The effect of soil conditions on the cost of construction projects.

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Declaration by student

I, the undersigned, hereby confirm that the attached treatise is my own work and that any of the sources used to compile the treatise are adequately acknowledged in the text and listed in the bibliography

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Chantel van Tubbergh

Acknowledgements

Thank you, Lord, for Your abundant love and for giving me the strength I needed as well as opportunities, talents and dreams.

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Abstract

Title of treatise: The effect of soil conditions on the cost of construction projects

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In certain areas soil of poor quality can be found and in order to build on it, the soil must be altered. This can be done by means of stabilization or modification of the soil or one can replace the poor quality soil with good quality soil. This soil improvements or replacement of the soil will have an impact on the construction cost therefore one should consider various options like the cost of stabilization versus the replacement of the poor quality soil.

If soil improvements or replacement of the soil are ineffective, impractical or too expensive; foundations can be used either alone or in combination with the soil improvements. The most basic types of foundations are spread footings and strip foundations and are mostly and effectively used in good, stable soils. Other foundation types like pad foundations, raft foundations and piling foundations are more complex foundation types and are mostly used where the soils are of poor quality or unstable.

Mechanical performance of stabilized soil as well as the influence a compound has on the soil stabilization processes, is a combination of the nature of the soil, the type of stabilization compound used e.g. cement or lime and the curing conditions of the stabilized soil.

It is not only important to assess whether the soil is suitable for stabilization with lime and cements, such as the type of soil and the presence of a substantial amount of a given compound in the soil, but it is also important to look at the curing conditions like the temperature, humidity, etc.

All of the above factors have an influence on the cost of the construction of a structure and needs to be taken into account before the construction of such a structure can proceed.

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CHAPTER 1: INTRODUCTION

1.1) INTRODUCTION

The problems with foundations, which can be seen as the most vulnerable part of a structure, in bad soils includes heaving, cracking and breaking-up of building foundations and slabs on grade. In view of the amount of structural damage caused by expansive soils, the properties and composition of swelling and shrinking soils and their interaction with structures, as well as with the extent of the damage they cause must be analyzed. Foundations are surely the most costly to repair and are frequently designed or constructed incorrectly. In the construction industry there is no regulation or constraint for a builder to have any qualifications at all (Cooke, 2007).

The cheapest way of founding a low rise residential building is to make use of strip footing foundations. This can however only be done where good, stable soil is found. Strip footing foundation is cheaper in relation to alternative foundation types e.g. raft foundations or piling, because it uses smaller quantities of materials and is of a simpler design as the latter.

1.2) BACKGROUND

Limited information is available on the overall impact of the mineralogy and wet-dry cycles on the strength and durability of stabilized soils, as well as soils stabilized with various additives and how foundation types compares to one another. The goal of this treatise is to determine the significance of changes in the strength and durability of stabilized soils due to the various minerals in the stabilized soils, how stabilized soils are influenced by the wet-dry cycles, compaction of soils and the different types of foundations that can be used (either with or in stead of stabilized or compacted soils).

Sometimes a certain type of foundation is used because it is the easiest to construct or the type of foundation used commonly. This sometimes will result in the client paying too much unnecessarily for an over designed foundation or in some cases a foundation that is under designed. Structural and civil engineers are also reluctant to use new methods.

The various scenarios can be compared to see where it will be better or more feasible to use which type of foundation, either alone or together with stabilized soil.

1.3) STATEMENT OF THE MAIN PROBLEM

Stabilization of soils is widely accepted as an effective means of improving soil properties. For some soils a single stabilization agent may provide superior performance, while for many soils more than one material may be effective and financial considerations or availability may be the determining factor on which to use (Parsons & Milburn, 2002).

However, soil stabilization faces a number of limitations, especially when the soil contains a significant amount of chemical compounds that may alter the effects of the additives (Cuisinier et. Al, 2011).

In theory it is cheaper to stabilize soil than using alternative foundation types e.g. piling or raft foundations. This is because soil is readily available, but if the stabilized soil becomes weaker and starts to change due to the expansion or shrinkage or deterioration, it can have a significant impact on a building's integrity and durability and can result in higher future costs resulting from the attempts to repair or hide the physical/visual effects this will have on a building.

1.4) STATEMENT OF THE SUB PROBLEMS

1.4.1) HOW CAN SOIL BE STABILIZED?

It is necessary to know the properties of the soils and the additives, as well as the compaction and extend of modification of the soils prescribed, in order to get the optimum results desirable in stabilizing the soils.

The properties of the soils can be analyzed by means of geotechnical investigations. This will give one a good indication of what types of soil one can expect. This is not always accurate because only a few test holes, used for the analyses, are dug on site and it can miss some valuable information regarding the soil on site e.g. boulders, bad soil patches, etc.

The type of soil will determine the type of additive to be used as well as the compaction and extend of the modification required will be determined and prescribed by the consulting engineer.

1.4.2) WHAT IS THE IMPACT OF MINEROLOGY AND WET-DRY CYCLES ON THE STRENGTH AND DURABILITY OF STABILIZED SOILS?

Under which conditions do minerals found in stabilized soil effect the strength and durability of the stabilized soil and which factors need to be present?

1.4.3) IF SOIL CAN NOT BE STABILIZED OR IT IS TOO EXPENSIVE TO STABILIZE, WHAT OTHER OPTIONS ARE AVAILABLE?

Due to the occurrence of bad soil in various areas, there are a number of alternative foundation types available. It is important to know the properties and applications of the different types and when or where the best combination of the foundation types can be applied.

1.4.4) A COST COMPARRISON OF VARIOUS TYPES OF FOUNDATIONS AND SOIL IMPROVEMENTS FOR ONE SPECIFIC PROJECT, INCLUDING REPAIR COST

It is important to know what the cost of the type of foundation (or combinations of different foundation types) will be and that one don't over or under pay just because the type chosen is the easier, but not always the best, option. It is important to look at the effectiveness and the long term effect it will have on the future maintenance cost of the building.

1.5) STATEMENT OF THE HYPOTHESES

The strength and durability of stabilized soils are affected by mineralogy and wet-dry cycles and this may results in higher future costs due to the unplanned and unforeseen physical and visual effects this will have on a building.

1.5.1) HOW CAN SOIL BE STABILIZED?

According to (http://onlinepubs.trb.org) there are two types of stabilizing methods, namely chemical and mechanical stabilization. Chemical stabilization makes use of chemicals and emulsions to stabilize soils and mechanical stabilization includes compaction and addition of additives to soils to improve the strength thereof. There are various additives available including lime, cement, fly ash, etc. Soils treated with cement will have the greatest increase in strength.

1.5.2) WHAT IS THE IMPACT OF MINEROLOGY AND WET-DRY CYCLES ON THE STRENGTH AND DURABILITY OF STABILIZED SOILS?

In areas with extreme weather conditions e.g. where it rains a lot or where it is very hot and dry, the behavior of stabilized will be effected. The soil may expand in the case of wet weather and shrink in the case of warm or dry weather. The right weather conditions will play a big role in compaction of soils to ensure the minimizing of expansion or shrinkage of the soils.

Clay soils are harder to stabilize than the other soils because it expands and contracts more excessively than other soils when it gets wet or dry.

It is better to use cement as a stabilizing additive on the sulfate bearing CH clays. Lime will be a better choice when stabilizing CL clays than cement or fly ash. Cement also performs well on the soil with little clay content, while fly ash performs well only on the SM soil (Parsons & Milburn, 2002).

1.5.3) IF SOIL CAN NOT BE STABILIZED OR IT IS TOO EXPENSIVE TO STABILIZE, WHAT OTHER FOUNDATION OPTIONS ARE AVAILABLE?

According to (Cooke, 2007) there are various foundation types, namely piling (pile and beam foundation), strip foundations, raft foundations and pad foundations.

1.5.4) A COST COMPARISON OF VARIOUS TYPES OF FOUNDATIONS AND SOIL IMPROVEMENTS FOR ONE SPECIFIC PROJECT, INCLUDING REPAIR COST

It is cheaper to stabilize soils and using strip footing foundation than making use of the other foundation types e.g. piling and raft foundations.

1.6) LIMITATIONS

This study is limited to one industrial building and a case study on another industrial building, both in the same region. This study will only be for buildings in South Africa and will not include all of the soil types and additives available in South Africa.

1.6.1) Industrial buildings

Building used for cost comparison of foundation types:

Industrial factory with office building (A &B) – Greengate, Jetpark (1,410 & 1,303 m2)

Building used for case study:

Industrial factory with office building – Kemach JCB, Jetpark (2,450 m2)

This treatise will focus more on a few types of additives that can be used to stabilize soil, which are relatively cheap and easily obtained in South Africa e.g. lime and cement. And it will also focus more on conventional foundation types, but a few other alternatives with regards to foundation types and additives or new products will be discussed briefly.

