A STUDY OF A MIXTURE OF COARSE AND FINE SANDS

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Abstract

The present study investigates both an experimental work on coarse (Leighton Buzzard Sand fraction B) and fine (Leighton Buzzard Sand fraction E) sand mixtures, and a modeling of the results. The experimental database is based on a laboratory study of saturated coarse and fine sand mixtures with various mix ratios. In the tests, pore water pressure generation (u), deviatoric stress (q), and strain levels (ε) have been measured in a triaxial testing apparatus. Then, the results have been modelled using stepwise regression (SR). The input variables in the developed SR models are the fines content, and strain, and the outputs are deviatoric stress, pore water pressure, and undrained Young's modulus. The proposed SR models are presented as simple explicit mathematical functions for further use by researchers.

Streszczenie

Obecna analiza dotyczy badań doświadczalnych wykonywanych zarówno na gruboziarnistej (Leighton Buzzard Sand fraction B), jak również drobnoziarnistej mieszaninie piasku (Leighton Buzzard Sand fraction E) i modelowaniu uzyskanych wyników. Wyniki doświadczeń oparte są na badaniu w różnych proporcjach nasyconych mieszanin gruboziarnistego i drobnoziarnistego piasku. Podczas wykonywania testów w aparacie trójosiowego ściskania mierzone były następujące wielkości: ciśnienie wody w porach (u), dewiator naprężenia (q) i poziomy odkształcenia (ε). Następnie, wyniki badań zostały zamodelowane, wykorzystując metodę regresji krokowej (SR). Danymi wejściowymi w zaawansowanej metodzie regresji krokowej (SR) są zawartości ziaren oraz odkształcenia, zaś danymi wynikowymi są dewiator naprężenia, ciśnienie wody w porach i niedrenowany moduł Younga. Zaproponowane modele regresji krokowej są przedstawione w prostych ustalonych funkcjach matematycznych w celu zastosowania ich w przyszłości przez naukowców.

Keywords: **Leighton Buzzard Sand fraction B; Leighton Buzzard Sand fraction E; Triaxial Testing; Stepwise Regression.**

1. INTRODUCTION

The field observations show that granular soils may contain fine geomaterials having different shape and size properties. The fines are to be expected to affect the engineering behaviour of sandy soils. Such researches related to the influence of fines on liquefaction potential have been subjected to intensive research in soil mechanics [1-3] Naeini and Baziar, 2004). These investigations were done to quantify the effects of finer particles on the liquefaction phenomena. The fines also affect the compressional characteristics of coarse grained soils. Several researches have been undertaken in order to study platy mica particles, as fines, in sandy soils [4-9]. Today, it is a well known fact that the presence of platy mica particles in coarse rotund sands alters the mechanical behavior of sandy soils. As early as 1925, Terzaghi [4] stated that much more experimental works were required for the foundation settlements prediction, as particle size alone was not enough to estimate a reasonable indication for the foundation settlements prediction. Gilboy [5] studied the influence of mica content on the compressibility of sand, and concluded that an increase in mica content resulted in an increase in the void ratio of the uncompressed material as well as an increase in compressibility. The observations, first made by Gilboy [5], that any system of analysis or classification of soil which neglects the presence and effect of the flat-grained constituents will be incomplete and erroneous. Olson and Mesri [7] concluded that for all apart from the most active of reconstituted clays, mechanical properties were the governing factors in determining compressibility. A recent experimental study by Theron [10] was conducted on mixtures of mica and sand, and demonstrated the enormous impact of particle shape on the mechanical properties. However, it is difficult to say that the influence of fines on liquefaction mechanism and compression behaviour is systematically considered in the literature [11-12]. Therefore, further investigation about the behaviour of mix of two submatrices (i.e. coarser grain and finer grain) is needed in order to gain a detailed insight regarding their influence on compression, liquefaction, and stress-strain behaviour.

