CHAPTER 4

Equipment and experimental work

4.1 Introduction

After the initial theoretical development of the method, data had to be collected in the field to test and evaluate the idea. The approach was to first test the method on a single layer situation. It was also important to obtain the density of the subsurface by other means, to have control over the data.

4.2 Development of the trial equipment

In order to save money, trial equipment was put together from different sources. A steel base plate of 50kg was acquired (Figure 4.1). The base plate is a square steel plate of 1.23m and is 5mm thick. The three-component Springheather geophone (Figure 4.2) was mounted onto the base plate. Bags were filled with sand to make weights of 50kg each. These bags are placed onto the base plate to provide the additional mass (Figure 4.2).

Figure 4.1: Large square 50kg steel base plate of 1.23m by 1.23m.

Figure 4.2: Mounting of Springheather 3-component geophone on base plate, with sand sacks to provide the weight.

The sand bags are put onto the base plate in an incremental fashion. The purpose of the sand bags is to change the weight of the system and hence the natural vibration frequency. The seismograph used for the original experimental equipment was an Ears-α seismograph system developed at the Council for Geoscience (Figure 4.3). The seismograph was originally developed by the Seismology Unit to monitor seismicity. It consists of a personal computer using a PC-104 interface operating from a 12V battery. It stores the data on a small internal hard disk drive. A DC to AC inverter was used to drive the monitor during the process.

The seismic source was a sledge hammer (Figure 4.4) and hammer blows were delivered at the four corners of the base plate. The hammer blows are delivered onto a small baseplate. The trigger is digital. Data recording length was set to 1s.

Figure 4.3: Ears-α seismograph system used which is developed by the CGS.

Figure 4.4: Seismic source was a sledge hammer. A hammer blow was delivered to corners of the plate.

4.3 First field test at Leeuwfontein

In order to verify the developed theory, it was necessary to find a locality which could represent a single layer only situation. The field survey should also be done where both geological and physical property control were good. The best locality found is just north of Pretoria at Leeuwfontein on the 2528CB Silverton sheet (Figure 4.5). The Leeuwfontein Syenites are igneous rocks present as a small outcrop on the farm Leeuwfontein (Figure 4.6) just north of Pretoria. It was mined for dimension stone in the past (Figure 4.7).

The Leeuwfontein syenite is part of the Roodeplaat Syenite Complex, situated in the Magaliesberg quartzites and diabase of the Pretoria Group. The depth extent of this syenite intrusion is more than 10m. This means that for the density sounding technique it can be regarded as a homogeneous single layer only situation.

The base plate was orientated in an N-S orientation. A sledge hammer was used as an energy source and a hammer blow was delivered to corners of the base plate. It was repeated for each weight, which was incremented with 50kg (a single sand sack) after four shots. The data was then recorded with the ears-α system.

The data was processed with a range of different software. The software used included Seisan^{TM}, a package used in seismology. The final plots were done in MS Excel. The main objective of the processing was to calculate the dominant frequency and the attenuation constant.

By plotting the obtained frequency against the added mass, and by substituting the frequency into equation 12 (Chapter 2), the value of the excited mass is obtained. To calculate the sample volume that is excited, the wave velocity is needed. This velocity and attenuation information is substituted into equation 41 (Chapter 2) to obtain the excited volume.

