Ground and Water: Theory to Practice
Proceedings of the 55th Canadian Geotechnical and 3rd Joint IAH-CNC and CGS Groundwater Specialty Conferences, Niagara Falls, Ontario, October 20-23, 2002
Edited by D. Stolle, A.R. Piggott and J.J. Crowder and published by the Southern Ontario Section of the Canadian Geotechnical Society

EVALUATION OF THE STRENGTH AND DEFORMATION PARAMETERS OF OLIMAG SYNTHETIC OLIVINE

Brian Lapos, Queen's University, Kingston, Ontario, Canada
Ian D. Moore, Queen's University, Kingston, Ontario, Canada

ABSTRACT

Over the past decade, two buried pipe test cells have been developed by Brachman, Moore and others to evaluate the behaviour of buried pipes under various loading conditions. Health concerns have meant the use of silica-based materials in these cells has been discontinued, being replaced with Olimag synthetic olivine, a uniform angular material used for sand blasting. This paper classifies the strength and deformation parameters of Synthetic Olivine, using results from a series of triaxial tests at varying confining pressures. Response was measured under loose and dense conditions, and Janbu deformation parameters K, and n are determined for both densities. The Synthetic Olivine is found to be a highly stress dependent soil with a low modulus. These strength and deformation parameters are used in pre-test predictions of expected behaviour, and post-testing analysis to interpret the measured response.

RÉSUMÉ

Pendant la dernière décennie, deux cellules d'essais de tuyaux enterrés ont été développées par Brachman, Moore et autres pour évaluer le comportement des tuyaux enterrés sous des diverses conditions de chargement. Des inquiétudes reliées aux problèmes de santé ont conduit à l'arrêt de l'utilisation des matériaux à base de silice dans ces cellules et à leur remplacement par Olimag Olivine Synthétique, un matériau angulaire uniforme utilisé dans le concassage du sable. Cet article classifie les paramètres de résistance et de déformation de l'Olivine Synthétique, en utilisant les résultats d'une série d'essais triaxiaux à diverses contraintes de confinement. La réponse a été mesurée sous des conditions lâche et dense, et les paramètres de déformation de Janbu K et n sont déterminés pour les deux conditions. Il est trouvé que l'Olivine Synthétique est un sol fortement dépendant du niveau de contrainte avec un module faible. Ces paramètres de résistance et déformation ont été utilisés dans la prédiction avant essai des comportements espérés, et des analyses après essai pour interpréter les réponses obtenues.

1. INTRODUCTION

Testing in the buried pipe test facility developed by Brachman et al (2000) has traditionally used Silica based soils. In the late 1980's the World Health Organization, WHO, released findings indicating health concerns associated with inhaled silica dust. The findings showed that inhalation of silica dust could cause irritation and allergies, and might even be carcinogenic (WHO 1986). More recently, the WHO have indicated that occupational exposure to inhaled silica can cause lung cancer (WHO 2000). Given the growing health concerns associated with silica dust, researchers have elected to begin using Olimag Synthetic Olivine in place of conventional silica sands. Synthetic Olivine does not contain silica dust and does not produce that material when handled (placed, compacted, loaded to high pressures, removed). However the practical use of Synthetic Olivine to simulate typical sand response needs investigation.

A series of triaxial tests have been performed on the Synthetic Olivine to obtain its strength and deformation parameters. Tests were performed for the material in both the loose and dense state, with corresponding densities of 1.3 tonnes/m^3 and 1.5 tonnes/m^3. The loose sample was tested using vacuum to produce the confining pressure where only the deflection and applied load were measured. The dense sample was tested fully saturated under drained conditions measuring the volume change, deflection, and applied load. Using the results of the triaxial tests, the internal angle of friction was determined along with the deformation parameters, K and n used in the model of (1963) classified as Janbu Hypoelastic (Chen 1990). The internal angle of friction was compared to the internal angle obtained using a standard Direct Shear Box test, provided by Law (2001), in-order to evaluate the results. The last test to be performed on the Synthetic Olivine was a standard sieve analysis, to determine the material grading. This project aims to evaluate the Synthetic Olivine for potential use in testing of buried infrastructure in the laboratory.

