Evaluating the stiffness of the boulder gravels underlying Stellenbosch

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ABSTRACT: Söhnge and Greef 1979 provided a detailed description of the geology of Stellenbosch as well as a summary of a number of structures constructed throughout the area. The presence of a well developed deposit of boulder gravels features centrally in the publication. While the boulder gravels are described in great detail in terms of material composition, the literature does not give any information on stiffness values or strains measured under influence of the loadings detailed. Modern day analysis of structures includes the calculation of strain under load of the structural foundations. Given the difficulty associated with determination of stiffness of the boulder layer either by way of in-situ or laboratory testing, analysis of the foundation settlements would historically have been somewhat subjective. Technological advances have allowed for the determination of in-situ stiffness profiles using Continuous Surface Wave testing. This paper will evaluate the stiffness of the sub-soils underlying the central Stellenbosch area, focussing on the properties of the boulder gravels, as established by Continuous Surface Wave testing in areas known to be underlain by substantial deposits of these boulder gravels as confirmed by geotechnical investigations. A sample of the structures listed in the Brink publication has been analysed for context with spread footings and loading configurations analysed to determine an allowable bearing capacity when founding in the boulder layer.

1 INTRODUCTION

In their 1979 publication titled “A town founded on alluvial gravel terraces” Söhnge and Greef provides a geological overview of Stellenbosch and details a number of multi-storey structures founded on the alluvial gravels underlying the town of Stellenbosch. Of note is the wide range of bearing pressures listed in the publication as well as the comments in the publication that the old historic buildings are still intact and remarkably free of cracking.

This paper discusses the determination of the stiffness properties of the alluvial boulder gravel horizon, applying investigative measures not available at the time of the original publication. Selected cases from the 1979 publication were analysed to evaluate the “engineering judgement” applied at the time when only limited stiffness values were available for the alluvial gravels.

From the data obtained, guidance is provided in the selection of preliminary footing sizes/bearing capacities and expected settlement where founding in/on the boulder gravels.

2 GEOLOGY

Approximately 35 – 5 million years ago the Stellenbosch area comprised an open valley landscape extending along a fault zone leading northwest from Jonkershoek to the coast. This valley was subsequently filled with talus consisting of sandstone boulders originating from the surrounding mountains.

Historic uplift of the coastal belt and fluctuation of sea levels lead to deviation of the Eerste River which resulted in the cutting off of the ancient Jonkershoek River system from the southwest. Three distinct terraces were cut into the landscape each associated with different periods of water fluctuation and flow rates and capped with a layer of boulder gravels.

Today the town of Stellenbosch is underlain by primarily the lower and middle terraces seated 4 and 7m above the riverbed. Only a small area located to the northeast of the town towards Helshoogte pass is underlain by the upper terrace with a level of 14m above the river bed. The underlying bedrock comprising weathered phyllites of the Tygerberg Formation.

The boulder gravels comprise rounded sandstone cobbles, boulders and to a lesser extent gravel of medium hard to hard rock consistency. The upper and middle terrace boulder gravels contain a sandy clay matrix. Shifting channels of the Eerste River led to the upper portion of the matrix material being washed out of the middle terrace. The lower terrace boulder gravels are characteristically open textured and free of matrix material with the cobbles and boulders well rounded and smaller in size of that was encountered in the other terraces.

From available data it is known that the boulder gravels typically occur from 1.0 – 2.0m below existing ground level and varies in thickness from 2.0 to 4.0m. Mantling the boulder gravels is a predominantly sandy soil which is often cemented, locally exhibiting collapse characteristics.