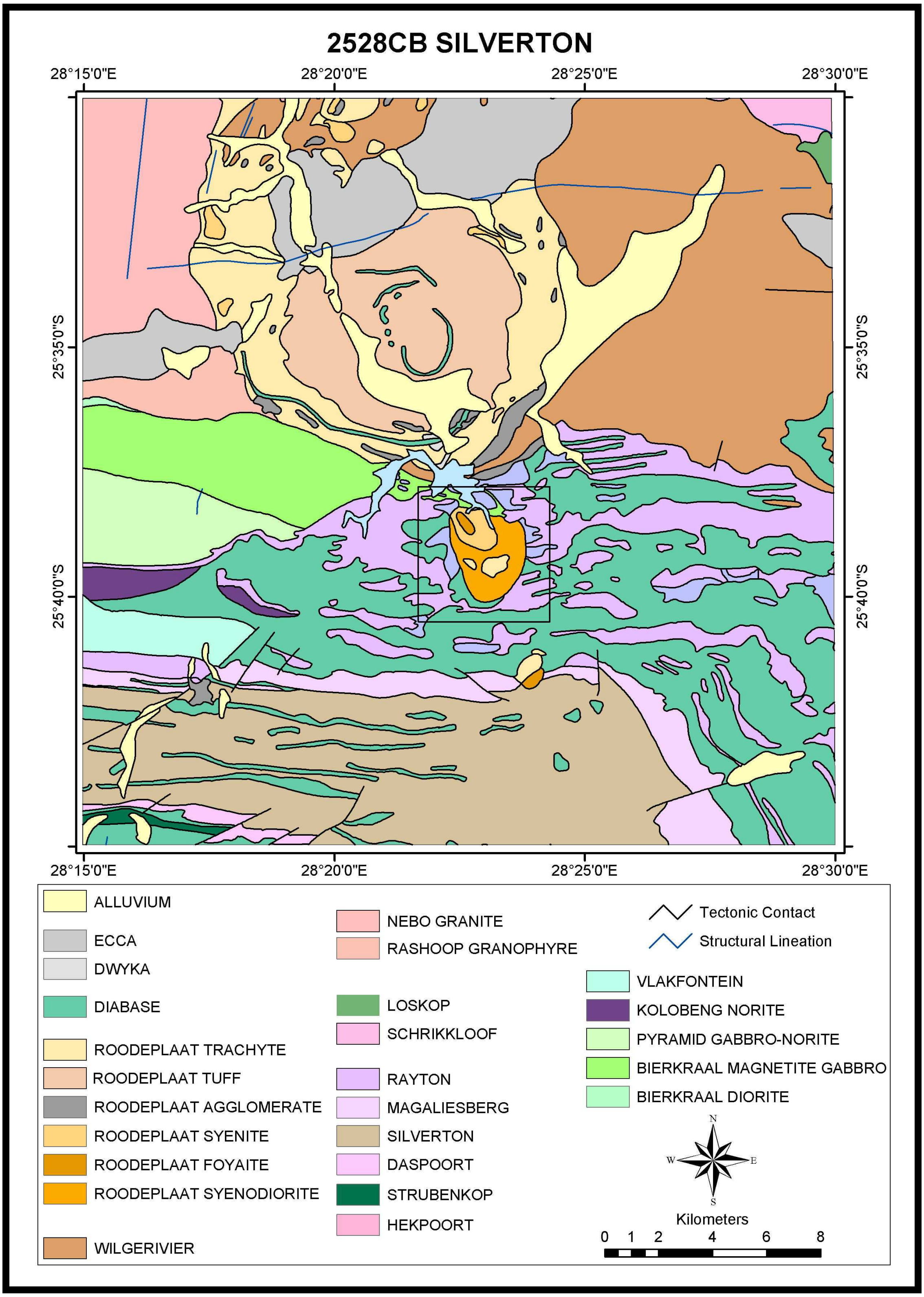

Figure 4.5: The 2528CB Silverton 1: 50 000 sheet. It depicts the geology of the immediate area just north of Pretoria. The Leeuwfontein area is indicated inside the square.

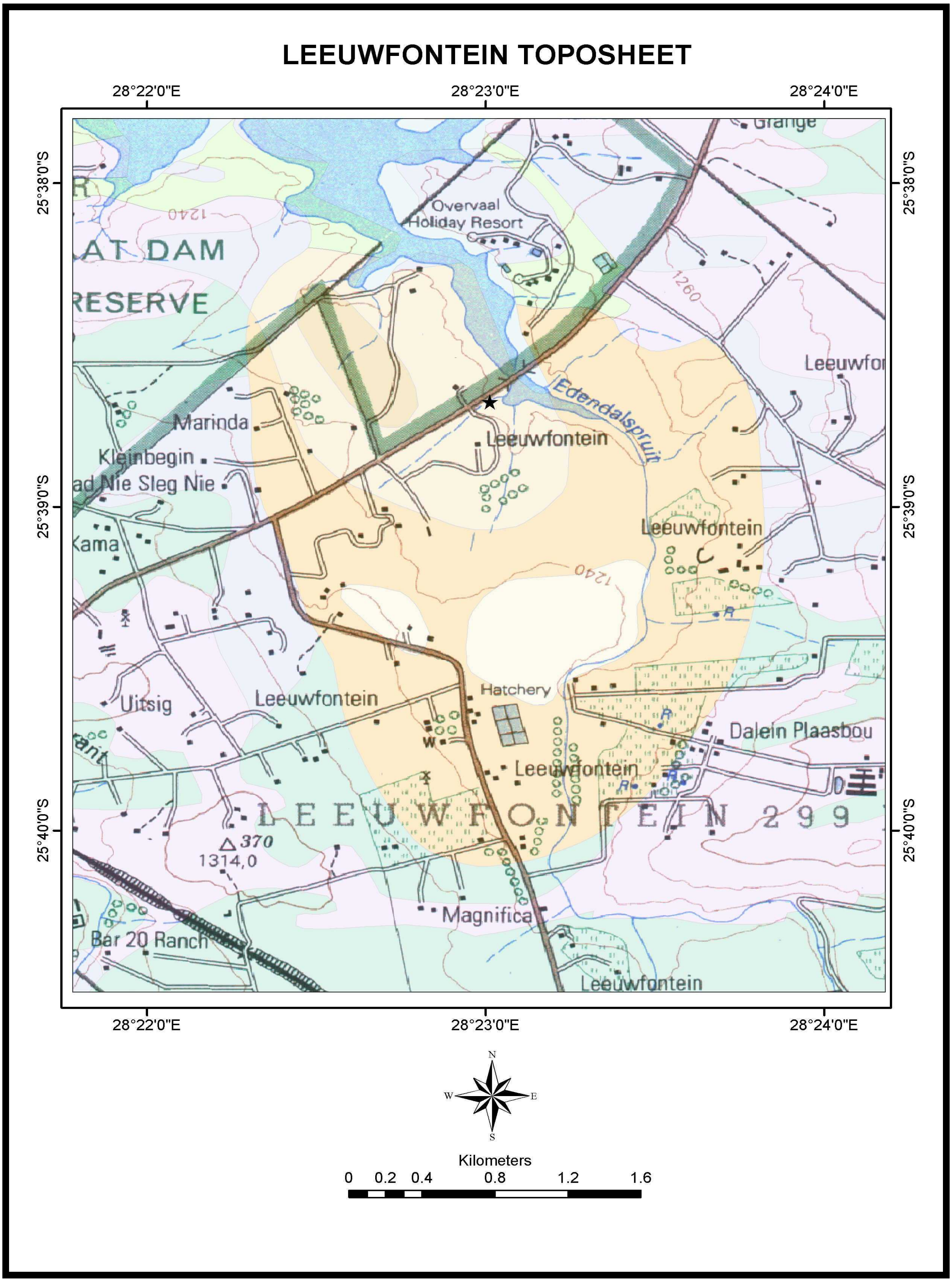

Figure 4.6: The topographic information of Leeuwfontein overlain on the geology. The quarry site and fieldwork position is indicated with the cross.

Figure 4.7: The quarry site where the first tests were carried out. The depth extent of the syenites is much more than the penetration of the technique: - simulating a single layer situation.

Figure 4.8: Hand held core drill used for sampling. Water with cutting oil is used to ease the drilling process.