The objective of this study is to develop Stepwise Regression (SR) based constitutive model for two types of sands mixtures (i.e., Leighton Buzzard Sand fraction B, Leighton Buzzard Sand fraction E) using experimental data. The experimental database used for SR modelling is based on a laboratory study of saturated sand mixtures with various mix ratios under a 100 kPa effective stresses in triaxial testing apparatus. Although SR techniques have been widely used in engineering applications, they have not been applied for the development of constitutive model equations of granular material mixture so far. Three different SR models are proposed; for deviatoric stress (q), pore water pressure (u), and undrained Young's Modulus (Eu). The predictions of SR models developed to predict behaviour of the mixtures are found to be quite accurate.

2. EXPERIMENTAL STUDY

Two different geomaterials were used in all the tests; Leighton Buzzard Sand fraction B and Leighton Buzzard Sand fraction E. The Leighton Buzzard Sand used in the experiments was fraction B supplied by the David Ball Group, Cambridge, U.K., confirming to BS 1881-131:1998. Its specific gravity, minimum and maximum dry densities were found to be 2.65, 1.48 g/cm^3 and 1.74 g/cm^3 respectively. As it can be seen from the Figure 1 and 2, more than 90% of the coarse sand particles, which are rounded and mainly quartz, are between (around) 0.6 mm and 1.1 mm. Leighton Buzzard Sand Fraction E supplied by the David Ball Group, Cambridge, U.K. confirming to BS 1881–131:1998, is uniform fine sand, with 85% by weight falling between 90-150μm. Its minimum and maximum dry densities were found to be 1.33g/cm^3 and 1.62 g/cm^3 respectively. Its specific gravity was found to be 2.65.

Leighton Buzzard Sand fraction B (coarse) and fraction E (fine) were mixed at various percentages of fines. The percentage of fine meant in this study refers to the dry weight of fine relative to the total dry weight of the mixture. Four fines percentages were considered; namely 5%, 10%, 15%, 20% and then compared with the clean Leighton Buzzard Sand. Figures 1 and 2 show the SEM picture for the coarse and fine sand particles used in the experimental study.

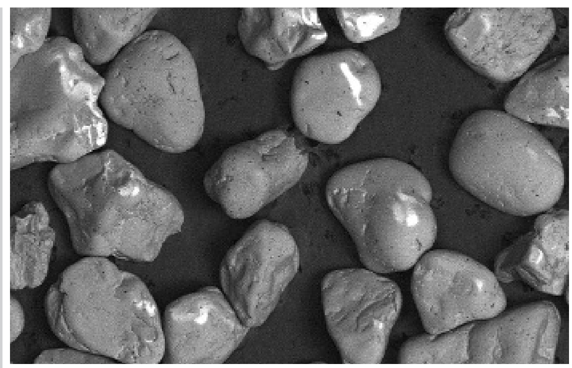

Figure 1.
SEM Picture of the Leighton Buzzard Sand fraction B used in the experimental study

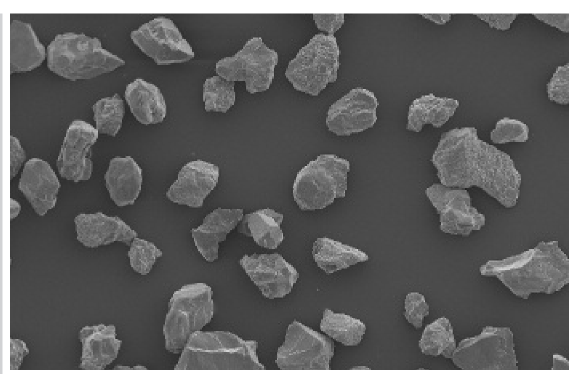

Figure 2.
SEM Picture of the Leighton Buzzard Sand fraction E used in the experimental study

All tests were conducted in a 100-mm-diameter Wykeham Farrance compression triaxial machine. Strain controlled loading was applied using a digitally controlled STALC 4958 type internal load cell at a constant rate of displacement. In order for the cell and the back pressures to be measured, two pressure transducers, PDCR 810 produced by Druck Limited, were used. Pairs of strain gauges were submersible LVDTs produced by R.D.P. Electronics Ltd., which were employed to measure the axial displacement in the middle third of the specimen in diametrically opposite positions.