This treatise will also not include methods for soil stabilization under adverse conditions, although such methods are needed, for example in areas prone to flooding. The need is especially pressing in developing countries where the effects of natural catastrophes must be minimized (onlinepubs.trb.org). Limited information is available for the latter.

1.7) DEFINITION OF TERMS

- CL – the C stands for clay, with L denoting low h compressibility and is principally an inorganic clay. This type of clay group includes gravelly clays, sandy clays, silty clays, and lean clays (http://www.itc.nl).

- CH – the C stands for clay, H denoting high compressibility and is principally inorganic clay. This type of clay group includes inorganic clays of high plasticity, including fat clays, volcanic clays, and bentonite (http://www.itc.nl).

- SM – is silty sands and poorly graded sand-silt mixtures (http://www.itc.nl).
- Geofibers are typically 2.5-5 cm long polypropylene threads blended in soils (mostly sand and clay soils). During the blending process the fibers open into a network of configurations that mechanically reinforce the soil by creating a new soil structure which enhances the engineering properties of the soil (http://www.geosyntheticsolutions.com).

- Pozzolan is defined as or siliceous and aluminous material. The material in itself possesses no or little cementing property, but will in the presence of moisture and in a finely divided form chemically react with calcium hydroxide, at everyday temperatures, to form compounds possessing cementitious properties (Malhotra, 1996).

1.8) ASSUMPTIONS

No assumptions were made.

1.9) IMPORTANCE OF THE STUDY

It is important to do a survey of the impact of bad soil conditions on construction projects' costs and to know what solution is best for both the cost and integrity of a building when bad soil conditions are present.

1.10) RESEARCH METHODOLOGY

1.10.1) Literature review

The literature review will be used to conduct the necessary knowledge to solve the main problem by answering the sub-problems. This will mean scrutinizing several journals, handbooks and reports and putting the necessary conclusions/information together, in order to make the most informative decision in choosing the best circumstances to stabilize soils or rather choosing from the different foundation types.

1.10.2) Data Collection and Analysis

In the sub-problem where the costs will be compared, the following information will be used:

- Case studies of projects where inferior soil conditions played a major role in construction costs and the processes used to stabilize the soil or the alternative foundation type(s) used will be explained.

- Bills of quantities prepared by a quantity surveyor and priced by different main contractors/bulk earthworks contractors will be analyzed, comparing the costs of the different foundation types and soil stabilization.

- Assumptions will be made on the maintenance or cover up costs to the buildings that can result from stabilized soils that were weakened in various ways. These costs will be at bill rates, obtained from priced bills of quantities prepared a quantity surveyor and priced by different main contractors.

- The lowest tender's for each project will be used for the costs.

- The information used to compile the bills of quantities will be provided by consulting Engineers which I will approach for help/opinions on some matters.

1.11) CASE STUDY

A case study based on an actual project will be included to explain that the construction method of a building and its foundations plays an equally big role as geotechnical investigations, soil improvements and the type of foundation used.

1.12) CONCLUSION

Soil is very cheap and readily available. The stabilized soil will be strong and durable when applying the correct method and additives. This will mean that it is cheaper to stabilize soil and using strip footing foundation than making use of the other foundation types.

CHAPTER 2 – SOIL STABILIZATION

2.1) INTRODUCTION

Engineers are often faced with the challenge of constructing foundations on or in soils which do not possess sufficient strength to support loads imposed upon them. It is, at times, necessary to alter these soils to provide a stable subgrade or a working platform (http://www.in.gov).

According to (http://www.scribd.com) the basic principles of soil stabilization will include evaluating the properties of the soil obtained from the site and to decide the lacking property of the soil, in order to choose the most effective and economical method of soil stabilization or alteration and ensuring to design the stabilized soil mix for the intended stability and durability values required.

Use of locally available materials in construction is necessary because, although soil is relatively cheap and readily available, good quality aggregates and soil for construction are scarce. Due to the rapid production and accumulation of different waste materials, such as fly ash, needs to be used (http://www.scribd.com).

This will help with the environmental problem caused by the increase in coal mining and the ever increasing use of coal. This creates various challenges such as the disposal and recycling of fly ash. Approximately 550 mega ton of fly ash are produced world wide per year and South Africa is the fourth largest fly ash generator at 30 mega ton per year (http://sheqafrica.com).

This calls for the development of innovative and environmentally sustainable options for the management and alternative use of fly ash, which includes soil stabilization with Fly ash (http://sheqafrica.com).

2.2) COMPOSITION OF SOILS

One must determine the type of soil present on the property intended for development before one can determine whether soil stabilization will be necessary as well as the extent of stabilization needed.

In order to look at the properties of soils, one needs to determine the composition of the soil. One can make use of textural systems of classification, which are solely based on a soil's texture or grain size distribution.

According to (http://www.dot.state.mn.us) the following procedure is used to categorize a soil within the triangular textural classification system. First, the sample's gradation must be determined by percentage of each of the following components. Sand is between 2.0 millimeters and 0.075 millimeters in size, silt is between 0.075 and 0.002 millimeters in size, and clay is smaller than 0.002 millimeters in size. Gravel and other stones larger than 2.0 millimeters are disregarded in this system. Next, the percentage of sand, silt, and clay in the sample found from test pits or holes taken on site is entered into the diagram shown in Figure 1. The soil classification is determined by locating the point of intersection of the gradation.

An acceptable classification for components smaller than 75 millimeters in diameter and larger than 2.0 millimeters in size is gravel. Any sample with more than about 25 percent gravel should include the term "gravelly" as a descriptor (http://www.dot.state.mn.us).

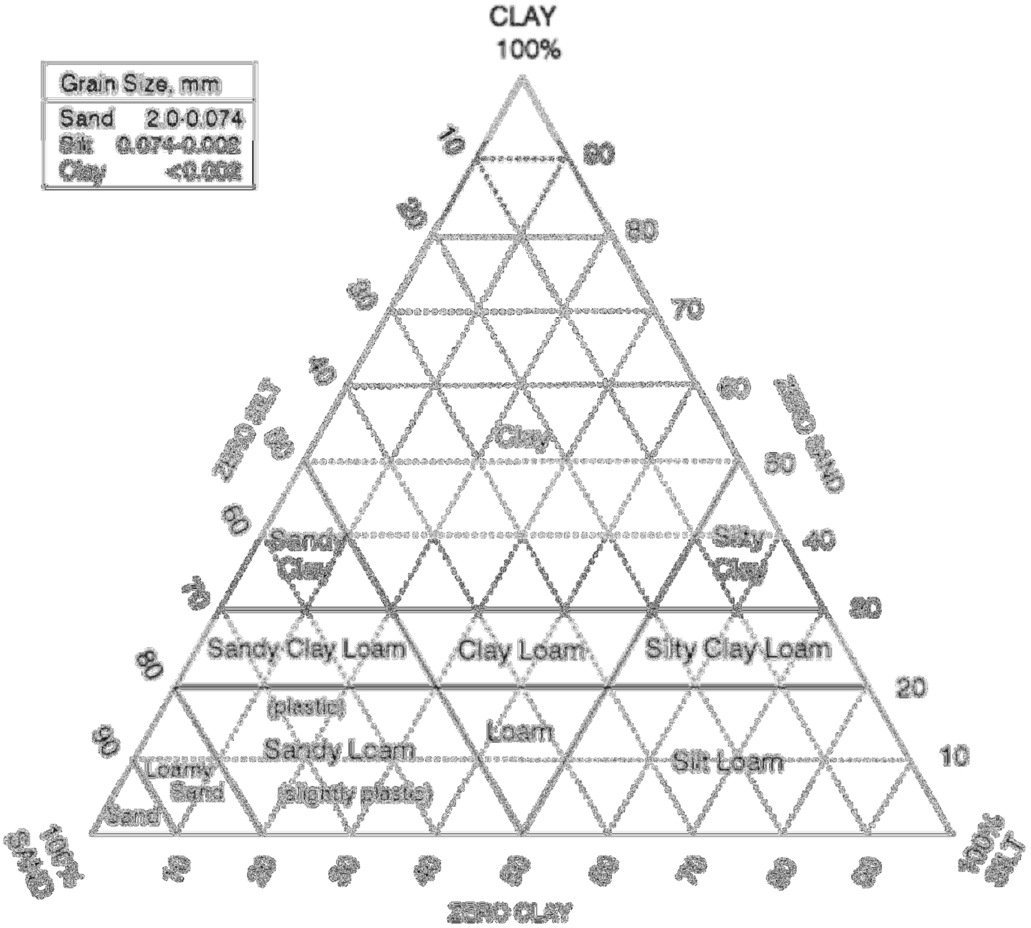


Figure 1: Triangular textural classification chart (http://www.dot.state.mn.us)

2.3) TESTING FOR TYPE OF SOILS

(http://www.dot.state.mn.us) refers to two types of testing of soils that are available, namely field and laboratory testing.