2. MATERIAL DESCRIPTION

Olimag Synthetic Olivine, the material discussed in this project, is produced by Olimag primarily for use in sand blasting. The material is visibly angular in shape with a gritty texture, containing less than 1% silica. To help describe the material, a sieve analysis was performed and the material was classified using the MIT classification system and the Unified Soil Classification System (USCS), Figure 1.

The results show that Synthetic Olivine is poorly graded sandy gravel with little or no fines, denoted SP. The samples tested are predominately single size, with more than half the sample finer than the #4 sieve, and more than half coarser than the 200 sieve. From the grain size distribution the coefficient of curvature and the uniformity coefficient for the Synthetic Olivine were determined to be 0.94 and 1.46 respectively (See Figure 1). To complete the material description, the specific gravity (relative density) of Synthetic Olivine was tested by Law (2001) according to ASTM 854 (Bowles, 1992), and found to be 3.2.

3. TESTING AND SETUP

The deformation parameters of Synthetic Olivine were obtained using a conventional triaxial test (Bishop and Henkel, 1957). Testing of the material in a loose and dense condition was undertaken using two different methods. The dense tests were performed at The University of Western Ontario and were undertaken for fully saturated, fully drained conditions, at a density 1.5 tonnes/m^3. During the tests, the volume change, deflection, and applied load were measured. The dense sample was prepared in five compacted lifts approximately 20 mm in height, for a total sample height of 100 mm. For each test, a backpressure of 20 kPa was applied to provide the final confining pressures of 150, 50 and 20 kPa. All the dense samples were loaded at a rate of 0.254 mm/min, and the results recorded. Due to scheduling problems, the loose tests were completed at Queen's University at a density 1.3 tonnes/m^3. The equipment used was conventional triaxial equipment, however the method of testing did not use water to apply the confining pressure. Rather than saturating the sample before testing, vacuum was applied internally not only to stabilize the sample but also to create the confining pressure. Preparation of the loose sample was similar to the dense, except the sample was poured continuously at a steady rate until the mold was filled. As with the dense samples, the loose samples were then loaded to failure at a rate of strain of 1.52 mm/min.

4. TRIAXIAL TEST RESULTS

Six triaxial tests were used to determine the deformation parameters of the Synthetic Olivine. Three samples were prepared in a dense state and tested at 150, 50, and 20 kPa. For the 150, 50, 20 kPa tests, maximum deviator stresses (σ_1 - σ_3) were measured to be 774, 336, 184 kPa respectively. Using the deviator stress and back pressure, σ_1 and σ_3 were calculated for each confining pressure and plotted to determine the Mohr Coulomb envelope. From the Mohr Coulomb envelope, the internal angle of friction (ϕ') under dense conditions was determined to be 44.2 degrees. The cohesion (c) for the densely prepared tests was approximately 30 kPa. This is typical of a dense granular material at these stress levels, since the Mohr-Coulomb envelope is non-linear.

Three samples were prepared in a loose condition to determine the non-linear strength parameters for low density. With the different equipment, the tests could not be performed at the same confining pressures as the dense samples. Confining pressures of 20, 46.6, and 72.4 kPa produced the maximum deviator stresses (σ_1 - σ_3) of 76, 201, and 293 kPa respectively. The internal angle of friction (ϕ') measured from the Mohr Coulomb envelope for the loose sample was measured to be 41 degrees. The cohesion (c) for the loose sample was approximately zero.

5. SHEAR BOX TEST RESULTS

Shear strength for the Synthetic Olivine was measured in the shear box by Law (2001). These shear box tests were performed for both levels of sand density (low and high), and interpreted to provide values of friction angle for these two densities, 38 and 41 degrees respectively. Comparison of these results with those from the triaxial tests (41 and 44 degrees, respectively) indicates that the difference in angle of internal friction between loose and dense conditions was measured to be 3 degrees in both test devices, but that both angles of friction measured under triaxial compression exceed those obtained from the shear box. A review of the literature indicates that this difference is typical of those measured for other soils, where a friction angle between 1 and 4 degrees lower is obtained in the shear box (e.g. Stark, 1997). Rowe (1969) suggests that the principal reason for this discrepancy is that the triaxial test produces more uniform strain.