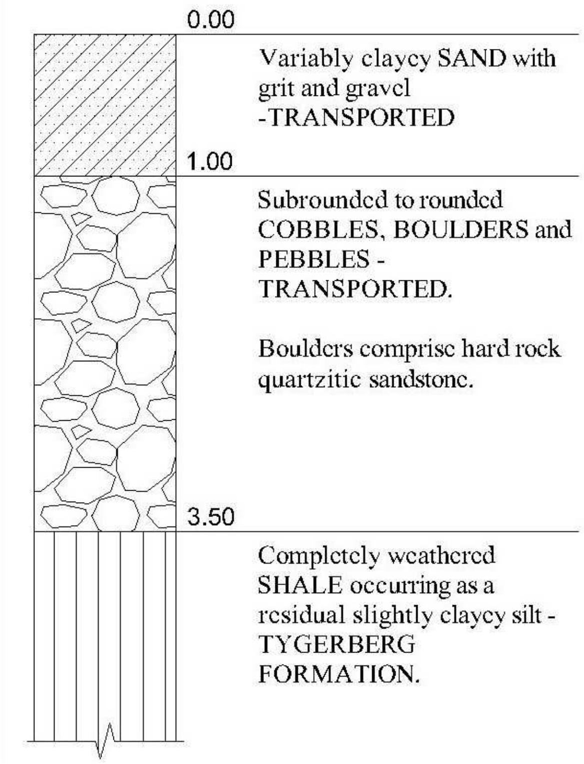

Figure 1. Typical subsoil profile

3 DETERMINATION OF BOULDER GRAVEL STIFFNESS

Traditional means of site investigation include the excavation of test pits and/or the drilling of boreholes for exposure of the subsoil profile. These invasive investigative measures are often supplemented by penetrometer (SPT, DCP & CPT) and laboratory tests to derive subsoil parameters for engineering design/analysis.

Advancement of a penetrometer through hard layers such as the boulder gravels underlying Stellenbosch typically prove extremely difficult with laboratory testing not practical given the particle size. The determination of soil parameters of the boulder gravels (in this case stiffness) would therefore have been based on either previous experience or published generic values during the time of the 1979 article, all of which would have been open for interpretation.

The use of geophysical techniques in site investigations has however now become part of the modern-day geotechnical engineer's toolbox. Although various geophysical tests such as spectral analysis of surface waves (SASW), multi-channel analysis of surface waves (MASW) and frequency-wave number (f-k) spectrum method are available, the impact source (typically a hammer) for these tests only generate a fixed frequency. In contrast the Continuous Surface Wave (CSW) test requires a variable frequency energy source to generate seismic energy. The variable frequencies allow the CSW test to measure the generated wave velocities through a range of depths with higher frequencies measuring the wave velocities through the shallower profile and the low frequencies measuring the wave velocities at depth. The depth range of the test is dictated by the soil stiffness and the energy of the shaker.

The CSW test measures the Rayleigh wave velocities for the various frequencies generated from which the soil stiffness can be calculated. This allows for the determination of stiffness of the boulder gravels as the seismic waves can travel through the hard rock boulders. Penetration testing cannot be undertaken in this material.

Forming the basis for this paper, five CSW tests were undertaken over areas where the subsoil profile has been established by previous investigations, this allowing for the accurate determination of the stiffness of the boulder gravels.

4 DISCUSSION

The Young's Modulus (E-value) of the subsoils were determined from CSW tests using a strain level of 0.1%, typically applied to the assessment of building foundations. The Young's Modulus of the boulder gravels was extracted from the test results for analysis as presented in Figure 2. The stiffness values obtained were somewhat variable, as would be expected in a horizon deposited by alluvial means and ranged from 61.9 to 179.7MPa. A characteristic value of 63MPa was obtained, this based on the lower 5 percentile value of all the stiffness values obtained in the boulder gravels.

Using the characteristic value obtained, a sample of the structures listed in the 1979 publication was analysed to gauge the applicability of the 63MPa characteristic value.