For the purpose of this thesis, laboratory testing will be necessary in all of the cases so field testing will not be explained in detail.

2.3.1) Field identification

Identification of soil types in the field, which is typically limited to an estimate of texture, plasticity, and color, is normally done without the benefit of major equipment, supplies, or time.

The following methods may be used in the field to estimate the soil's texture, which is defined as the relative size and proportion of the individual grains in a given soil type.

- **Visual Examination**

  By carefully examining the soil, it can be divided into its gravel, sand, and fine (silt and clay combined) components. Silt and clay particles cannot be visually separated without further magnification because the naked eye can only distinguish particle sizes down to about 0.05 millimeters (http://www.dot.state.mn.us).

  The examination is performed by drying a sample, spreading it on a flat surface, segregating it into its various components, and estimating the relative percentage of each component. The percentage refers to the dry weight of each soil fraction, as compared to the dry weight of the original sample. Table 1 provides the defined particle sizes for each component and a common reference to aid in identifying the various particle sizes (http://www.dot.state.mn.us).

- **Sedimentation/Dispersion**

  This test is done by shaking a portion of the sample into a jar of water and allowing the material to settle. The material will settle in layers. The gravel and coarse sand will settle almost immediately, the fine sand within about a minute, the silt within an hour, and the clay will remain in suspension indefinitely. The percentage of each component is estimated by comparing the relative thickness of each of the layers in the bottom of the jar, keeping in mind that the larger sized particles will typically settle into a denser mass than the fines (http://www.dot.state.mn.us).

- **Plasticity**

  The ability to be molded within a certain range of moisture contents is termed plasticity. It is dependent upon the percentage and type of clay component, and it therefore requires differentiation between silt (non-plastic fines) and clay (plastic fines). Quantitatively, a soil's plasticity is defined by its Atterberg limits and used in the AASHTO and Unified classification systems (http://www.dot.state.mn.us).

  The following methods can be used in the field to approximate the plasticity of particles that would pass an approximately 0.4mm sieve. For field classification purposes, remove by hand the coarser particles that interfere with the tests (http://www.dot.state.mn.us).

- **Ribbon/Thread**

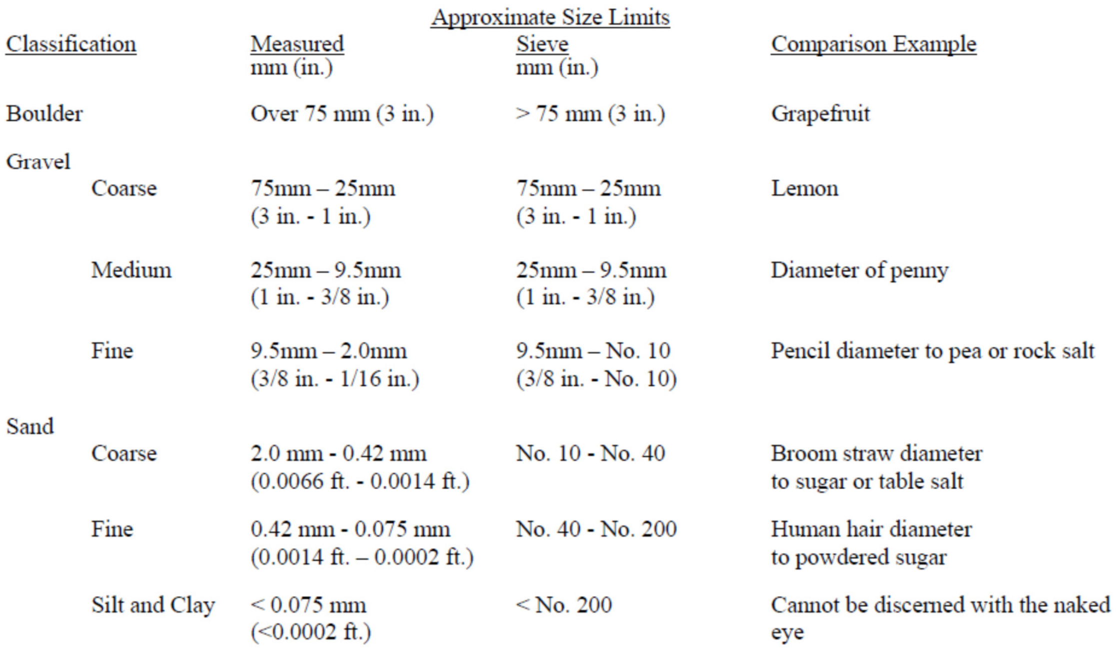
  In the ribbon/thread test, a moist roll of soil approximately 12 to 19mm in diameter and 75 to 125 mm long is pressed between the thumb and index finger to form a ribbon about 3 mm thick. The longer the ribbon that can be formed before the soil breaks under its own weight, the higher the soil's plasticity. Highly plastic clays can be ribboned to 100 mm longer than their original cast. Clays of low plasticity can be ribboned only with some difficulty into short lengths, while non-plastic materials cannot be ribboned at all (http://www.dot.state.mn.us).

- **Dry-Strength/Breaking**

  The dry-strength/breaking test is normally made on a dry patch of soil about 12mm thick and about 30 mm in diameter that has been allowed to air dry completely. Attempts are made to break the pat between the thumb and fingers, with very highly plastic clays being resistant to breakage or powdering and highly plastic clays being broken with great effort. Caution must be exercised with highly plastic clays to distinguish between shrinkage cracks, which are common in such soils, and a fresh break. Clays of low plasticity can be broken and powdered with increasing ease (http://www.dot.state.mn.us).

- **Shaking**

In the shaking test, a pat of soil with a volume of about 8 cubic centimeters is moistened to a putty-like state and placed in the palm of the hand. The hand is then shaken vigorously or jarred on a table or other firm object. If the sample's surface begins to glisten, it is an indication that moisture within the sample has risen to the surface. When this does not occur, the soil is probably clayey. Where this occurs sluggishly or slowly, the soil is predominantly silty, perhaps with a small amount of clay. For silts or very fine sands, the moisture will rise to the surface rapidly and the test can be repeated over and over by remolding and reshaking the pat (http://www.dot.state.mn.us).



		Approximate Size Limits		
Classification		Measured mm (in.)	Sieve mm (in.)	Comparison Example
Boulder		Over 75 mm (3 in.)	> 75 mm (3 in.)	Grapefruit
Gravel				
	Coarse	75mm – 25mm (3 in. - 1 in.)	75mm – 25mm (3 in. - 1 in.)	Lemon
	Medium	25mm – 9.5mm (1 in. - 3/8 in.)	25mm – 9.5mm (1 in. - 3/8 in.)	Diameter of penny
	Fine	9.5mm – 2.0mm (3/8 in. - 1/16 in.)	9.5mm – No. 10 (3/8 in. - No. 10)	Pencil diameter to pea or rock salt
Sand				
	Coarse	2.0 mm - 0.42 mm (0.0066 ft. - 0.0014 ft.)	No. 10 - No. 40	Broom straw diameter to sugar or table salt
	Fine	0.42 mm - 0.075 mm (0.0014 ft. – 0.0002 ft.)	No. 40 - No. 200	Human hair diameter to powdered sugar
	Silt and Clay	< 0.075 mm (<0.0002 ft.)	< No. 200	Cannot be discerned with the naked eye

Table 1: Visual grain-size identification (http://www.dot.state.mn.us).

2.3.2) Laboratory testing

A qualified geotechnical engineer should visit the project prior to the start of the construction starts to collect samples of each type of soil in sufficient quantity for performing the specified tests. The geotechnical engineer should review the project's geotechnical report and other relevant documents such as soil maps, etc., prior to the field visit. The geotechnical consultant shall submit the test results and recommendations, along with the current material safety data sheet or mineralogy to the engineer for approval.

When the geotechnical engineer determines the necessity of chemical-soil stabilization during the design phase, a subgrade treatment utilizing the chemical for the stabilization in the geotechnical report should designed. According to (http://www.in.gov) the following tests should be performed and the soil properties should be checked prior to any modification or stabilization:

- The grain size and hydrometer test results in accordance with AASHTO T 89, 90, and M145,
- Atterberg limits
- The maximum dry unit weight (92 pcf minimum) in accordance with AASHTO T 99,
- Loss of ignition (LOI) not more than 3% by dry weight of soil in accordance with AASHTO T 267,
- Carbonates not more than 3 % by dry weight of the soils, if required,
- As received moisture content in accordance with AASHTO T 265.

2.4) CLASSIFICATION SYSTEMS

The purpose of any classification system is to categorize soils by relating their appearance and behavior with previously established engineering properties and performance.