Leighton Buzzard Sand fraction B, water and Leighton Buzzard Sand fraction E were mixed in the desired proportions to produce a uniform paste. A cylindrical membrane was attached to the bottom endplate using two o-rings and the split mould was placed around the endplate. Prepared uniform paste was then gently spooned into the split mould on the pedestal. Great care was taken to ensure that no vibration was employed. When the mould was completely filled, the excess sand particles were removed and the weight of the specimen was recorded. The top end plate was attached with two o-rings and 20 kPa suction was applied to the inside of the specimen. The split mould was carefully split to prevent any disturbance to the specimen. The test cell was then assembled and filled with water to apply cell pressure. After the test cell was completely assembled, the loading frame was placed. The suction inside the specimen was decreased while gradually increasing cell pressure of the desired value was achieved. During the consolidation process, the pore-pressure, cell pressure, volume, strain measurements were closely examined and recorded. Following the consolidation, the drainage valve to the specimen was closed, and then compressive load was commenced at a constant displacement rate of 0.015 mm/min.

3. PRESENTATION OF EXPERIMENTAL RESULTS

The effect of fine sand particles (i.e. Leighton Buzzard Sand fraction E) on the stiffness, strength, and pore pressure characteristics of the coarse sand particles (i.e. Leighton Buzzard Sand fraction B) was investigated. In order to investigate if the use of various mix ratios achieves any effect on mechanical properties, a triaxial compression test was first performed on de-aired water saturated specimen of clean coarse sand to be a reference test, and then to judge the effects of different ratios on the behavior of sand. The results are presented by displaying the pore water pressure (u, kPa) versus average axial local strain (%), deviatoric stress (q, kPa) versus average axial local strain (%), and undrained Young's modulus versus average axial local strain (%).

Figures 3, and 4 show the effects of increasing fine sand content on the deviatoric stress-strain behaviour of the coarse sand, and pore water pressure generation respectively. The clean coarse sand specimen behaves as might be expected, but the dilation of 10% and more by weight of fine grains causes the suppression of any dilation, low undrained shear strengths,

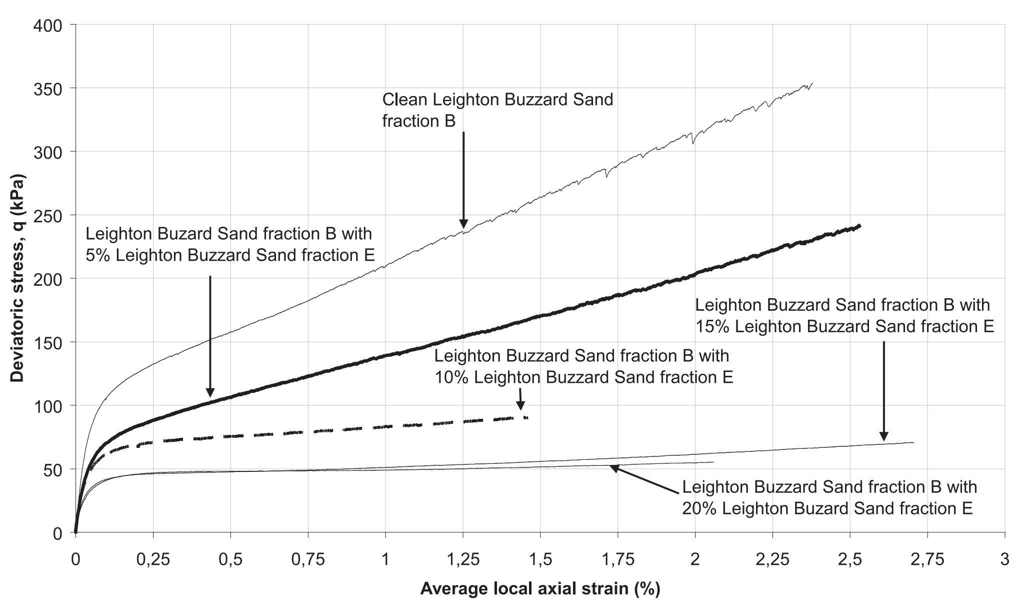

Figure 3.
Stress-strain curve for clean Leighton Buzzard Sand fraction B with different proportions of Leighton Buzzard Sand fraction E