To verify the results, it was necessary to obtain some physical property information about the syenites, which included the seismic velocity and density. This was achieved by taking samples of the rock using a small hand held drill (Figure 4.8). The drill uses a diamond tipped drill bit to drill cores of 25mm in diameter up to a length of 30cm. In the physical property laboratory of the CGS the seismic velocities and the densities were measured. Table 4.1 shows the physical property information as measured in the laboratory.

Leeuwfontein Syenite		
Sample Name	**Density (g/cm^3)**	**Seismic Velocity (m/s)**
PS1	2.578	4705.9
PS2	2.582	4695.2
PS3	2.595	4692.5
PS4	2.603	4592.6
Average	2.590	4671.6

Table 4.1: Physical property values of Leeuwfontein Syenites as determined in the physical property laboratory of the CGS.

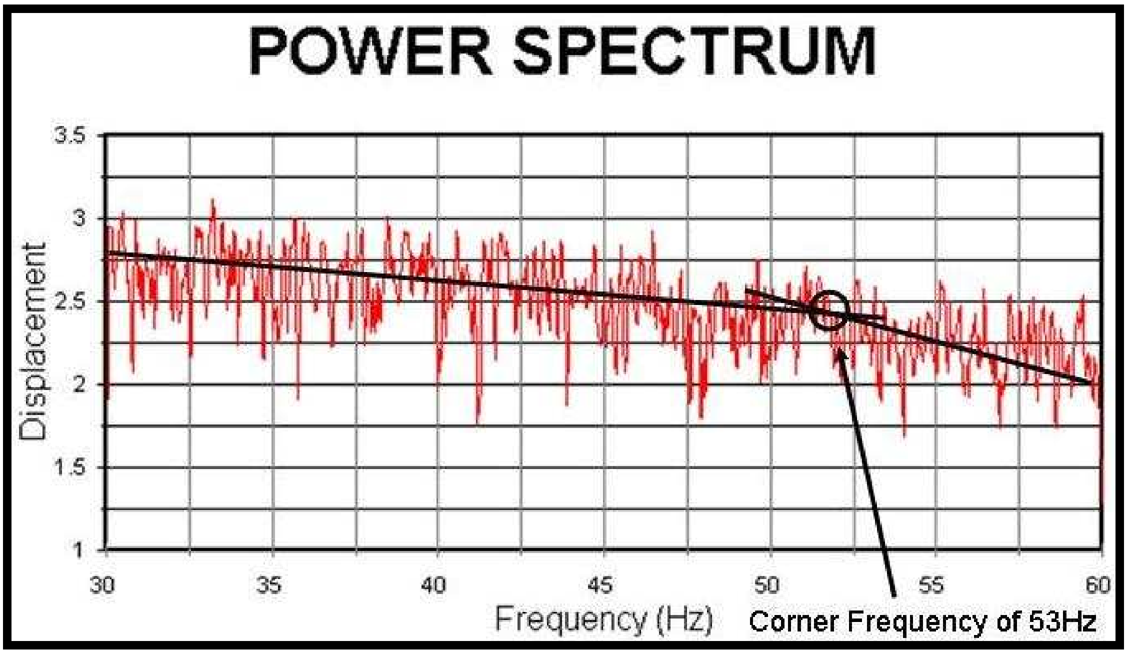

Figure 4.9: Example of a frequency spectrum of the traces that were used to determine the corner frequencies used for the calculation of the masses.

The data was processed using "Seisan^{TM}". In order to obtain the dominant frequency of the different traces, a power spectrum was calculated for each trace (Figure 4.9). The corner or dominant frequencies were determined on these power spectra, as indicated on Figure 4.9. All these frequencies were plotted against the masses (Figure 4.10). From this figure the excited mass was obtained. This data is given in Table 4.2. This process was repeated for all soundings.

The velocity in Table 4.1 was used in conjunction with an attenuation factor to calculate the depth of penetration. This depth of penetration was used to calculate the volume of mass that was excited. The densities were calculated and compared with the values obtained from the physical property laboratory. Table 4.3 gives the information as generated from both soundings and comparative values obtained from the physical property laboratory.