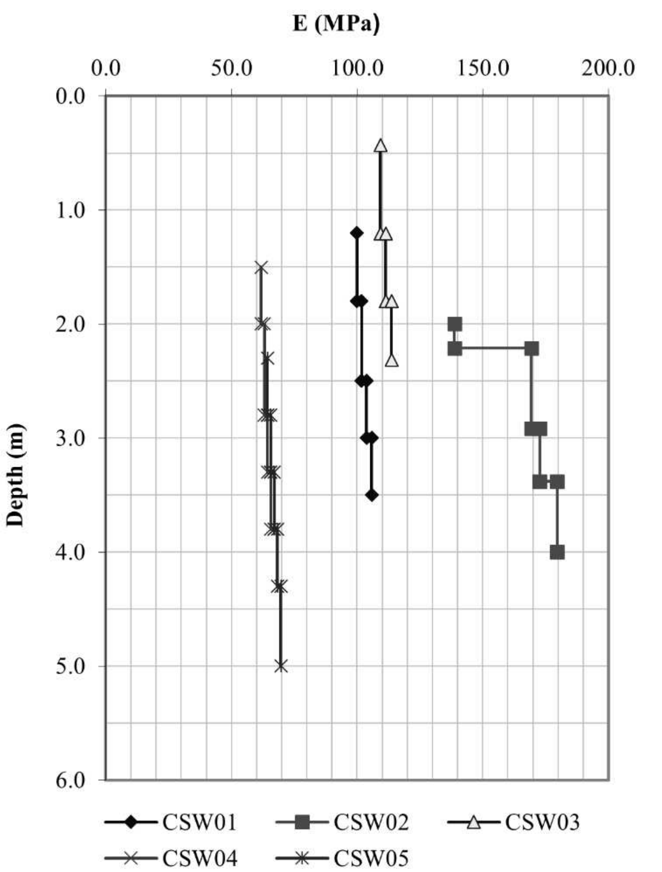

Figure 2. Stiffness values obtained in boulder gravels.

The settlements were calculated using Rocscience software Settle 3D utilising the stiffness values determined at 0.1% strain and Versak (developed the University of Pretoria) using the small strain stiffness values G_0 which determines the strain and computes stiffness for that level of strain.

Table 1. Settlements calculated applying the determined characteristic stiffness value.

Building	Footing Size	Bearing Press.	Settlement (Versak)	Settlement (Settle 3D)
	m	kPa	mm	mm
Rupert International	2.0 x 2.0	350	7.8	12.1
Perm	1.5 x 1.5	350	6.1	9.3
Serruria Hostel	1.0 strip	200	3.2	7.5
Standard Bank Building	1.0 strip	175	2.6	6.5
Helshoogte Hostel	3.5 x 3.5	400	15.3	23.2

* All footings pad footings unless otherwise noted

The results obtained in table 1 indicate settlements which would be regarded as acceptable (EN 1997-1 Part 1) for most structures confirming sound engineering judgement at the time. The variance in the settlement results between Versak and Settle 3D can be attributed to the determination of the soil stiffness values.

Given the results obtained above, settlement charts for both strip and pad footings were generated using the characteristic stiffness value to provide preliminary guidance on expected settlement where founding on the boulder gravels in Stellenbosch.

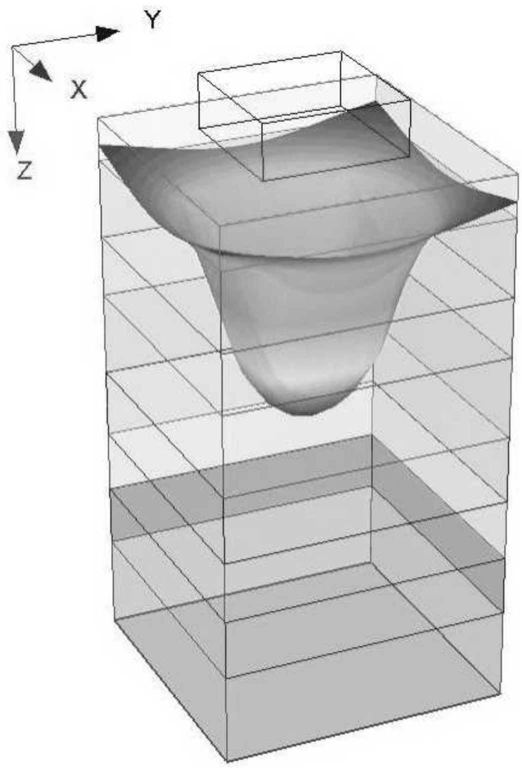

Figure 3. Example of Settle3D model.