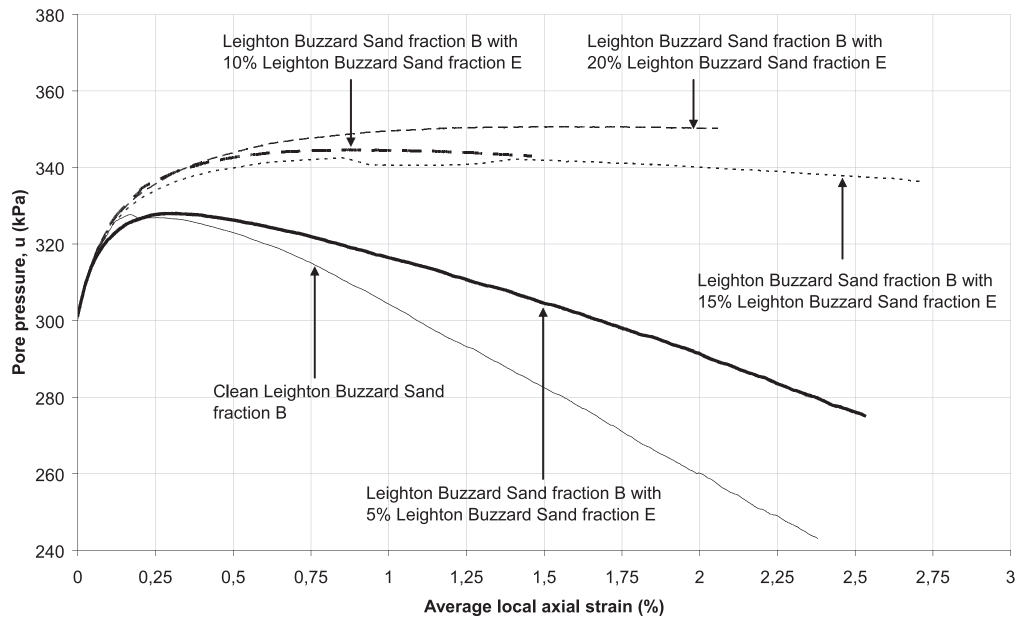

Figure 4.
Stress-strain curve for clean Leighton Buzzard Sand fraction B with different proportions of Leighton Buzzard Sand fraction E