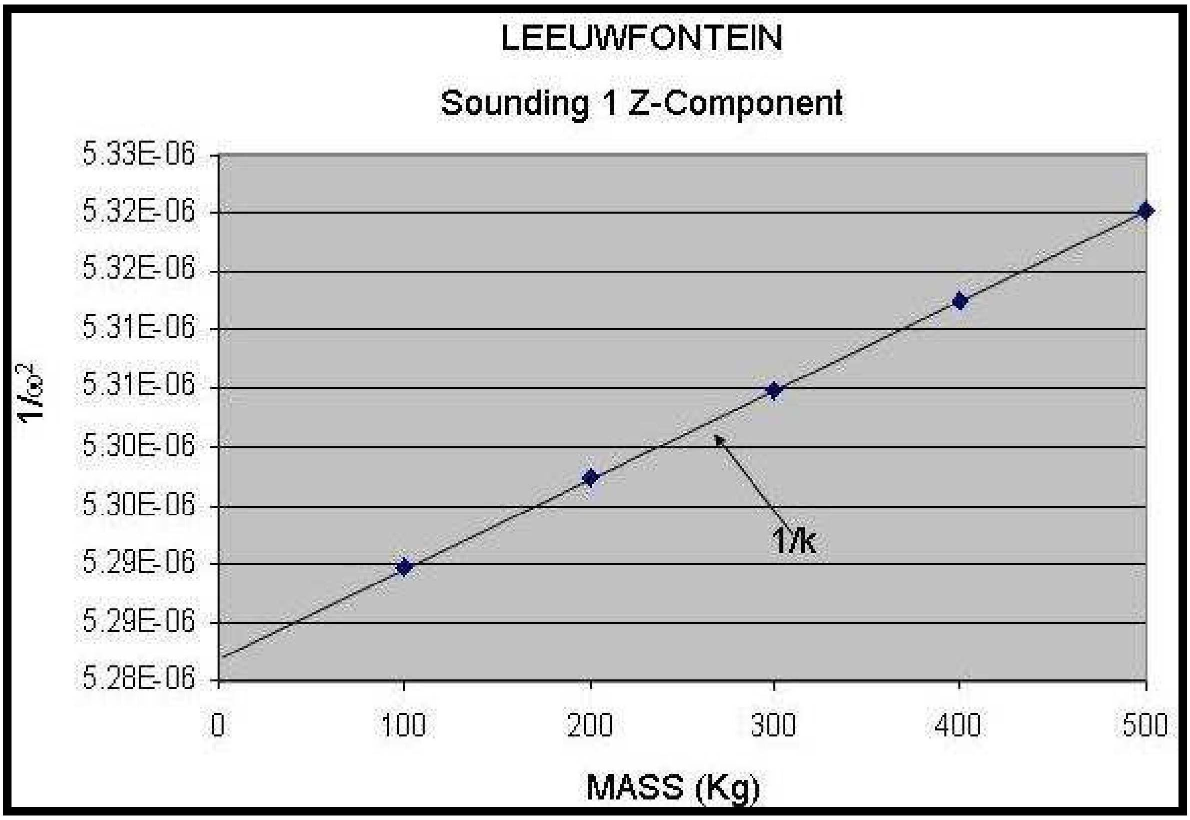

Figure 4.10: Plot to obtain excited mass M_0 from sounding 1 for the Z-component. The gradient is 1/k.

Sounding 1				
Mass (Kg)	**Freq (Hz)**	**ω**	**ω^2**	**$1/\omega^2$**
100	69.2	434.7964233	189047.9297	5.29E-06
200	69.15	434.482264	188774.8377	5.3E-06
300	69.1	434.1681047	188501.9432	5.3E-06
400	69.05	433.8539455	188229.246	5.31E-06
500	69	433.5397862	187956.7462	5.32E-06
	K=	**571Mpa**	**Mass=**	**7042Kg**
Sounding 2				
Mass (Kg)	**Freq (Hz)**	**ω**	**ω^2**	**$1/\omega^2$**
100	73.06	459.0495	210726.4605	4.75E-06
200	72.9	458.0442	209804.4973	4.77E-06
300	72.3	454.2743	206365.1376	4.85E-06
400	72.2	453.646	205794.6744	4.86E-06
500	71.5	449.2477	201823.5404	4.95E-06
	K=	**465Mpa**	**Mass=**	**7546kg**

Table 4.2: Results for both soundings performed at Leeuwfontein.

SOUNDING1					
Mass(kg)	**Volume(m^3)**	**Density (g/cm3)**	**Depth (m)**	**Lab density (g/cm3)**	**Difference (g/cm3)**
7042	2.718	2.591	1.80	2.580	+0.011
SOUNDING2					
7546	2.908	2.594	1.922	2.599	-0.005

Table 4.3: Final results from Leeuwfontein soundings.

4.4 Discussion of Leeuwfontein experiment and results

The results from the initial experiment at Leeuwfontein proved to be promising for a single layer only situation. The comparison of the analytical results with the laboratory measurements was encouraging, thus justifying further testing of the method.

The instruments used during this experiment was a makeshift setup that consisted of modules from different instrumentation. This instrumentation was large and heavy and proved to be clumsy. This was especially true with the sand bags that were used as weights. Certain modifications had to be done to the instrumentation.

4.5 Second field test at Donkerhoek

Single layer only, igneous basement rock environments, similar to Leeuwfontein are not often encountered. The main application envisaged for this method would be testing ground stability and foundation applications on the weathered layer. The next step was to test the technique on a single layer weathered profile. In order to verify the developed theory, for a weathering layer situation, it was necessary to find a locality representing a single layer only situation where a good geological knowledge existed. It was decided to do the test at Donkerhoek. Some good geological data exist there. The Donkerhoek locality is to the east of Pretoria, on the 2528CD Rietvleidam sheet (Figure 4.11).