According to (http://www.csir.co.za) several different materials classification systems have been developed over the years. In South Africa, the TRH14 (1985) system is most commonly used. In this system, the untreated or granular materials are classified as:

- Graded crushed stone: G1, G2, G3
- Natural gravels (including modified and processed gravel): G4, G5, G6
- Gravel-soil: G7, G8, G9, G10
- Water bound macadam: WM
- Dump rock: DR

Another classification system used often is the AASHTO Soil Classification system. This is the American Association of State Highway and Transportation Officials (AASHTO) system rates soils for their suitability for support. The AASHTO system uses both grain-size distribution and the Atterberg limits data to assign a group classification and a group index *t*o the soil. The group classification ranges from A-1 (best soils) to A-8 (worst soils). Group index values near 0 indicate good soils, while values of 20 or more indicate very poor soils (Caduto, 1998).

2.5) Types of stabilization

These treatments are generally classified into two processes, soil modification or soil stabilization. The purpose of subgrade modification is to create a working platform. The purpose of subgrade stabilization is to enhance the strength of the subgrade (http://www.in.gov).

This increased strength is then taken into account in the design process. Stabilization requires more thorough design methodology during construction than modification. The methods of subgrade modification or stabilization include physical processes such as soil densification, blends with granular material, use of reinforcements (Geogrids), undercutting and replacement, and chemical processes such as mixing with cement, fly ash, lime, lime byproducts, and blends of any one of these materials (http://www.in.gov).

According to (http://www.in.gov) soil properties such as strength, compressibility, hydraulic conductivity, workability, swelling potential and volume change tendencies may be altered by various soil modification or stabilization methods. Subgrade modification shall be considered for all the reconstruction and new alignment projects.

Standard specifications provide the contractor options on construction practices to achieve subgrade modification that includes chemical modification, replacement with aggregates, geosynthetic reinforcement in conjunction with the aggregates, and density and moisture controls. Geotechnical Engineers have to evaluate the needs of the subgrade and include where necessary, specific treatment above and beyond the standard specifications (http://www.in.gov).

It is necessary for the Engineers to take into consideration the environmental conditions and location of the project in order to make practical decisions for the design.

The use of high quality materials and the ever increasing cost associated with good quality materials have led to the need to make use of local soils that might be of poor quality but stabilized. This can be difficult, especially when these soils have a high water content and/or low workability (Muhunthan & Sariosseiri, 2008).

According to (Hansson, 2008) there are various methods one can use to stabilize soils. One of the methods is called mass soil stabilization which means that binding agents are mixed with the total mass of soil. Although a large area can easily be covered using this method, it is difficult to make the stabilized layer more than a few meters deep. Mass soil stabilization is mostly used in cases where the weakest layers of the soil are the topmost layers and where a large area needs to be covered (Hansson, 2008).

The other method is called deep soil stabilization. Deep soil stabilization is performed in the form of piles. The piles do not cover an entire area but they reach several meters into the ground. This type of stabilization is important when one needs to build railroads and road embankments (Hansson, 2008).

This treatise will focus more on mass soil stabilization which includes the stabilization of geo-materials such as soils and rocks and can be done through chemical, mechanical and geosynthetic stabilization processes.

2.6) Modification or Stabilization of Soils

2.6.1) Chemical Modification or Stabilization

Chemical stabilization includes the use of chemicals and emulsions (additives) as compaction aids to soils. Such additives include binders, water repellents, etc. and are used to modify the behavior of soils. The chemical reactions that occur when these additives are added to the soils can be speedy reactions and can be referred to as modification. This is because the additives modify the soil to a fairly workable state as compared with the original state of the soil (http://onlinepubs.trb.org).

According to (Muhunthan & Sariosseiri, 2008) the effectiveness and selection of an additive or a combination of additives as well as the percentage of the additives to be used depends on the classification of the soil, the improvement of its quality preferred, the conditions of its field as well as the method of stabilization used. However knowledge of mechanistic behavior of treated soil as well as selecting the stabilizer is very important.

There is a number of additives to choose from like lime, cement, fly ash, lime-cement-fly ash admixture, cement kiln dust, emulsified asphalt, Geofibers (figure 2), and polymer stabilizers, etc. For the purpose of this treatise focus will be on lime and cement.

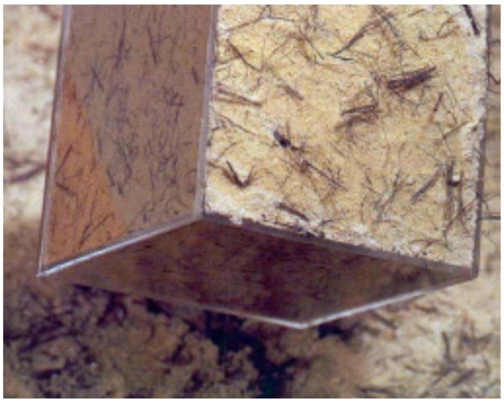


Figure 2: Soil stabilized with Geofibers (http://www.geosyntheticsolutions.com)

Lime stabilization

Lime is a very old, but still popular additive used with medium- to fine-grained soils. This is because lime will react with these soils to produce increased workability and strength as well as decreased plasticity. There are four major lime based additives used in construction namely; hydrated high calcium lime Ca(OH)2, Calcitic quick lime CaO, monohydrated dolomitic lime Ca(OH)2 MgO, and dolomitic quick lime CaO MgO (Muhunthan & Sariosseiri, 2008).

According to (Mallela et al. 2004) lime can be used as a stabilizing additive where the construction activity can be facilitated in three ways

Firstly, the plasticity index will reduce significantly because of an increase in the plastic limit and a decrease in the liquid limit. A reduction in the plasticity index will result in higher workability of the treated soil.

Secondly, a reduction in water content occurs as a result of the chemical reaction between soil and lime. This will help with the compaction of soils that is very wet.

Lastly, the addition of lime to the soil will increase the most favorable water content, but will decrease the maximum dry density and finally it will instantly increase in strength in modulus of elasticity, resulting in a stable platform.

Stabilization of soils with lime has been found to increase optimal water content, decrease swell potential, decrease maximum dry density and increased strength (Muhunthan & Sariosseiri, 2008).

The effects of lime stabilization on pertinent soil properties can be classified as immediate and long-term effects. Immediate modification effects are achieved without curing and are of interest primarily during the construction stage. Long-term stabilization effects take place during and after curing, and are important from a strength and durability point of view (Mallela et al. 2004).

Fatigue strength is related to the number of cycles of loads that the material can carry at a given stress level. The addition of lime to soil increases its fatigue strength significantly. Lime treated soils gain in strength over time thus contributing to the decrease in applied stress to strength and an increase in fatigue strength, resulting in an increase in the number of cycles of load necessary to cause failure of treated materials (Muhunthan & Sariosseiri, 2008).

Lime works best for clayey soils, especially those with moderate to high plasticity index i.e. soils with a PI of more than 15.

The quantity of lime required varies based on the properties of the material that needs to be treated and the degree of stabilization required.

For modification purposes, normally 2-3% by dry weight of the soil is sufficient. For stabilization purposes, typically 5-10% by weight of the dry soil is used (Muhunthan & Sariosseiri, 2008).

Cement stabilization

Soil stabilization with cement causes a similar chemical reaction as lime and can be used for both stabilization and modification purposes.

Any type of soil can be stabilized with cement, except those with organic content greater than 2% or having a pH lower than 5.3 (Muhunthan & Sariosseiri, 2008). Many studies have shown that granular soils and clayey materials with low plasticity index are better suited to be stabilized with cement (Muhunthan & Sariosseiri, 2008).

A considerable decrease in the plasticity index and swell potential and a remarkable increase in strength, modulus of elasticity and resistance against the effects of moisture can be achieved by cement stabilization. The addition of cement was also found to increase optimum water content but decrease the maximum dry density (Muhunthan & Sariosseiri, 2008).

Typical amounts of cement for stabilization purposes vary from 5- 10% of weight of dry soil. Note, that most of the manuals and guidelines in U.S do not recommend cement stabilization for soils with plasticity index greater than 15. In order to overcome this, small amount of lime can be added to soil prior to cement stabilization (Muhunthan & Sariosseiri, 2008).

Fly ash

Fly ash forms as a result of coal combustion in power plants and contains silica, alumina, and different oxides as well as alkalis in its composition. Fly ash is considered as a pozzolanic material. There are two types of fly ash: type “C” and “F”. This classification is based on the chemical composition. Fly ash can improve the engineering properties of soil by increasing the compacted dry density as well as reducing the optimum moisture content of the soils. However it must be noted that fly ash properties are highly variable and depend on chemical composition of coal and combustion technology (Muhunthan & Sariosseiri, 2008).

