPHY is a record of the bonafide research work carried out by him. Mr. Prakash C. Rawat has worked under my guidance for the submission of this thesis which to my knowledge has reached the requisite standard.

The thesis or any part thereof, has not been submitted to any other University or Institution for the award of any degree or diploma.



(Professor T. Ramamurthy)

Soil Mechanics and Foundation Engineering
Department of Civil Engineering
Indian Institute of Technology,
New Delhi - 110029.

SYNOPSIS

It has long been felt that if rapid progress is to be made in design and predicting the performance of increasingly complicated soil structures more emphasis should be given to the stress-strain behaviour of soils under conditions operating in the field. The development of theoretical stress-strain relationships for soils calls for a test apparatus which offers application of any increment of stress (or strain) to the specimen with any orientation of the specimen. It should also permit measurement of stress and strain without any interference from the components of the apparatus.

Unfortunately, no such ideal equipment, so far, exists which can meet the above requirements fully. Various equipments have been fabricated so far in which principal stresses and strains acting on a soil specimen could be independently controlled and measured employing various combinations of flexible and rigid boundaries. All these equipments suffer from one or the other defects in terms of mechanical complexities, restricted stress paths and limited stress levels.

In this thesis the design and performance of a modified Universal Triaxial Apparatus is described. This apparatus employs a combination of flexible and rigid boundaries to subject a 7.6 cm cubical soil sample to three different and uniform direct stresses and to permit measurement and control of strains.

Consolidated - drained tests were conducted in the Universal Triaxial Apparatus (UTA) to study the effect on strength-deformation characteristics of dense, medium and loose samples of Ottawa sand and of dense dense/samples of glass ballotini under various combinations of major, intermediate, and minor principal stresses employing different stress paths. Tests in plane strain conditions were also conducted. Compression tests on cylindrical samples (10.15 cm dia. and 20.30 cm high) were conducted in the conventional triaxial apparatus (CTA) over a complete range of initial porosities of both the granular materials.

In the case of compression tests under axisymmetric conditions ($\sigma_2' = \sigma_3'$) practically identical results in terms of the peak strength and the volumetric strain rate at failure are obtained from the conventional triaxial apparatus and the Universal Triaxial Apparatus over a complete range of initial porosities.

An approximately linear increase in the peak strength is obtained for samples of a given porosity when the intermediate principal stress increases from being equal to the minor principal stress (i.e.

$$b = \frac{\sigma_2' - \sigma_3'}{\sigma_1' - \sigma_3'} = 0.0) \text{ to the value required to maintain}$$

the conditions of plane strain and then the peak strength continually decreases to its original value at

$b = 1$ ($\sigma_1' = \sigma_2'$). It is observed that the resulting linear strains and the volumetric strains are influenced by the stress path followed. The ratio of octahedral shear stress $(\tau_{\text{oct}})_f$ to octahedral normal stress $(\sigma_{\text{oct}})_f$ is found to be uniquely related to the octahedral shearing strain $(r_{\text{oct}})_f$ at failure and the maximum angle of shearing resistance ϕ' .

ACKNOWLEDGEMENTS

The research for this thesis was carried out in the Soil Mechanics Laboratory of the Department of Civil Engineering at the Indian Institute of Technology, Delhi.

The Author expresses his gratitude to Dr. T. Ramamurthy, Professor of Soil Mechanics and Foundation Engineering, for his guidance, stimulation and encouragement throughout the ~~research~~ programme.

Special thanks are due to the staff of Soil Mechanics Laboratory and workshop particularly to Messrs. G.K. Mehta, A.S. Bonga and T.R. Bhogal for their excellent cooperation and work in fabricating the Universal Triaxial Apparatus.

The Author is grateful to the Director, Indian Institute of Technology, Delhi, for a grant of Research scholarship and financial assistance.

Thanks are also due to Mr. A.K. Berli for typing the thesis and to Mr. R.K. Rastogi for tracing all the drawings presented in this thesis.