6. DEFORMATION PARAMETERS

The triaxial test data for the Synthetic Olivine were also used to determine the deformation characteristics. The Janbu (1963) deformation parameters, K and n, are obtained for use in finite element analysis as outlined in Cande (1989). Janbu's soil model for initial elastic module, E_i takes the form

$$\frac{E_I}{P} = K\left(\frac{\sigma_3}{P}\right)^n$$

where, P = atmospheric pressure = 101.3 kPa
K, n = deformation parameters
σ_3 = effective confining stress

Chen (1990) provides a detailed description of the Janbu (1963) model. It is the simplest class of Hypoelastic model. This model is very practical since the parameters are easily determined from standard triaxial tests, and the results are suited for implementation in finite-element codes. The model uses stress-strain relations that are formed directly as an extension of the isotropic linear elastic model, replacing the elastic constants with variable tangential moduli, expressed as functions of the stress or strain invariants.

Using the triaxial test data for Synthetic Olivine, the Janbu constants were determined for both loose and dense conditions. The constants K and n, for the high density were found to be 340 and 0.81 respectively. Figures 2 and 3 show the stress-strain curves used to determine the initial tangent moduli and the logarithmic plots used to obtain the constants for this dense condition. The constants for the loose condition, K and n were found to be 190 and 0.98 respectively.

The constant K is used to quantify the magnitude of initial modulus as a multiple of atmospheric pressure at an effective stress of one atmosphere (a typical earth pressure at a depth of 10 metres). The coefficient n indicates the extent that the modulus is dependent on earth pressure. A value close to zero means that the modulus is stress independent, whereas a value close to unity means that modulus is a linear function of stress. Comparing the measured and the theoretical E_i and σ_{Fail} in Table 1, the Janbu equation and Mohr Coulomb failure criterion predicts the theoretical EI and σFail within 10% of the measured. Figure 4, compares the theoretical and measured E_i and σ_{Fail} for the dense condition at confining pressure of 150 kPa.

7. CONCLUSIONS

Synthetic Olivine has been identified as a suitable replacement for laboratory use of silica based soils to reduce health risks. Triaxial tests have been performed, which indicate that Synthetic Olivine is more stress dependent than typical backfill materials, likely the result of the angular particle shape. The Janbu deformation parameters K and n have been estimated for both dense and loose conditions, facilitating pre- and post-test evaluation and interpretation.

8. ACKNOWLEDGEMENTS

The work has been supported by the Natural Sciences and Engineering Research Council of Canada through a Discovery Grant provided to Dr. Ian D. Moore. Dr. Moore's position at Queen's University is funded by the Canadian Government through the Canada Research Chairs Program.

9. REFERENCES

Bishop, A And Henkel, D.J. 1957. *The Triaxial Test.* Edward Arnold (Publishers) Ltd. Reprinted 1978.

Bowles, J.E. 1992, Fourth Edition. *Engineering Properties Of Soil And Their Measurements.* Mcgraw-Hill, Inc, Page 43, 71, 165, 189, 201.

Brachman, R.W.I., Moore, I.D. and Rowe, R.K., 2000. *The design of a laboratory facility for evaluating the structural response of small-diameter buried pipes*. Canadian Geotechnical Journal, Vol. 37, No. 2, April, pp. 281-295.

Chen, W.F And Mizuno, E. 1990. *Nonlinear Analysis In Soil Mechanics, Theory And Implementation.* Elsevier Science Publishers B.V, Amsterdam, Developments In Geotechnical Engineering, Vol 53, Pp 65-70.

Holtz, Robert D And Kovacs, William D. 1981. *An Introduction To Geotechnical Engineering.* New Jersey.

Janbu, N. 1963. *Soil Compressibility As Determined By Oedometer And Triaxial Test.* Proceedings Of The European Conference On Soil Mechanics And Foundation Engineering, Vol. 1, Pp 19-25, Weisbaden.

Law, L.C.M. (2001). *Personal Communication*. Unpublished Laboratory Test Data.

Rowe, P.W. 1969. *The Relation Between The Shear Strength Of Sands In Triaxial Compression, Plane Strain, And Direct Shear.* Geotechnique, London, England, 19(1), Pp 75-86.

Muser, S. (1989) *Cande User Manual*, Appendix A.

Stark, Timothy D And Hisham Eid T. April 1997. *Slope Stability Analyses In Stiff Fissured Clays.* Journal Of Geotechnical And Geoenvironmental Engineering, Vol 123(4), Pp 335-343.