Lime-Cement-Fly ash

Coarse-grained soils with little or no fines can be stabilized by a combination of lime and fly ash. The presence of various chemical components in fly ash enables it to produce a hardened cementitious material with improved compressive strength when mixed with lime and water. In order to accelerate the reaction and obtain the higher compressive strength a small amount of cement can be added. It is noted that for this admixture to be useful, fly ash must contain components that can react with the lime. 1% (of the dry weight of the soil to be stabilized) cement is added for additional strength gain. If the achieved strength does not meet requirements, cement should be added in increments of 0.5% until the desired strength is obtained. The total added material should not exceed 15% of the dry weight of the soil (Muhunthan & Sariosseiri, 2008).

Emulsified asphalt

According to (http://www.dictionaryofconstruction.com) emulsified asphalt can be explained as: “Asphalt cement that has been mixed with water containing a small amount of an emulsifying agent.”

Stabilization with emulsified asphalt is more applicable for coarse-grained soils; however this method can also be applied to stabilize fine-grained soils as well. Water absorption of soils decreases with an increase in the amount of emulsified asphalt (Muhunthan & Sariosseiri, 2008).

Sandy soils can be stabilized by emulsified asphalt easily, if they contain less than 25% fine material with plasticity index of less than 12. The emulsified asphalt binds sand particles together and leads to significant increase in soil bearing capacity especially if the soil contains some fine material. Typical amount of emulsified asphalt that is used to stabilize the sandy soils is 2% to 6% of the dry weight of soil (Muhunthan & Sariosseiri, 2008).

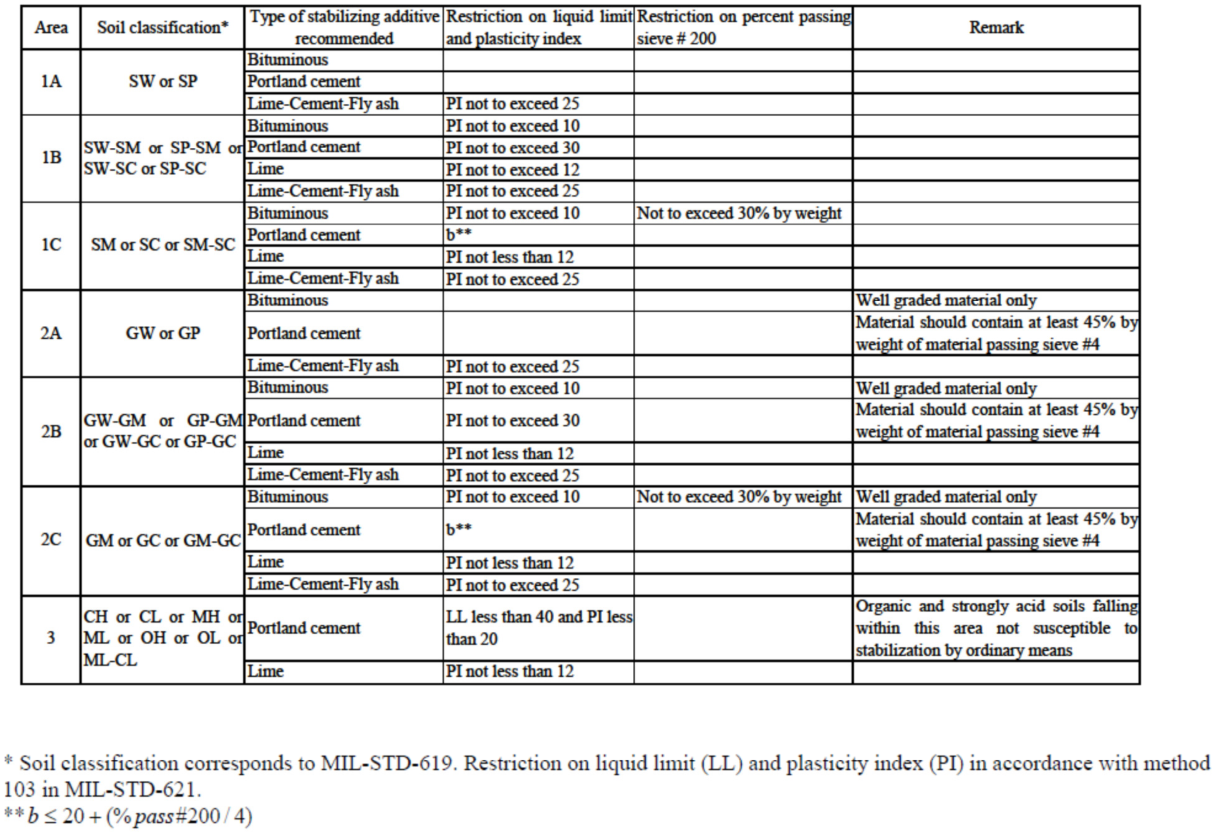
In order to obtain better performance of emulsified asphalt in gravelly soils the amount of fines with the plasticity index of less than 12 must be less than 15%. Typical amount of emulsified asphalt required to stabilize gravely soils is 2% to 6% of the dry weight of soil (Muhunthan & Sariosseiri, 2008).

In order to stabilize the fine soils with emulsified asphalt, the soil should have the liquid limit less than 40 and plasticity index no greater than 18 (12 to 18). Rapid curing asphalt emulsions work better for fine soils stabilization rather than medium and slow curing asphalt emulsions. Typical amount of emulsified asphalt required to stabilize fine soils is 4% to 8% of the dry weight of soil.

The type and amount of emulsified asphalt highly depends on type of soil and other parameters such as the weather conditions of the area. In order to obtain better stabilization results soil should be mixed with water slightly less than optimum water content, before adding emulsified asphalt. Unlike stabilization with lime, cement, and fly ash use of emulsified asphalt does not cause pozzolanic reactions. Therefore, the strength gain is accomplished based on the binding of particles alone. Although better results can be achieved by better compaction (Muhunthan & Sariosseiri, 2008).

Selection of additive

Guidelines to determine the appropriate stabilizer agent for different type of soils are abundant in the literature. One of the methods to choose from is based on U.S. Army Corps of Engineers publications (EM1110-03-137).



Area	Soil classification*	Type of stabilizing additive recommended	Restriction on liquid limit and plasticity index	Restriction on percent passing sieve # 200	Remark
1A	SW or SP	Bituminous			
		Portland cement			
		Lime-Cement-Fly ash	PI not to exceed 25		
1B	SW-SM or SP-SM or SW-SC or SP-SC	Bituminous	PI not to exceed 10		
		Portland cement	PI not to exceed 30		
		Lime	PI not to exceed 12		
		Lime-Cement-Fly ash	PI not to exceed 25		
1C	SM or SC or SM-SC	Bituminous	PI not to exceed 10	Not to exceed 30% by weight	
		Portland cement	b**		
		Lime	PI not less than 12		
		Lime-Cement-Fly ash	PI not to exceed 25		
2A	GW or GP	Bituminous			Well graded material only
		Portland cement			Material should contain at least 45% by weight of material passing sieve #4
		Lime-Cement-Fly ash	PI not to exceed 25		
2B	GW-GM or GP-GM or GW-GC or GP-GC	Bituminous	PI not to exceed 10		Well graded material only
		Portland cement	PI not to exceed 30		Material should contain at least 45% by weight of material passing sieve #4
		Lime	PI not less than 12		
		Lime-Cement-Fly ash	PI not to exceed 25		
2C	GM or GC or GM-GC	Bituminous	PI not to exceed 10	Not to exceed 30% by weight	Well graded material only
		Portland cement	b**		Material should contain at least 45% by weight of material passing sieve #4
		Lime	PI not less than 12		
		Lime-Cement-Fly ash	PI not to exceed 25		
3	CH or CL or MH or ML or OH or OL or ML-CL	Portland cement	LL less than 40 and PI less than 20		Organic and strongly acid soils falling within this area not susceptible to stabilization by ordinary means
		Lime	PI not less than 12		

* Soil classification corresponds to MIL-STD-619. Restriction on liquid limit (LL) and plasticity index (PI) in accordance with method 103 in MIL-STD-621.
$** \, b \leq 20 + (\% pass\#200 / 4)$

Table 2: Guide for selecting stabilizing additives (Muhunthan & Sariosseiri, 2008)

Criteria for chemical selection

When the chemical stabilization or modification of subgrade soils is considered as the most economical or feasible alternate, the following criteria should be considered for chemical selection based on index properties of the soils according to (http://www.in.gov):

1. Chemical Selection for Stabilization.
a. Lime: If PI > 10 and clay content (2μ) > 10%.
b. Cement: If PI ≤ 10 and < 20% passing No. 200 sieve

Note: Lime shall be quicklime only.
2. Chemical Selection for Modification
a. Lime: PI ≥ 5 and > 35 % Passing No. 200 sieve
b. Fly ash and lime fly ash blends: 5 < PI < 20 and > 35 % passing No. 200 sieve
c. Cement and/ or Fly ash: PI < 5 and ≤ 35 % Passing No. 200 sieve

Fly ash shall be class C only.
Lime Kiln Dust (LKD) shall not be used in blends.