INDEX

<u>SYNOPSIS</u>	i
<u>ACKNOWLEDGEMENTS</u>	ii
<u>INDEX</u>	v
<u>LIST OF NOTATION</u>	ix
<u>CHAPTER 1</u> <u>INTRODUCTION</u>	1-3
1.1 Importance of simulating field condtions in the laboratory	1
1.2 The present investigation	3
<u>CHAPTER 2</u> <u>PREVIOUS WORK</u>	4-86
2.1 The conventional triaxial apparatus	4
2.2 Shear box apparatus	12
2.3 Hollow cylinder test apparatus	21
2.4 Torsion shear test apparatus	22
2.5 Plane strain apparatus	27
2.6 Equipments to apply a general stress system	38
2.6.1 Rigid platens	38
2.6.2 Flexible rubber bags	46
2.6.3 Combinations of flexible and rigid boundaries	60
2.7 Stress-strain theories pertaining to soils	76
2.7.1 Elasticity applied to soils	76
2.7.2 Plasticity applied to soils	79
2.7.3 Rowe's stress dilatancy theory	83

<u>CHAPTER 3</u>	<u>DESCRIPTION OF APPARATUS</u>	87-104
3.1	Introduction	87
3.2	General description of universal triaxial apparatus	88
3.3	Details of universal triaxial apparatus	95
3.3.1	The base	95
3.3.2	The cap	97
3.3.3	The guides	97
3.3.4	Rubber bags	99
3.3.5	The sample former	101
3.3.6	Rubber membrane	101
3.3.7	End lubrication	103
3.4	Modifications in universal triaxial apparatus	103
<u>CHAPTER 4</u>	<u>EXPERIMENTAL WORK</u>	105-129
4.1	Introduction	105
4.2	Properties of the materials used	106
4.3	Preparation of cubical specimens	107
4.4	Preparation of cylindrical specimens	114
4.5	Test programme	115
4.5.1	Tests in the universal triaxial apparatus	115
4.5.1.1	Series A	117
4.5.1.2	Series B	117
4.5.1.3	Series C	118
4.5.1.4	Series D	118
4.5.1.5	Series E	119
4.5.1.6	Series F	119
4.5.2	Tests in the conventional triaxial apparatus	120

4.6	Test calculations	121
4.6.1	Tests in the conventional triaxial apparatus on cylindrical samples	121
4.6.2	Tests in the universal triaxial apparatus on cubical samples	122

CHAPTER 5 PRESENTATION AND DISCUSSION OF TEST RESULTS 130-279

5.1	Introduction	130
5.2	Comparison of axisymmetric compression tests in the conventional triaxial apparatus and in the universal triaxial apparatus	131
5.2.1	Stress-strain characteristics	136
5.2.2	Peak strengths	140
5.2.3	Axial strains at failure	143
5.2.4	Volumetric strain rates at failure	143
5.2.5	Conclusions	146
5.3	Plane strain tests	148
5.3.1	Peak strengths	151
5.3.2	Axial strains at failure	156
5.3.3	Volumetric strains and volumetric strain rates at failure	158
5.3.4	Ratio of intermediate principal stress to the sum of the other two principal stresses	161
5.3.5	Ratio of octahedral shear stress to octahedral normal stress at failure and octahedral shearing strain at failure	163
5.4	Compression tests in the UTA under general stress system with different stress paths in the region $0 < b < 0.3$.	168
5.4.1	Stress-strain characteristics	175
5.4.2	Peak strengths	179
5.4.3	Linear strains at failure	192
5.4.4	Volumetric strains and volumetric strain rates at failure	211
5.4.5	Octahedral shearing strains	234
5.4.6	Ratio of octahedral shear stress to octahedral normal stress	234

5.5	Extension tests on cubical samples in the UTA under general stress system in the region $b = 0.6$ to $b = 1.0$.	251
5.5.1	Introduction	251
5.5.2	Extension tests in the present investigation	258
5.5.2.1	Stress-strain characteristics	262
5.5.2.2	Peak strengths	264
5.5.2.3	Linear strains, volumetric strains, volumetric strain rates at failure	272
5.5.2.4	Ratio of octahedral shear stress to octahedral normal stress at failure	273
 <u>CHAPTER 6</u> <u>CONCLUSIONS</u>		 280-286
6.1	Performance of the modified universal triaxial apparatus	280
6.2	Comparison of axisymmetric compression tests in the conventional triaxial apparatus and in the universal triaxial apparatus	280
6.3	Plane strain tests	281
6.4	Compression tests in the UTA under general stress system with different stress paths in the region $0 < b < 0.3$	282
6.5	Extension tests on cubical samples in the UTA under general stress system in the region $b = 0.6$ to $b = 1.0$.	284
 <u>FUTURE WORK</u>		 287
 <u>REFERENCES</u>		 288
 <u>LIST OF FIGURES</u>		 302
 <u>LIST OF TABLES</u>		 313
 <u>APPENDIX A</u>		 314
 <u>BIO-DATA</u>		 415