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In-Situ Subsurface Density Estimations using a Seismic Technique

By

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I, C.J.S. Fourie hereby declare that this thesis "In-Situ Subsurface Density Estimations using a Seismic Technique", which I hereby submit for the degree PHd (Exploration Geophysics) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution - Regulation 57.4(e)

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ABSTRACT

A new geophysical method was developed to satisfy a need for in-situ density measurements. Various situations, such as a gravity dam wall requires that density measurements should be done without damage to the structure. The sample volume should also not be that large in order to be sensitive enough for variations.

This method measures the in-situ density of the weathered layer and other man made structures, using seismic waves in three directions. The seismic waves utilized are P-waves and S-waves. It is however surface waves that are treated like body waves because they do not separate at this shallow depth.

These waves are very sensitive to the attenuation factor, which is in turn sensitive to certain physical properties of the propagation medium. This factor is utilised when the multi layer problem is encountered. The maximum depth of exploration is 2-5m and depends solely on the seismic skin depth.

This method utilises a large base plate. The source is a large sledge hammer and shots are done at each side of the base plate. Different dominant frequencies are identified and used to calculate the densities of the layers associated with that specific frequency. The velocities of the subsurface are determined by small seismic refraction surveys.

The method will find application mainly in the civil and engineering geology fields. The main application will be to determine subsurface densities and small movement elasticity modulli for engineers to aid in obtaining adequate design parameters.

Case studies on three different geologic environments are presented. The results indicate that this method will be useful, although certain modifications are recommended to make this method even faster and more user friendly.

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List of Symbols

| SYMBOL | EXPLANATION | SYMBOL | EXPLANATION |
|-----------------|------------------------------------|-----------------|------------------------------------|
| F_p | P - wave force | F_s | S - wave force |
| k_p | P - wave spring constant | k_s | S - wave spring constant |
| x_p | P - wave displacement | x_s | S - wave displacement |
| M_{0p} | Excited Groundmass | M_{0s} | Excited Groundmass |
| \ddot{x}_p | P-wave acceleration | \ddot{x}_s | S-wave acceleration |
| ω_{0p} | P-wave Initial Angular Frequency | ω_{0s} | S-wave Initial Angular Frequency |
| Δm | Additional mass | ω_{1s} | Angular Frequency of the S - wave |
| ω_{1p} | Angular Frequency of the P - wave | h_s | Depth below base plate |
| A | Area of influence | V_{0s} | Volume of excited mass by S - wave |
| L | Length of base plate | b_s | Damping factor of the S - wave |
| h_p | Depth below base plate | v_s | Velocity of the S - wave |
| α | Influence angle | ϵ_s | S – wave attenuation |
| V_{0p} | Volume of excited mass by P - wave | Q_s | S – wave quality factor |
| b_p | Damping factor of the P-wave | A_{0s} | Initial S - wave amplitude |
| v_p | Velocity of the P-wave | $A_s(\epsilon)$ | Decayed S - wave amplitude |
| ϵ_p | P – wave attenuation | E_s | S - wave energy |
| Q_p | P – wave quality factor | δ_s | S – wave logarithmic decrement |
| A_{0p} | Initial P - wave amplitude | f_s | S – wave frequency |
| $A_p(\epsilon)$ | Decayed P - wave amplitude | λ_s | S - Wave length |
| E_p | P - wave energy | E_{ks} | S - wave kinetic energy |
| δ_p | P – wave logarithmic decrement | ρ_{0s} | Horizontal density |
| f_p | P – wave frequency | | |
| λ_p | P-Wave length | | |
| E_{kp} | P - wave kinetic energy | | |
| ρ_{0p} | Vertical density | | |



| SYMBOL | EXPLANATION | SYMBOL | EXPLANATION |
|-----------------|------------------------------------|-----------------|------------------------------------|
| F_p | P - wave force | F_s | S - wave force |
| k_p | P - wave spring constant | k_s | S - wave spring constant |
| x_p | P - wave displacement | x_s | S - wave displacement |
| M_{0p} | Excited Groundmass | M_{0s} | Excited Groundmass |
| \ddot{x}_p | P-wave acceleration | \ddot{x}_s | S-wave acceleration |
| ω_{0p} | P-wave Initial Angular Frequency | ω_{0s} | S-wave Initial Angular Frequency |
| Δm | Additional mass | ω_{1s} | Angular Frequency of the S - wave |
| ω_{1p} | Angular Frequency of the P - wave | h_s | Depth below base plate |
| A | Area of influence | V_{0s} | Volume of excited mass by S - wave |
| L | Length of base plate | b_s | Damping factor of the S - wave |
| h_p | Depth below base plate | v_s | Velocity of the S - wave |
| α | Influence angle | ϵ_s | S – wave attenuation |
| V_{0p} | Volume of excited mass by P - wave | Q_s | S – wave quality factor |
| b_p | Damping factor of the P-wave | A_{0s} | Initial S - wave amplitude |
| v_p | Velocity of the P-wave | $A_s(\epsilon)$ | Decayed S - wave amplitude |
| ϵ_p | P – wave attenuation | E_s | S - wave energy |
| Q_p | P – wave quality factor | δ_s | S – wave logarithmic decrement |
| A_{0p} | Initial P - wave amplitude | f_s | S – wave frequency |
| $A_p(\epsilon)$ | Decayed P - wave amplitude | λ_s | S - Wave length |
| E_p | P - wave energy | E_{ks} | S - wave kinetic energy |
| δ_p | P – wave logarithmic decrement | ρ_{0s} | Horizontal density |
| f_p | P – wave frequency | | |
| λ_p | P-Wave length | | |
| E_{kp} | P - wave kinetic energy | | |
| ρ_{0p} | Vertical density | | |