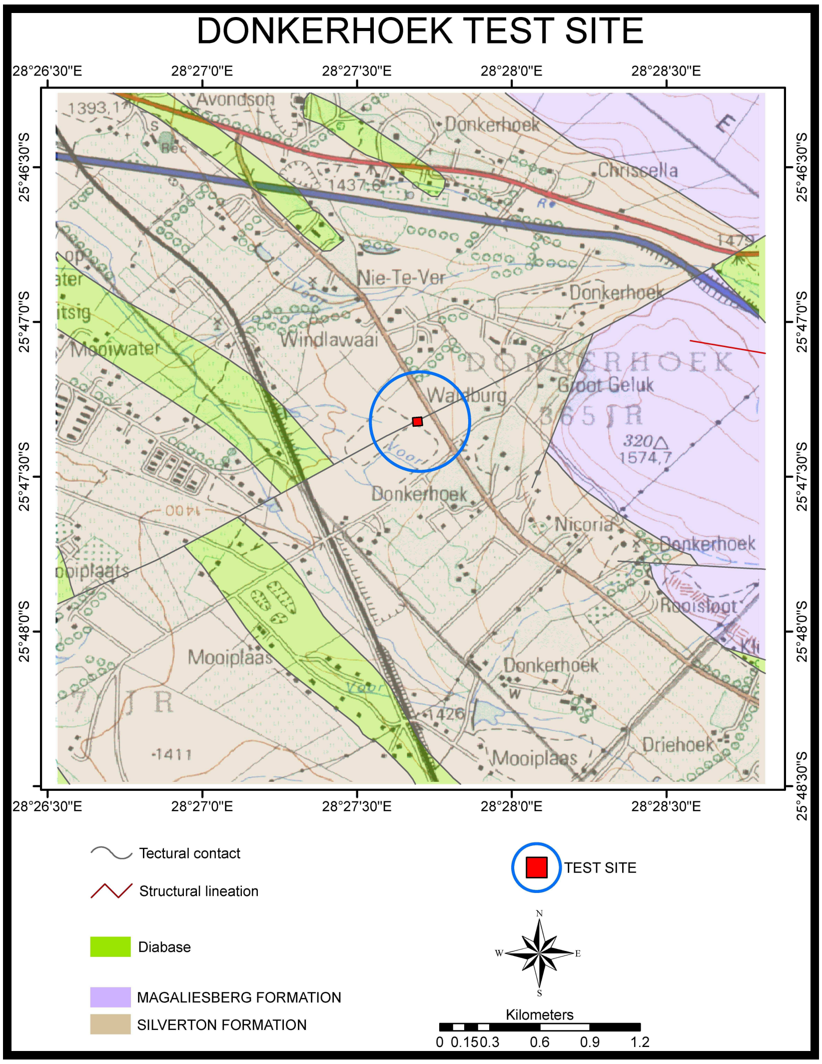

Figure 4.11: The geology of the Donkerhoek area.

The geology of the area consists mainly of shales of the Silverton Formation with bands of the Hekpoort andesitic lavas, lying on top of the Magaliesberg Quartzites. The weathered product in the Donkerhoek area is very thick heaving clay, which originates from the Silverton shales and the andesites. The thickness of this clay varies between 1.2 to 3m, representing a single layer only situation ideal for the testing of the technique (Figure 4.12).

Figure 4.12: Clays weathering product of the Silverton shales at Donkerhoek.

The equipment was modified to make the field operations a bit smoother, more reliable and to increase the quality of the data. The sand bags were substituted by weights (Figure 4.13) and the Ears-α seismograph was replaced by a 24-channel Bison 8024 seismograph (Figure 4.14). Unfortunately the seismograph is not a floating point system and amplitude clipping occurs when the hammer blow is too hard. The single Springheather 3-component geophone was replaced by three SM-6 geophones; one p-wave geophone and two s-wave geophones (Figure 4.15).

Three soundings were executed at Donkerhoek. The data collected from Donkerhoek was tested against a DCP test at each sounding position (Figure 4.16). The data from the DCP test is given in appendix II. At each sounding position a test pit was opened with a backacter. The soil profile was described and an undisturbed sample was taken. The sample was tested at credible soil labs and the results are shown in appendix II.

Figure 4.13: 50Kg weight that was constructed to replace sand sacks.

Figure 4.14: Bison seismograph that replaced ears-α seismograph

Figure 4.15: Geophones that replaced the single Springheather 3-D geophone used in the first experiment.

Figure 4.16: DCP test performed at each sounding position.

The base plate was also orientated in an N-S orientation. A sledge hammer was used as an energy source and a shot was done at all four sides of the base plate. It was repeated for each weight, After four shots it was incremented with 50kg (Figure 4.13) The data was recorded with the Bison seismograph. A very small seismic refraction survey was completed with a 0.5m geophone spacing to determine the velocity of the clay layer.

The data was processed with a range of software that was developed on Matlab and the final plots were done in Excel. The main objective of the processing was to determine the dominant frequency and the attenuation constant.

By plotting the obtained frequency against the added mass, and by substituting the frequency into equation 12 in Chapter 2, the excited mass is obtained. To calculate the excited sample volume, the wave velocity from the small refraction seismic survey is also needed. This velocity and attenuation information is substituted into equation 41 in Chapter 2 to obtain the excited volume. Table 4.4 displays the velocity information as obtained from the small seismic refraction surveys at each sounding position.

Donkerhoek – Silverton shales		
Sounding Number	**Geophone spacing (m)**	**Seismic Velocity (m/s)**
1	1	483.2
2	1	490.0
3	1	495.3
Average	1	489.5

Table 4.4: Seismic wave velocity values of Silverton shales as determined by small seismic refraction surveys.

Figure 4.17 shows the excited mass results from sounding 1 in all three directions. From the figure, one can see that it is more difficult to fit a straight line through the data with a low error margin. This is due to the fact that the sounding sites did not represent a true single layer only situation, and the deviations are shown in the data.