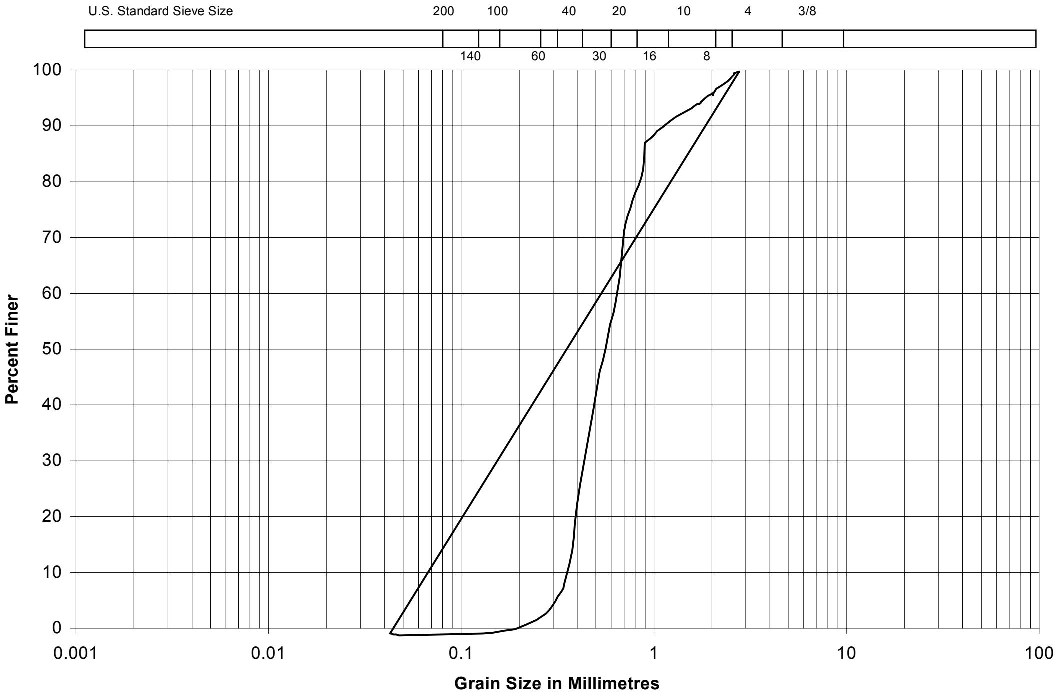
World Health Organization. 2000. *Crystalline Silica, Quartz.* Concise International Chemical Assessment Document, #24 (Ipcs), Geneva, Pp 23-25.

World Health Organization, Geneva. 1986. *Recommended Health-Based Limits In Occupational Exposure To Selected Mineral Dusts (Silica, Coal).* Technical Report Series 734, Geneva, Pp 5-20

9.1.1

9.1.2 Table 1. Summary of Parameters Measured During Testing

	Pressures (kPa)			**(kPa)**		**Measured (kPa)**		**Theoretical (kPa)**	
10. DENSE	**Total**	**Back**	σ_3	σ_1-σ_3	σ_1	E_i	σ_{Fail}	E_I	σ_{Fail}
Test 1	40	20	20	184	204	9462	184	9255	112
Test 2	70	20	50	336	386	15385	336	19441	278
Test 3	170	20	150	774	924	48850	774	47334	833
11. LOOSE									
Test 1	0	-46.3	46.3	201	247	8600	201	8992	223
Test 2	0	-20	20	76	96	3412	76	3925	96
Test 3	0	-72.4	72.4	293	365	12500	293	13848	348



$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.6}{0.41} = 1.46 \quad C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.48^2}{0.6 \times 0.41} = 0.94$$