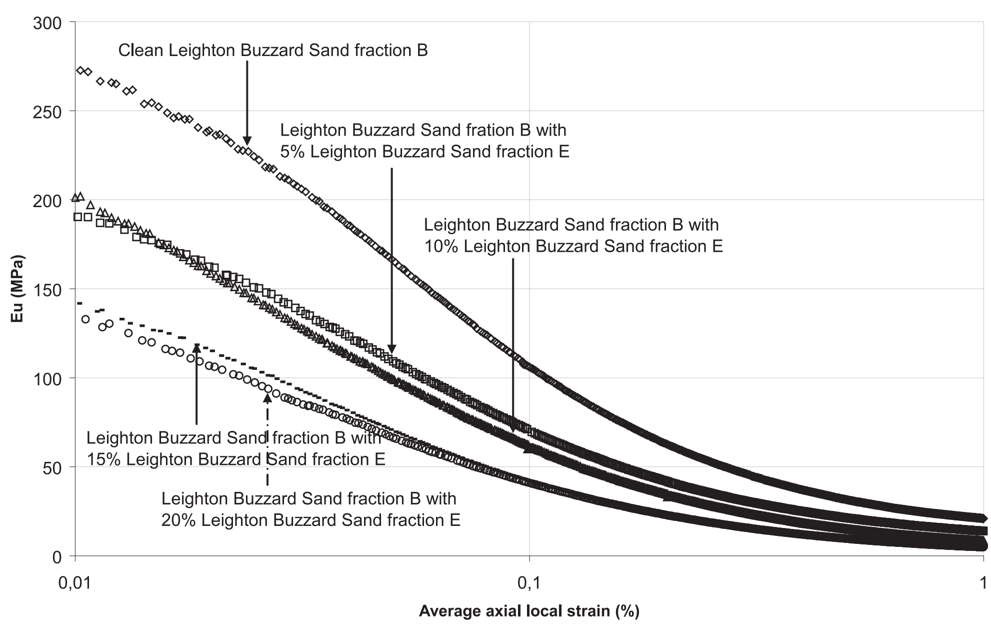

Figure 5.
Undrained Young's modulus as a function of local axial strain Leighton Buzzard Sand fraction B with different proportions of Leighton Buzzard Sand fraction E

and high level of pore pressure generation during shear. Figure 5 shows the undrained Young's modulus as a function of local axial strain Leighton Buzzard Sand fraction B with different proportions of Leighton Buzzard Sand fraction E. The test results show that the characteristics of the coarse sand (Leighton Buzzard Sand fraction B) tested are principally ascribable to the presence of the fine grains (Leighton Buzzard Sand fraction E). The author postulates that fine particles occupy the voids between

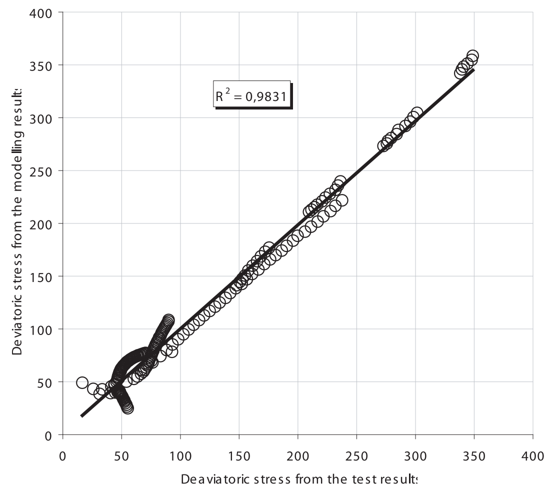

Figure 6.
SR vs. Test Results for the deviatoric stress (q)

coarse particles. Depending on the amount of fine particles present, the coarse sand particles are either in contact with each other and the behaviour of the samples tested is controlled by coarse sand particles, or they are separated by fine particles.

The shape of particles controlling the mechanical behaviour of the fine sand-coarse sand mixtures seems to be dependent on the contact mechanism between the coarse sand particles. When the coarse sand particles are in clear contact with each other, and the fine sand particles only partially fill the pores, the mechanical behaviour of the mixes under these situations is governed by the coarse sand. As the fine particles fill the pore spaces, the coarse sand particles are held apart, and the fine sands start to control the behaviour of the mixes. The contacts between the coarse sand particles reduce; the behaviour of the samples becomes clay like. With large volume of fine particles, the coarse and particles are suspended in a fine sand matrix which dominates the mechanical behaviour of the mixes. This shows the significance of the amount and position of the fine particles among the mixes.

4. STEPWISE REGRESSION MODELING

Modeling by Stepwise Regression (SR) is a robust tool for selection of the best subset models [13]. Subset models' determination is based on deleting or adding the variable(s) with the greatest impact on the residual sum of squares. The selection of variables may be using three ways; forward, backward or a combination of them. In the first one, the subset models are selected by adding one variable at a time to the previously selected subset. In each successive step, the variable in the subset of variables is added to the subset. Without an ending rule, forward selection longs until all variables are included to the model. However, backward stepwise method chooses the subset models by commencing with the full model and then eliminating at each step one variable whose deletion will cause the residual sum of squares to increase the least and continues until the subset model contains only one variable [14].