3.02 Suggested chemical quantities for modification or stabilization
a. Lime or Lime By-Products: 4% to7 %
b. Cement: 4% to 6%
c. Fly ash Class C: 10% to 16%
% for each combination of lime-fly ash or cement-fly ash shall be established based on laboratory results.

The above mentioned materials are inexpensive, relatively easy to use and apply and add benefits to many different soil types. The addition of the above mentioned additives to improve the strength and durability properties of soils is the most common method used to stabilize soils in South Africa (Newman, et al, n.d.).

However, there is a variety of non-traditional soil stabilization or soil modification additives available from the commercial sector such as polymer emulsions, acids, lignin derivatives, enzymes, tree resin emulsions and silicates. These additives may be in liquid or solid form and are often touted to be applicable for most soils.

Previous research studies in this area have demonstrated that many soil additives have little to no benefit for silty and sandy soil types. Sandy soils are problematic for stabilization and often require cement and/or asphalt emulsion to provide cohesion for the soil. Generally, lime works well with most clay soils, and cements and asphalt emulsions can be used for a wide range of soils (Newman, et al, n.d.).

2.6.2) Mechanical modification or stabilization

Mechanical stabilization includes compaction, and fibrous and other non-biodegradable reinforcement, such as the blending of two or more gradations of geomaterials i.e. processed or unprocessed soils, rocks or minerals to achieve a mixture that meets the specifications required. Mechanical stabilization is more suitable in areas where there is low traffic and rainfall and it also involves the correct proportioning of aggregates and soil that must be compacted adequately to get mechanically stable layers. (http://onlinepubs.trb.org).

Mechanical stabilization or modification is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction efforts, or undercutting the existing soils and replacing them with granular material (http://www.in.gov).

A common remedial procedure for wet and soft subgrade is to cover it with granular material, to rip and compact the subgrade or to partially remove and replace the wet subgrade with a granular material to a pre-determined depth below the grade lines. The compacted granular layer distributes the loads over a wider area and serves as a working platform (http://www.in.gov).

To provide a firm-working platform with granular material, the following conditions should be met:

- The thickness of the granular material must be adequate usually 300-600mm to develop acceptable pressure distribution over the wet soils, however deeper undercut and replacement may be required in certain areas
- The backfill material must be able to withstand the load without rutting

- The compaction of the backfill material should be in accordance with the Standard Specifications (http://www.in.gov)

The undercut and backfill option is widely used for construction traffic mobility and a working platform. This option could be used either on the entire project or for spot treatment.

There are various factors affecting mechanical stabilization and this includes the following:

- Mechanical Strength - When soil is applied in a small quantities to fill voids. The crushing strength of the aggregates is important

- Gradation - A mix with high stability values and high dry densities will be achieved by using well graded aggregate soil mix

- Properties of soil – It is advised to use soil with a limited plastic index because a mix with a high plasticity index results in poor stability of he soil under soaking conditions

- Presence of Chemicals – Not all chemicals present in soil are undesirable like sulphates. Calcium chloride can be beneficial

- Compaction - Efficient compaction is wanted to produce a stable mix with high density

(http://www.scribd.com)

All of the specifications must be given by the geotechnical engineer and will be different for each project.

2.6.3) Geosynthetic stabilization

Geogrids are can be used to reinforce soils, especially to reinforce road sections. The inclusion of Geogrids in subgrades changes the performance of the roadway. Tensile reinforcement, lateral reduction of spreading, construction uniformity and reduction in strain has been identified as key reinforcement mechanisms. Geogrids with reduced aggregate thickness options are designed for urban areas (http://www.in.gov).

Application of recycled and waste products.

Improved chemical and mechanical stabilization techniques are needed for waste materials such as old crushed asphalt pavement, copper and zinc slag, paper mill sludge, and rubber tire chips. In Finland, for example, attempts have recently been made to mix paper mill sludge with fly ash for use in the construction of roads, liners for landfills, and stabilized layers in areas where slope stability is of concern. Experiments in South Korea involve mixing waste lime that is produced as a by-product in the manufacturing of sodium carbonate with weathered granite for the stabilization of offshore reclaimed land. At present, the pressure to use waste materials for construction is much higher due to the increased emphasis on environmental protection (http://onlinepubs.trb.org).

Need to consider global climate change.

Global climate change may affect the durability and application of stabilizers. It may be desirable to consider these potential changes in the development of future soil stabilization techniques.

The objective of the Atterberg limits test is to obtain basic index information about the soil used to estimate strength and settlement characteristics. It is the primary form of classification for cohesive soils (http://www.civil.umaine.edu).

Fine-grained soil is tested to determine the liquid and plastic limits which are moisture contents that define boundaries between material consistency states. These standardized tests produce comparable numbers used for soil identification, classification and correlations to strength (http://www.civil.umaine.edu).

The liquid (LL) and plastic (PL) limits define the water content boundaries between non-plastic, plastic and viscous fluid states. The plasticity index (PI) defines the complete range of plastic state (http://www.civil.umaine.edu). The following figure gives a good illustration:

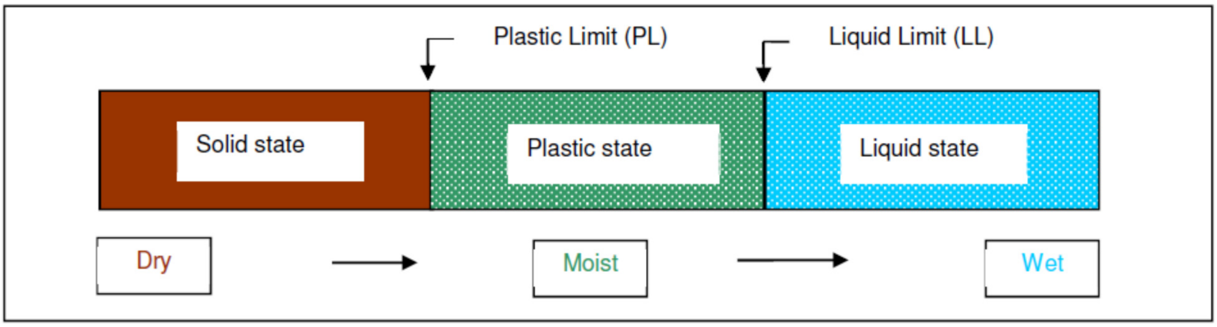


Figure 3: Atterberg limits illustration (http://www.csir.co.za)

Plastic Limit (PL)

The plastic limit defines the boundary between non-plastic and plastic states. It is determined simply by rolling a thread of soil and adjusting the moisture content until it breaks at +- 32mm diameter (http://www.civil.umaine.edu).

2.7) SUMMARY

The type of soil and its properties can be tested in the field and/or in a laboratory. Soil properties such as strength, compressibility, hydraulic conductivity, workability, swelling potential, and volume change tendencies may be altered by various soil modification or stabilization methods. Soil can be stabilized or modified in three ways namely: chemically, mechanically and by means of geosynthetic stabilization.

Different soils will need different stabilization or modification and are used for different applications which will be decided by the geotechnical engineer. Financial resources of the client, environmental impact of the development and the availability of additives and the type of soil will be some of the factors influencing the type and extend of soil to be used.

2.8) CONCLUSION

Due to the poor quality of soil(s) in certain geographic areas, one should look at ways to alter the soil(s) by means of stabilization or modification or replace the poor quality soil with good quality soil. This will have an impact on the cost of construction so one should consider various options for example the cost of stabilization versus the replacement of the poor quality soils. In order to determine the properties of the soil(s) it has to be tested, preferably in a laboratory. The geotechnical engineer will then look at the results and/or report and will make a recommendation regarding the method, materials to be used, etc.

2.9) TESTING OF HYPOTHESIS

There are two types of stabilizing methods, namely chemical and mechanical stabilization. Chemical stabilization makes use of chemicals and emulsions and mechanical stabilization includes compaction and addition of additives to soils to improve the strength thereof. There are various additives available including lime, cement, fly ash, etc. Soils treated with cement will have the greatest increase in strength.

Different soil types require different additives to stabilize it. As seen from above most of the additives can be used to stabilize any type of soil, but some additives are just better for a certain type of soil that the other:

Cement - Cement can stabilize any type of soil, except those with organic content greater than 2% or having pH lower than 5.3. Granular soils and clayey materials with low plasticity index are better suited to be stabilized with cement.