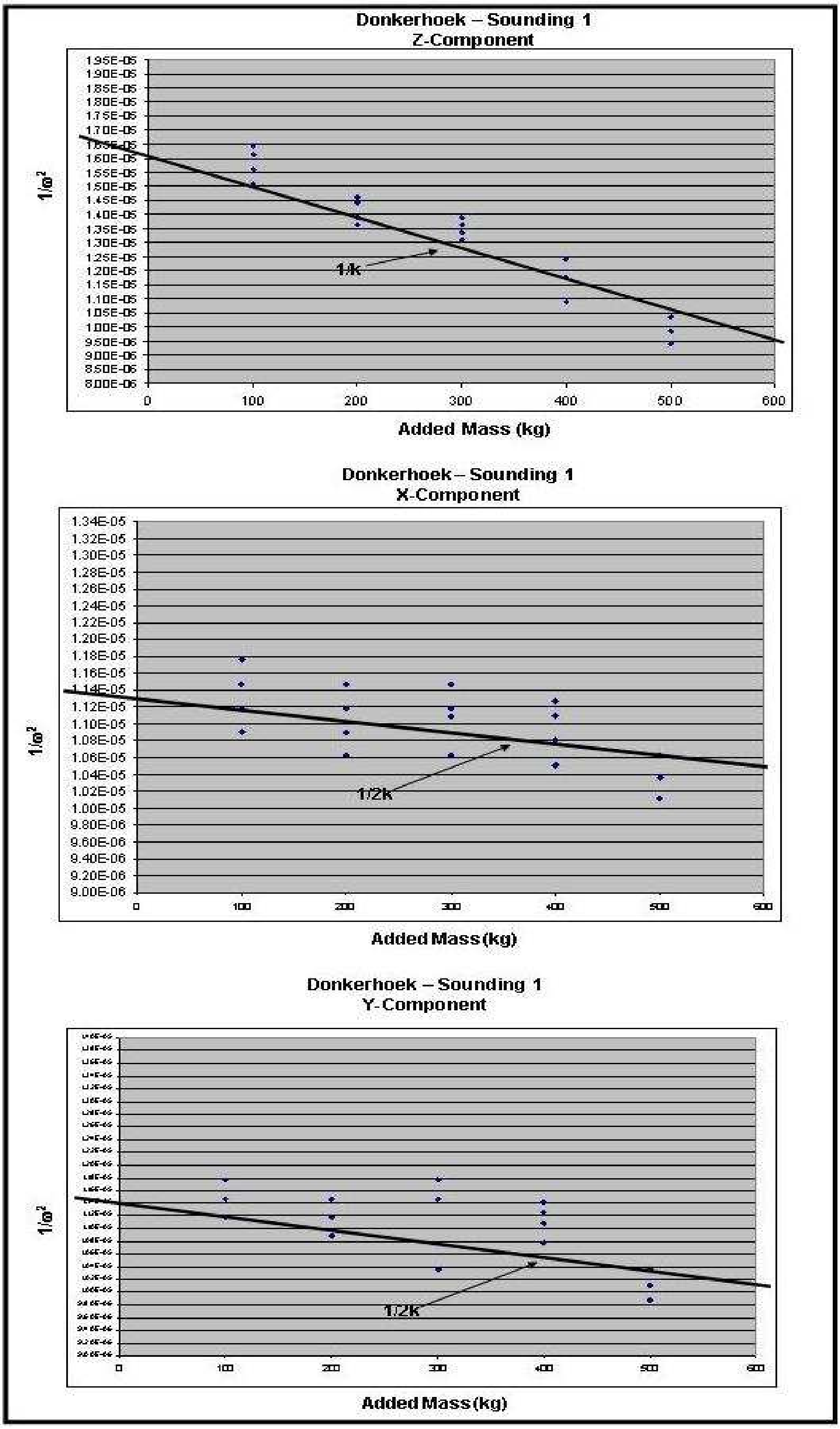

Figure 4.17: Plot to obtain excited mass M_0 from sounding 1. The gradient is 1/k for the Z-Component (P-wave) and 1/2k for the X and Y-Components (S-wave).

The depth of penetration for the seismic wave at the dominant frequency was calculated for each sounding position by determining the Q-factor. The decay is exponential as indicated in Chapter 2. The density measurements from the results from Soillabs are given in Appendix II. The comparison between the soundings and the results from Soillabs are shown in Table 4.5.

SOUNDING1					
Mass(kg)	**Volume(m^3)**	**Density (g/cm3)**	**Depth (m)**	**Lab density (g/cm3)**	**Difference (g/cm3)**
6643	4.478	1.830	2.95	1.835	-0.005
SOUNDING2					
6270	4.591	1.634	3.10	1.632	+0.002
SOUNDING3					
6450	4.033	1.695	2.66	1.734	-0.039

Table 4.5: Final results from Donkerhoek soundings.

4.6 Discussion of Donkerhoek experiment and results

The results from the second experiment at Donkerhoek proved to be promising for a single layer only situation on the weathered layer. The comparison between analytical results and the laboratory measurements was encouraging, and justified further investigations. The larger difference between Sounding3 could be due to the fact that no undisturbed sample was taken from the testpit and an average density was taken as the laboratory result. The larger value for the density is assumed because of the larger shear modulus.

The instrumentation used during this experiment was an improved version to the one used for the first trail experiment. This instrumentation is still heavy but somewhat smaller and proved to be less clumsy. The Bison seismograph proved to be much easier to control and to operate and it was easier to produce results. The only major problem is the fact that the Bison is not a floating point instrument, as clipped traces produce inaccurate power spectrums.

The software in Matlab proved to be slightly easier to use than using Seisan^{TM}. It is however imperative that dedicated software has to be developed for this method.

4.7 Third field test at Country View

The Bison seismograph was replaced by a Geometrics Strataview 24-channel seismograph (Figure 4.18). This seismograph is a floating point system and it will prevent clipping of the traces.

The next step was to test the technique on a multi layer environment where geological control was possible. The area between Johannesburg and Pretoria, mainly underlain by the Halfway House granites, yields a good weathering product. It was decided to do the test at Country View an area earmarked for development. The locality is located on the 2528CC Verwoerdburg sheet (Figure 4.19). The main purpose of the survey was to evaluate the subsurface with the density sounding technique and to compare it with other laboratory techniques and the Troxler test.

Figure 4.18: Geometrics Strataview seismograph with 24 channels that replaced the Bison Geopro seismograph, mainly because it is a floating point system.