In both forward and backward methods, it should be noted that the influence of deleting or adding a variable on the contributions of other variables into the model is not being taken into account. Hence stepwise regression is a forward selection process that re-evaluates in each step the significance of all previously included variables. If the partial sums of squares for previously considered variables do not have a minimum requirement to stay in the model, the selection way changes to backward one and variables are dropped one at a time by all remaining variables have the minimum requirement. Stepwise selection of variables needs more computing than forward or backward way but, it has an advantage in potential subset models evaluated before the model for each subset size is fixed. It seems to be reasonable that the stepwise selection has a significant chance of choosing the best subsets in the sample data, however, selection of the best subset for each subset size is not under guarantee. Stepwise selection of variables uses both the forward and backward elimination criteria to stop the rule. The variable selection process ends when all variables in the model have the requirements to stay and no variables outside the model have the requirement to enter [14].

This paper aims at single empirical formulation of deviatoric stress (q), pore water pressure (u), and undrained Young's modulus (Eu) of coarse and fine sand mixtures SR based on experimental results. Therefore, an extensive experimental program has been performed on various coarse-fine sand mixtures. The details of the experimental study including the ranges of parameters have already been given in previous sections. Deviatoric stress, pore water pressure, and Young's modulus values have been modeled as a function of fine content in percentage, and strain, and the following equations have been obtained:

$$q = 36.91 + 161.74 * \varepsilon^{1/2} - 34.44 * FC^{1/2} * \varepsilon^{1/2} + 12.99 * \varepsilon^2 - 0.92 * FC * \varepsilon^2$$

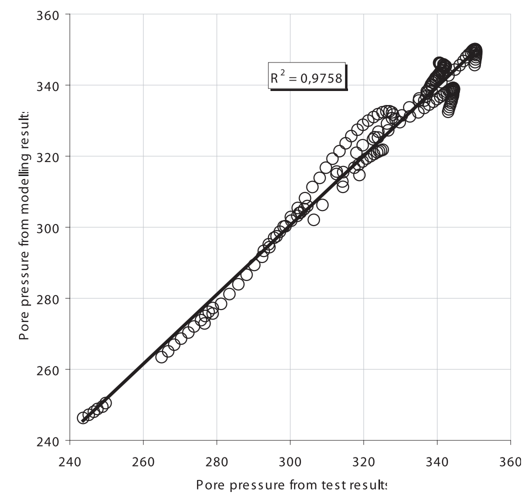

Figure 7.
SR vs. Test Results for the pore pressure (u)

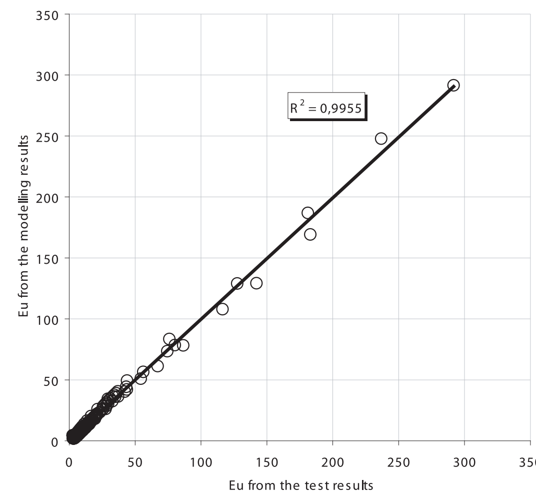

Figure 8.
SR vs. Test Results for the undrained Young's modulus (Eu)