Lime - the clay fraction may often be altered through chemical reaction or ion exchange, such as with lime

Lime-Cement-Fly ash - Coarse-grained soils with little or no fines can be stabilized by a combination of lime and fly ash

Emulsified asphalt - Stabilization with emulsified asphalt is more applicable for coarse-grained soils; however this method can also be applied to stabilize fine-grained soils as well. Sandy soils can be stabilized by emulsified asphalt easily, if they contain less than 25% fine material with plasticity index of less than 12

CHAPTER 3 – ALTERNATIVE FOUNDATION SYSTEMS

3.1) INTRODUCTION

Foundations can be seen as the most vulnerable part of any building and it is certainly the most expensive element of a building to repair. There are various types of foundations can be used in construction and they vary depending on the structure as well as the climate, geographic location, soil, and the needs of the structure which serves as criteria. It is not uncommon that foundations are incorrectly designed or constructed. When designing the foundation(s) the designer must comply with regulations to insure the foundations are effective and without or with limited risk of failure (Cooke, 2007).

Some failures cannot be prevented or foreseen by the designer or builder of the foundations and this includes the effects of water which is the most common challenge to the designer and builder. The different foundation types and designs are discussed in this chapter in relation to types of soils and loading.

The definition of a foundation can be described as follows: “The purpose of a foundation is to transfer the imposed load of a building or structure onto a suitable substratum.” (Cooke, 2007)

3.2) CONSIDERATIONS

3.2.1) Loads

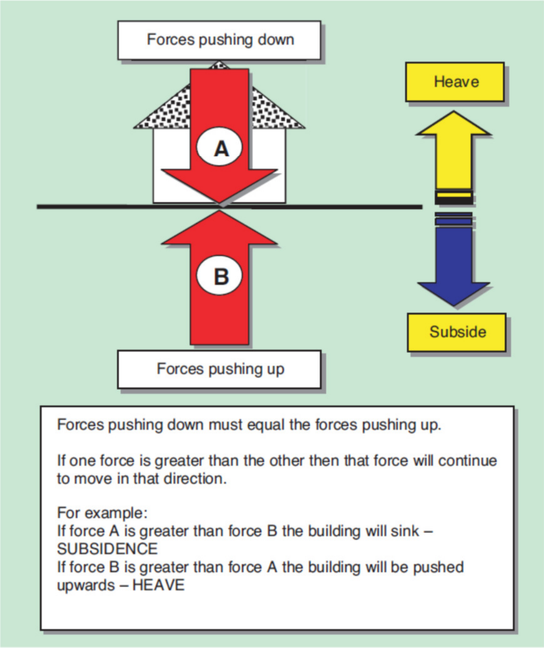
According to (Cooke, 2007) there are three important types of load that one must consider when designing a foundation:

- **Dead loads -** the stationary or constant weight of the building or structure consisting of the walls, roof, floors and other fixed elements.

- **Imposed loads** (or live loads) – this includes people, furniture, etc which is seen as movable elements in or on a building or structure. Loads caused by weather also forms part of variable loads, such as rain and snow.

- **Wind loads -** do not form part of the above loads and therefore require specific consideration. These loads can be calculated and expressed as a force that needs to be transferred onto the ground.

To ensure that a structure is stable, the force bearing downwards must be opposed by the same force pushing upwards. The forces will be in equilibrium when the upward and downward forces are of the same magnitude. If they are not in equilibrium the building or structure may either subside or heave as seen in Figure 4.



Forces pushing down must equal the forces pushing up.

If one force is greater than the other then that force will continue to move in that direction.

For example:
If force A is greater than force B the building will sink – SUBSIDENCE
If force B is greater than force A the building will be pushed upwards – HEAVE

Figure 4: Ground movement and forces (Cooke, 2007)

3.2.2) What causes heave?

Weather is seen as the main cause of movement of buildings or structures. The buildings or structures built on clay soils are effected mostly because of the reason that clay dries out during dry periods which will cause the clay to shrink and this in turn will cause the support beneath a structure to become uneven. Figure 5 shows how ground surrounding a building dries when it is exposed to the sun and has a lot of access to air whereas beneath the building the ground stays moist. This causes uneven support of the building or structure and may cause failure of the foundations (Cooke, 2007).

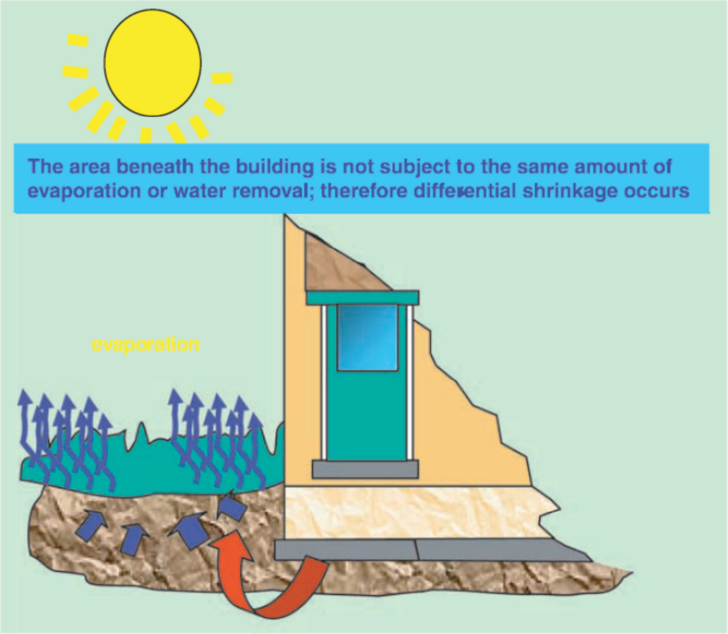


Figure 5: Subsidence caused by evaporation (Cooke, 2007)

The Building Regulations Approved Document A: 2004, paragraph: 2E4 in the UK requires that foundations in clay must have a be a minimum depth of 0.75m below ground level because it is considered that the effects of the sun cannot penetrate lower than that level. Where in other sands and gravels (non-cohesive soils), the minimum depth of foundations can be 0.45 m (http://www.planningportal.gov.uk)

Water has a significant effect on ground. Between saturated and dry conditions some clay soils can swell by up to 75mm. The plasticity of clay increases as the moisture levels rise and this allows for landslip. The presence of trees can also be one of the causes of water loss, removing vast quantities of water from the ground, especially during their growing period in the summer and spring months (Cooke, 2007).

Clay swells when it is wetted which causes heaving and softening of the soil, it is said to become plastic. When clay is saturated with water, its compressive strength is reduced significantly. This could not only influence the integrity of the building foundations and structure, but influences access to and movement on the site. Clay substratum can lose up to 50% of its load bearing capacity when saturated and buildings may subside (Cooke, 2007).

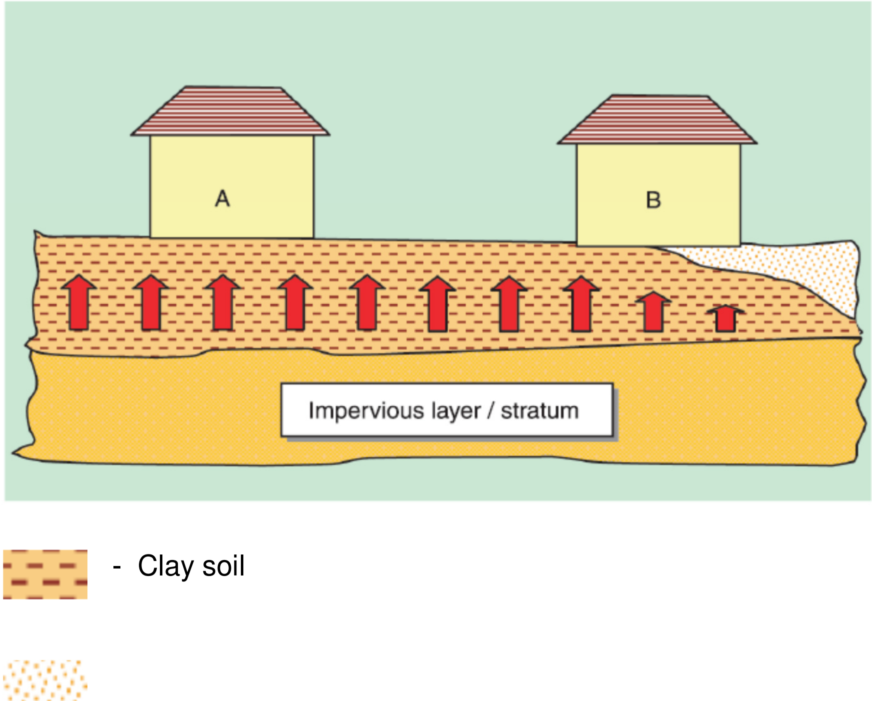


Figure 6: Differential ground movement (Cooke, 2007)

In Figure 6, structure A may be pushed upward evenly because it rests on clay soil only and therefore is unlikely suffer damages. However, if the ground strata change as in the case beneath structure B, the force pushing upward will be uneven. This may result in a reduced load bearing capacity which in turn may cause slip and heave therefore structural damage is likely.