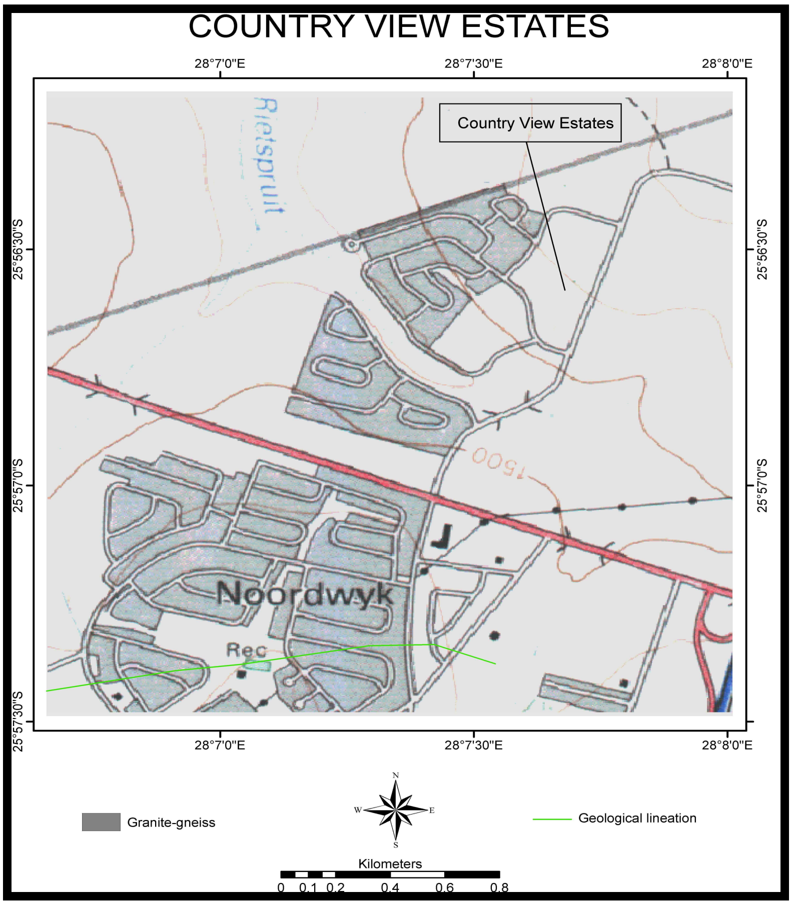

Figure 4.19: Enlarged portion of the 2528CC Verwoerdburg 1:50 000 sheet indicating Country view.

Figure 4.20: Weathering profile of the Halfway House Granites at Country View

The geology of the area consists mainly of Halfway House Granites. It is old Archean aged granite and forms the basement. The granites can be highly weathered and large areas are therefore covered by the weathering product (Figure 4.20). This is the case at Country View estates.

4.8 Fieldwork at Country View

Density soundings were performed on a multi layer weathered profile from the Halfway House Granites. It usually weathers to a soft top layer and a clay rich bottom layer, which transgresses slowly into fresh granite. The purpose of this survey was to determine the density of the layering for development of a small housing complex at Country View (Figure 4.21).

Test pits were dug at each density sounding position. Troxler tests, DCP tests as well as laboratory tests done by Soillab were used to verify the answers obtained from the density sounding technique. Table 4.6 gives the summarised results of the site. All the DCP profiles and laboratory results are given in Appendix II

Figure 4.21: Site at Country View estates.

SOUNDING 2: P-wave											
Layer	**Total Mass (kg)**	**Mass (kg)**	**Total Volume (m^3)**	**Volume (m^3)**	**Total thick (m)**	**Thick (m)**	**Density (kg/m^3)**	**E-Modulus**	**LAB (kg/m^3)**	**DCP (kg/m^3)**	**Troxler (kg/m^3)**
1	1309	1309	0.670	0.670	0.443	0.443	1953.73	1.88E9	1891		1661
2	5046	3737	2.33	1.660	1.540	1.079	2211.24	1.63E9			
3	6557	2820	2.81	1.15	1.856	0.777	2452.17	4.89E8	2596	2594	1623
SOUNDING 2: S-wave (North-South)											
Layer	**Total Mass**	**Mass**	**Total Volume**	**Volume**	**Total thick**	**Thick**	**Density**	**E-Modulus**	**LAB**	**DCP**	**Troxler**
1	1311	1311	0.680	0.670	0.442	0.442	1952.24	1.09E9	1891		1661
2	5034	3723	2.37	1.560	1.470	1.028	2428.21	1.07E9			
3	6740	3017	2.86	1.32	1.897	0.869	2065.15	4.89E8	2596	2594	1623
SOUNDING 2: S-wave (East-West)											
Layer	**Total Mass**	**Mass**	**Total Volume**	**Volume**	**Total thick**	**Thick**	**Density**	**E-Modulus**	**LAB**	**DCP**	**Troxler**
1	1308	1308	0.670	0.670	0.442	0.442	1952.24	1.09E9	1891		1661
2	5096	3788	2.23	1.560	1.470	1.028	2428.21	1.07E9			
3	6514	2726	2.88	1.32	7.897	0.869	2065.15	4.63E8	2596	2594	1632
						Ave1	**1954.23**	**1.35E9**			
						Ave2	**2280.80**	**1.25E9**			
						Ave3	**2356.32**	**4.80E8**			

Table4.6: Summarised results from Country View.

SOUNDING 3: P-wave											
Layer	**Total Mass (kg)**	**Mass (kg)**	**Total Volume (m^3)**	**Volume (m^3)**	**Total thick (m)**	**Thick (m)**	**Density (kg/m^3)**	**E-Modulus**	**LAB (kg/m^3)**	**DCP (kg/m^3)**	**Troxler (kg/m^3)**
1	1309	1309	0.670	0.670	0.443	0.443	1957.15	2.87E9			
2	4998	3689	2.33	1.660	1.540	1.079	2222.29	1.04E9			
3	6551	2862	2.81	1.15	1.856	0.777	2488.69	4.28E8			
SOUNDING 3: S-wave (North-South)											
Layer	**Total Mass**	**Mass**	**Total Volume**	**Volume**	**Total thick**	**Thick**	**Density**	**E-Modulus**	**LAB**	**DCP**	**Troxler**
1	1307	1307	0.680	0.670	0.442	0.442	1928.68	1.91E9			
2	5195	3888	2.37	1.560	1.470	1.028	2300.59	3.09E9			
3	6415	2527	2.86	1.32	1.897	0.869	2159.83	3.78E8			
SOUNDING 3: S-wave (East-West)											
Layer	**Total Mass**	**Mass**	**Total Volume**	**Volume**	**Total thick**	**Thick**	**Density**	**E-Modulus**	**LAB**	**DCP**	**Troxler**
1	1302	1302	0.670	0.670	0.442	0.442	1962.71	1.87E9			
2	5002	3700	2.23	1.560	1.470	1.028	2371.79	3.03E9			
3	6510	2810	2.88	1.32	7.897	0.869	2128.79	4.81E8			
						Ave1	**1949.51**	**2.22E9**			
						Ave2	**2298.29**	**2.39E9**			
						Ave3	**2259.10**	**4.29E8**			

Table 4.6: Summarised results form Country View.