It should be noted that given the variability of the stiffness values obtained, differential settlement must be considered. However, given the low settlements calculated, this should not be of great concern.

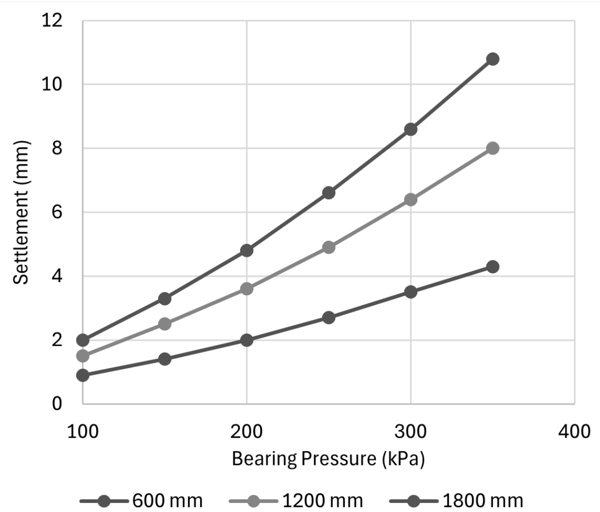

Figure 4. Load-settlement chart for founding a 600mm, 1200mm and 1800mm wide strip footing in the Stellenbosch boulder gravels.

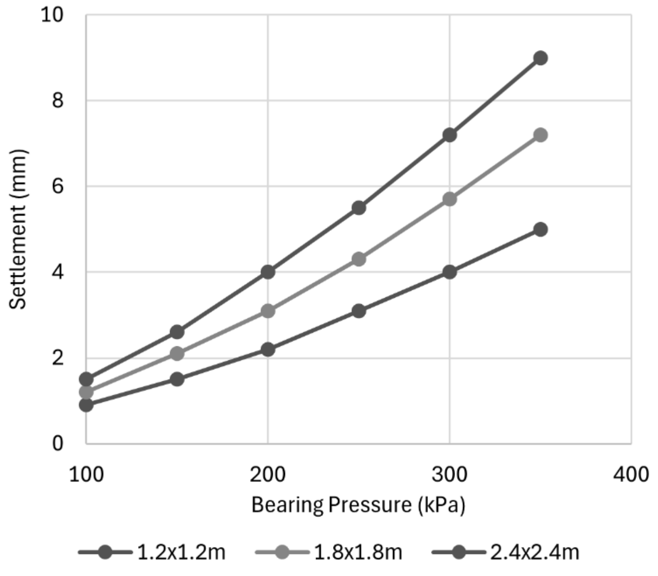

Figure 5. Load-settlement chart for founding a pad footing in the Stellenbosch boulder gravels.

For the above it was assumed that the footings were constructed on the boulder gravels and that the influence depth (pressure bulb) of the footings is developed in this horizon only.

5 CONCLUSIONS

Historically the boulder gravels underlying Stellenbosch provide a stable bearing stratum for conventionally founded structures. However, given the emphasis on strain levels and performance of structures the determination of settlement plays a significant role in modern-day design. Given the hard rock consistency of the boulders, the only realistic means of determining the stiffness of the boulder gravels is by way of geophysical testing, the CSW test deemed the most appropriate.

The settlement results obtained correspond to the performance of the documented existing structures. On the basis of this, load settlement curves were generated to provide preliminary guidance on anticipated settlement. It is however recommended that given the limited test sample and variance in results, site investigations be undertaken to confirm not only the stiffens of the subsoils but also to determine the level at which the boulder gravels occur and the extent thereof.

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