Figure 1. Grain Size Distribution

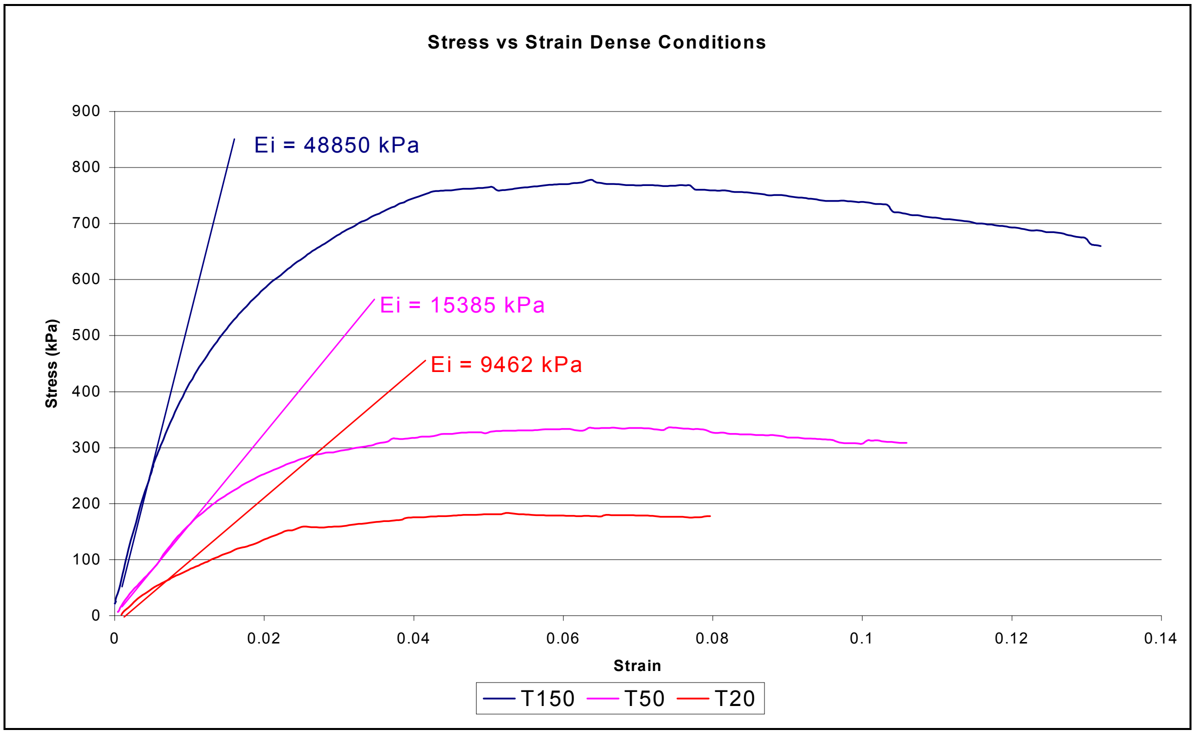


Figure 2. Initial Moduli For Dense Condition (Confining Pressures 20, 50, 150 KPa)