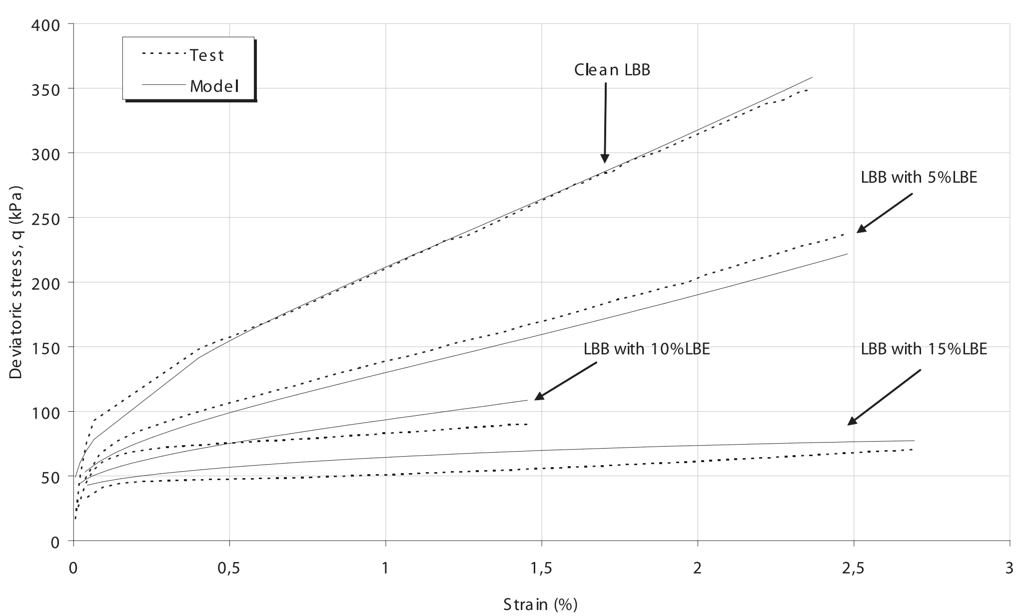

Figure 9.
A comparison between the deviatoric stress (q) values from the test results and those from the model (LBB: Leighton Buzzard Sand fraction B, LBE: Leighton Buzzard Sand fraction E).

$u = 333 + 4.54 * FC^2 - 29.2 * \varepsilon^{3/2} + 3.6 * FC * \varepsilon^2 - 0.2 * FC * 1/\varepsilon^{1/2} - 1.46 * \varepsilon^5 - 5.6 * \varepsilon^{-1/2} - 2.2 * FC^{1/2} * \varepsilon^3 - 0.08 * FC^2 * \varepsilon^2 + 8.8 * \varepsilon^4 + 0.26 * 1/\varepsilon$

$Eu = -31 + 40.1 * \varepsilon^{-(1/2)} - 2*10^{-5} / \varepsilon^4 - 4.3 * (FC/\varepsilon)^{1/2} + 12.9 * \varepsilon^{1/2}$

Where;

q = deviatoric stress (kPa)

u = pore water pressure (kPa)

Eu = undrained Young's modulus (MPa)

ε = average axial local strain (%)

FC = fines content (%)

The SW results vs. actual test results for all the models are presented in Figures 7, 8 and 9 respectively. Typical results of comparison between SW and test