SOUNDING 4: P-wave											
Layer	**Total Mass (kg)**	**Mass (kg)**	**Total Volume (m^3)**	**Volume (m^3)**	**Total thick (m)**	**Thick (m)**	**Density (kg/m^3)**	**E-Modulus**	**LAB (kg/m^3)**	**DCP (kg/m^3)**	**Troxler (kg/m^3)**
1	1309	1309	0.681	0.681	0.450	0.450	1920.54	3.67E8	1891		1711
2	4991	3683	2.345	1.664	1.550	1.100	2213.34	3.73E8			
3	6439	1448	2.995	0.651	1.980	0.430	2224.27	3.74E8	2526	2634	1697
SOUNDING 4: S-wave (North-South)											
Layer	**Total Mass**	**Mass**	**Total Volume**	**Volume**	**Total thick**	**Thick**	**Density**	**E-Modulus**	**LAB**	**DCP**	**Troxler**
1	1318	1318	0.681	0.681	0.450	0.450	1935.39	3.38E8	1891		1711
2	4966	3648	2.345	1.664	1.550	1.100	2192.31	7.78E8			
3	6427	1461	2.995	0.651	1.980	0.430	2244.24	7.89E8	2526	2634	1697
SOUNDING 4: S-wave (East-West)											
Layer	**Total Mass**	**Mass**	**Total Volume**	**Volume**	**Total thick**	**Thick**	**Density**	**E-Modulus**	**LAB**	**DCP**	**Troxler**
1	1313	1313	0.681	0.681	0.450	0.450	1928.05	3.38E8	1891		1711
2	4992	3679	2.232.345	1.664	1.550	1.100	2210.94	1.05E8			
3	6496	1504	2.995	0.651	1.980	0.430	2310.99	4.32E8	2526	2634	1697
						Ave1	**1927.99**	**3.28E8**			
						Ave2	**2205.53**	**4.34E8**			
						Ave3	**2259.83**	**5.32E8**			

Table 4.6: Summarised results from Country View.

SOUNDING 5: P-wave											
Layer	**Total Mass (kg)**	**Mass (kg)**	**Total Volume (m^3)**	**Volume (m^3)**	**Total thick (m)**	**Thick (m)**	**Density (kg/m^3)**	**E-Modulus**	**LAB (kg/m^3)**	**DCP (kg/m^3)**	**Troxler (kg/m^3)**
1	1309	1309	0.670	0.670	0.443	0.443	1957.15	2.87E9			1891
2	4998	3689	2.33	1.660	1.540	1.079	2222.29	1.04E9			
3	6551	2862	2.81	1.15	1.856	0.777	2488.69	4.28E8			1645
SOUNDING 5: S-wave (North-South)											
Layer	**Total Mass**	**Mass**	**Total Volume**	**Volume**	**Total thick**	**Thick**	**Density**	**E-Modulus**	**LAB**	**DCP**	**Troxler**
1	1307	1307	0.680	0.680	0.450	0.450	1928.68	1.91E9			1891
2	5195	3888	2.37	1.690	1.570	1.120	2300.59	3.09E9			
3	6415	2527	2.86	1.17	1.888	0.768	2159.83	3.78E8			1645
SOUNDING 5: S-wave (East-West)											
Layer	**Total Mass**	**Mass**	**Total Volume**	**Volume**	**Total thick**	**Thick**	**Density**	**E-Modulus**	**LAB**	**DCP**	**Troxler**
1	1302	1302	0.670	0.670	0.442	0.442	1962.71	1.87E9			1891
2	5002	3700	2.23	1.560	1.470	1.028	2371.79	3.03E9			
3	6510	2810	2.88	1.32	1.897	0.869	2128.79	4.18E8			1645
						Ave1	**1949.51**	**2.22E9**			
						Ave2	**2298.29**	**2.39E9**			
						Ave3	**2259.10**	**4.29E8**			

Table 4.6: Summarised results from Country View.

4.9 Discussion of Country View experiment and results

Three layers were identified at Country View from the gathered field data. The first is a thin top layer of approximately 0.45m in thickness. The second layer is approximately 1m thick, while a third layer was also interpreted. This data show that the second layer has a lower density and is also softer than the first layer. This relationship was also substantiated by the DCP tests shown in Appendix II. This was also corroborated from visual and physical inspection of the test pits.

The density soundings also revealed that the area is anisotropic with weaker direction North-South relative to the East-West direction. This is obvious from inspection of the modulli in Table 4.6. Where possible, the design of the buildings needs to be altered in such a way that the heavier loads are orientated in the East-West direction to ensure stronger foundations.

From Table 4.6 it is clear that the density sounding technique yielded density values closer to the laboratory results or those obtained by Troxler neutron method. The values obtained from the density sounding technique are in-situ values and a fixed moisture content is always present. Differences in the moisture content may be the largest reason why the values differ. However it is true that the densities sounding methods is no different to any other geophysical method approximating the real situation and in rare occasions yield precisely the same results as the laboratory.