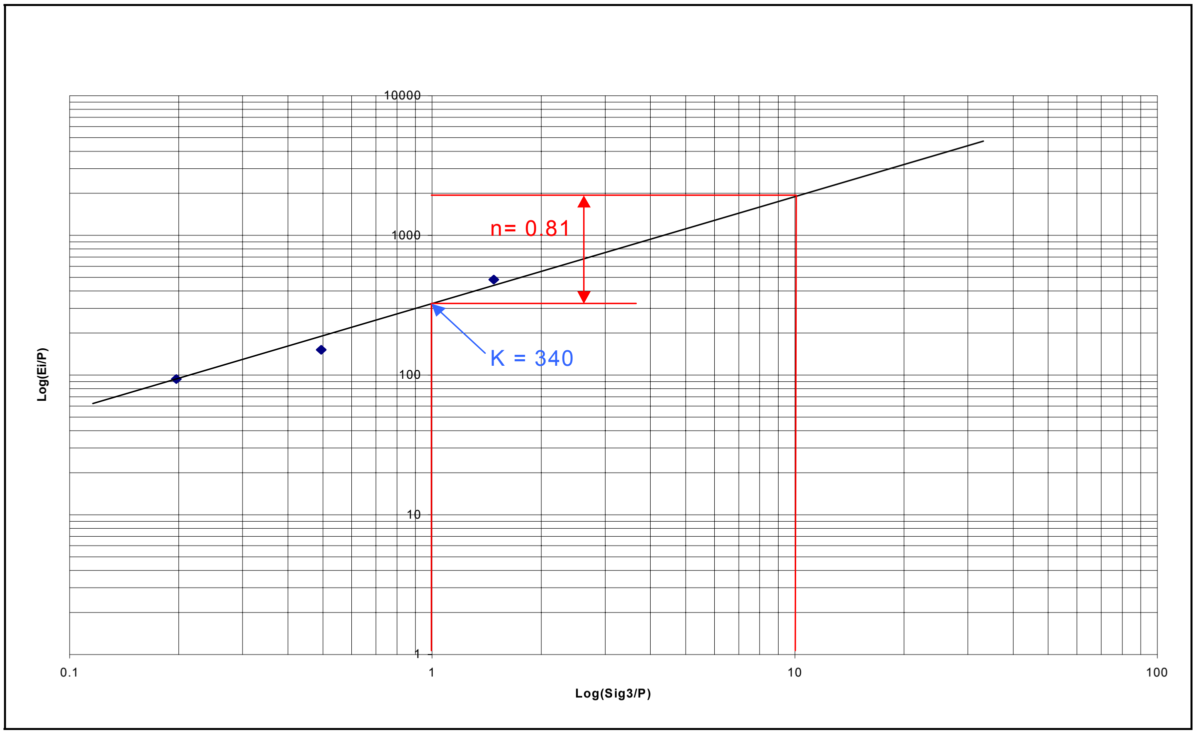


Figure 3. Deformation Parameters, Dense Condition (Atmospheric Pressure P = 101.3 KPa)

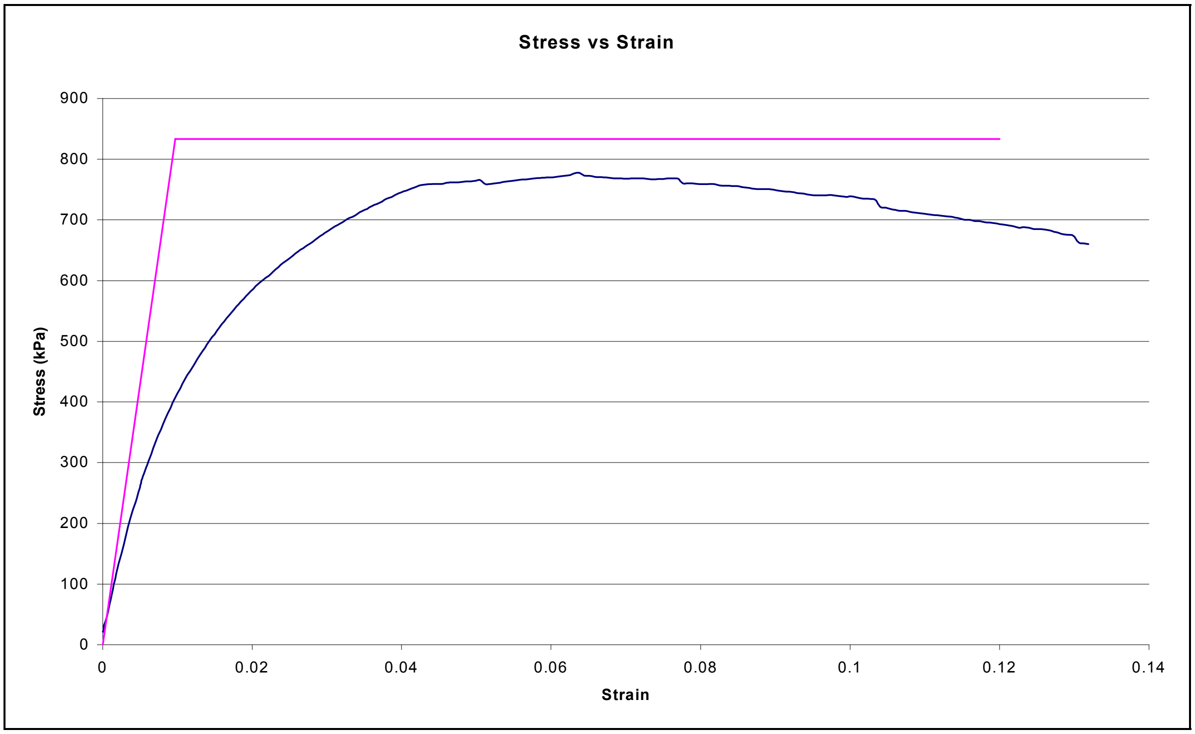


Figure 4: Measured and Theoretical E_i and σ_{Fail} for Dense conditions (confining pressure 150 kPa)