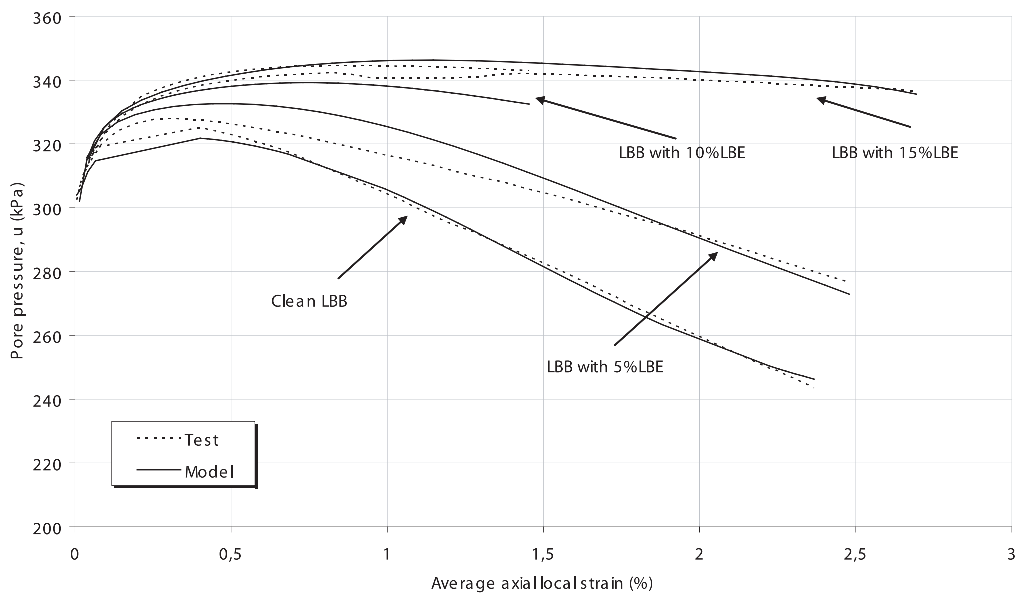

Figure 10.
A comparison between the pore pressure (u) values from the test results and those from the model (LBB: Leighton Buzzard Sand fraction B, LBE: Leighton Buzzard Sand fraction E)

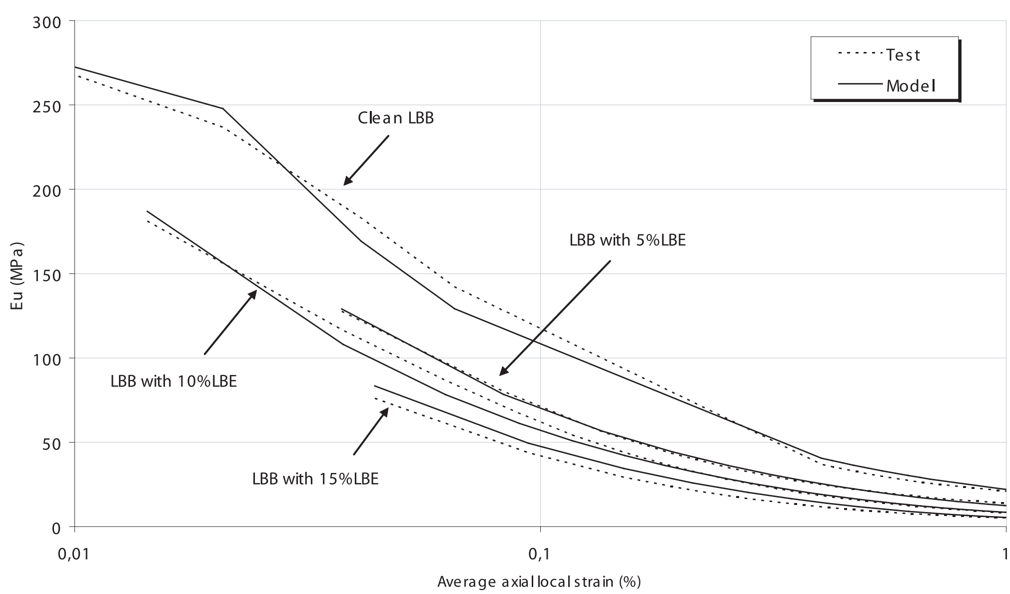

Figure 11.
A comparison between the undrained Young's modulus (Eu) values from the test results and those from the model (LBB: Leighton Buzzard Sand fraction B, LBE: Leighton Buzzard Sand fraction E)

results are observed very closely as presented in Figures 10 and 11 for deviatoric stress, pore pressure and Young's modulus respectively.

5. CONCLUSIONS

The study aimed at experimental determining variation of the deviatoric stress, pore water pressure, and Young's modulus. It was also aimed at developing empirical stepwise regression (SR) based models for prediction of deviatoric stress, pore water pressure, and Young's modulus of coarse-fine sand mixtures as a function of fine content and strain level. The experimental data presented here in the paper reveals that the high compressibility of the mixes is likely to be a result of particle shape.

Modeling of granular materials is a complex phenomenon particularly where a mixture of two or more materials exist. In this paper, it is shown that alternative methods such as soft computing techniques can be used to overcome this difficulty. This study is a work that inquires into the capability of SR approach for the empirical modeling of coarse-fine sand mixtures regarding deviatoric stress, pore water pressure, and Young's modulus. The predictions of developed SR equations for deviatoric stress ($R^2 = 0.98$), pore water pressure ($R^2 = 0.97$), and undrained Young's modulus ($R^2 = 0.99$) are observed to be quite accurate compared to test results.

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