Broken drains and changes to the water courses as well as water abstraction to be used for human use, manufacturing and irrigation can cause ground movement and my have considerable effects on the stability of the ground.

3.3) Foundation types

In rare cases the bedrock is close to the surface which makes it is possible to level it off and build directly onto it due to its stability. But in most cases you will build in areas where the bedrock is very deep, so a person would be forced to build on the soils which are not as strong as rock so foundations will be required.

3.3.1) Spread footings

The base of the wall is broaden using brickwork as inverted corbelling and was commonly used on structures prior to about the 1920s (Cooke, 2007).

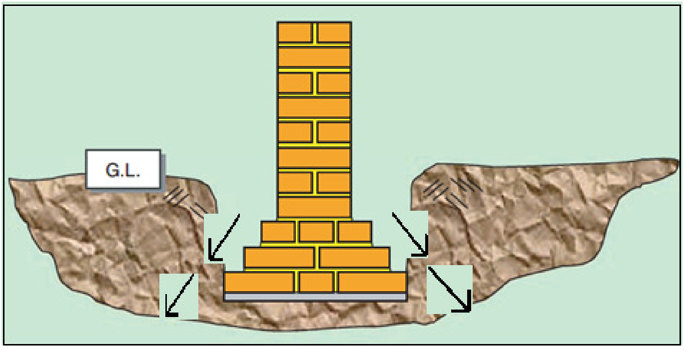


Figure 7: Spread footings (Cooke, 2007).

Sand, coal or ash dust was used to provide a smooth surface to the formation level. This type of foundations is not used anymore.

3.3.2) Strip foundations

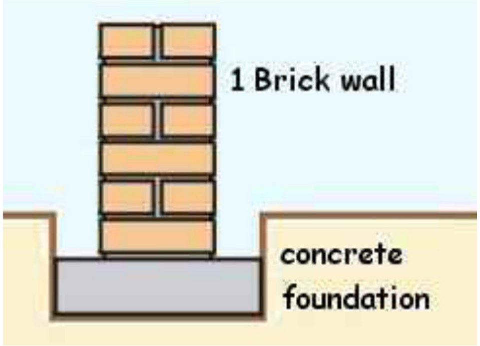
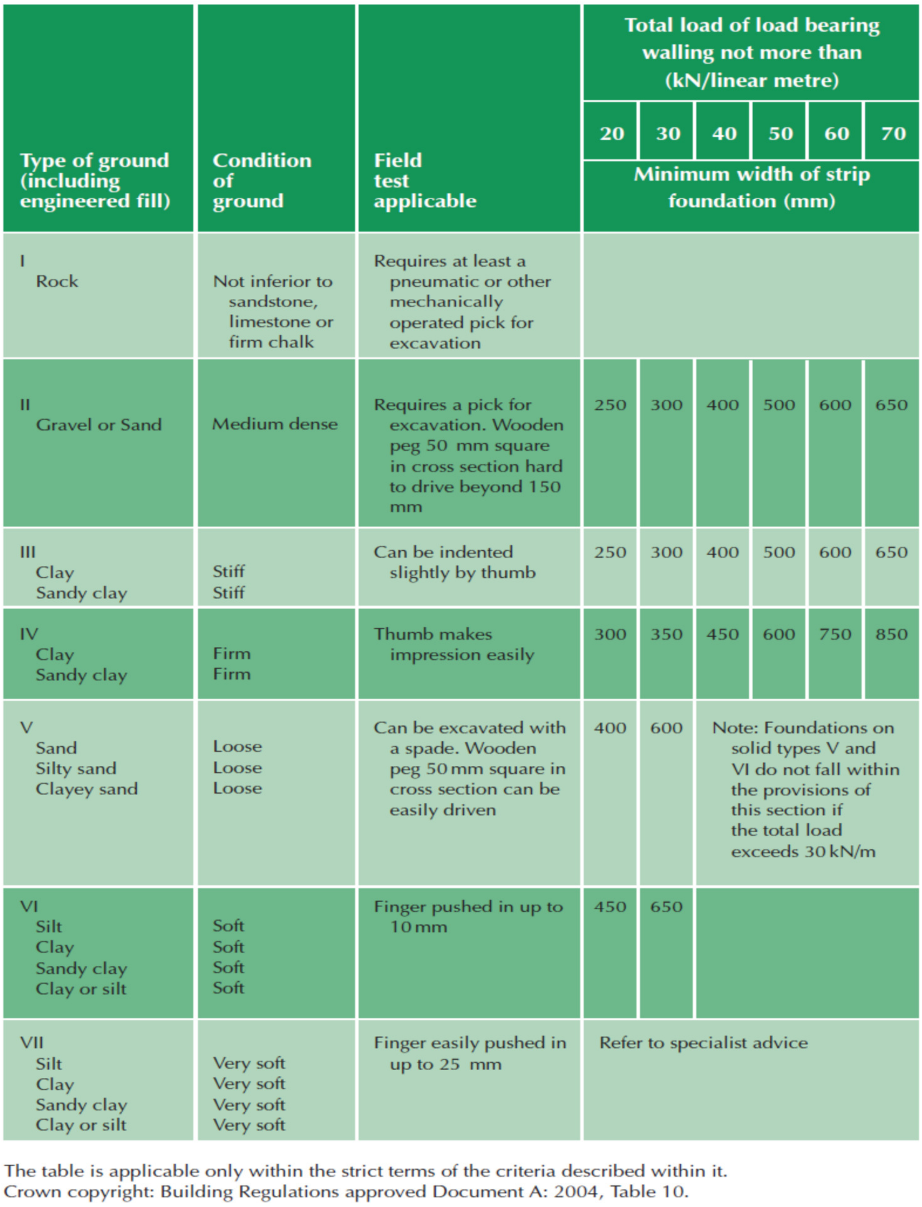


Figure 8: Simple strip foundation (http://www.bne.uwe.ac.uk)

Strip foundations is by far the most commonly used type of foundations because in most cases it is the cheapest way founding for low rise buildings or structures, provided that the soil to be founded in is of acceptable strength and density . The strip foundation can basically be described as a strip of in-situ concrete running under the entire load bearing walls, which includes all of the external walls and some of the internal walls in some cases (http://www.bne.uwe.ac.uk).

The consulting engineer will be in charge of the design of the foundation, stating which the width and thickness the concrete footing should be. The engineer must also determine the depth of the footing, which will be influenced by the type of the soil to be founded in. Table 3 can be used as a guideline, but the final sizes are determined by the engineer.



Type of ground (including engineered fill)	Condition of ground	Field test applicable	Total load of load bearing walling not more than (kN/linear metre)					
			20	30	40	50	60	70
			Minimum width of strip foundation (mm)					
I Rock	Not inferior to sandstone, limestone or firm chalk	Requires at least a pneumatic or other mechanically operated pick for excavation						
II Gravel or Sand	Medium dense	Requires a pick for excavation. Wooden peg 50 mm square in cross section hard to drive beyond 150 mm	250	300	400	500	600	650
III Clay Sandy clay	Stiff Stiff	Can be indented slightly by thumb	250	300	400	500	600	650
IV Clay Sandy clay	Firm Firm	Thumb makes impression easily	300	350	450	600	750	850
V Sand Silty sand Clayey sand	Loose Loose Loose	Can be excavated with a spade. Wooden peg 50 mm square in cross section can be easily driven	400	600	Note: Foundations on solid types V and VI do not fall within the provisions of this section if the total load exceeds 30 kN/m			
VI Silt Clay Sandy clay Clay or silt	Soft Soft Soft Soft	Finger pushed in up to 10 mm	450	650				
VII Silt Clay Sandy clay Clay or silt	Very soft Very soft Very soft Very soft	Finger easily pushed in up to 25 mm	Refer to specialist advice					

The table is applicable only within the strict terms of the criteria described within it.
Crown copyright: Building Regulations approved Document A: 2004, Table 10.

Table 3: Guideline of footing sizes (Cooke, 2007)

The load bearing walls can be many different widths and may consist of solid walls or cavity walls with or without concrete infill, depending on the type of soil, the height and size of the building, etc.

3.3.3) Raft foundations

Raft foundations, also called floating foundations, are basically large pad footings in a soil mass, especially where the soil has little load bearing qualities or in areas where dolomite is found and the risk of sinkholes are present (http://www.gautrain.co.za).

In some cases the soil mass needs to be pre-treated to improve the density and strength of the soil mass or in other cases it may be necessary to pile the raft itself as seen in figure 10 where the piles then extend down to a better founding horizon to reduce the risk of structural failure (http://www.gautrain.co.za).

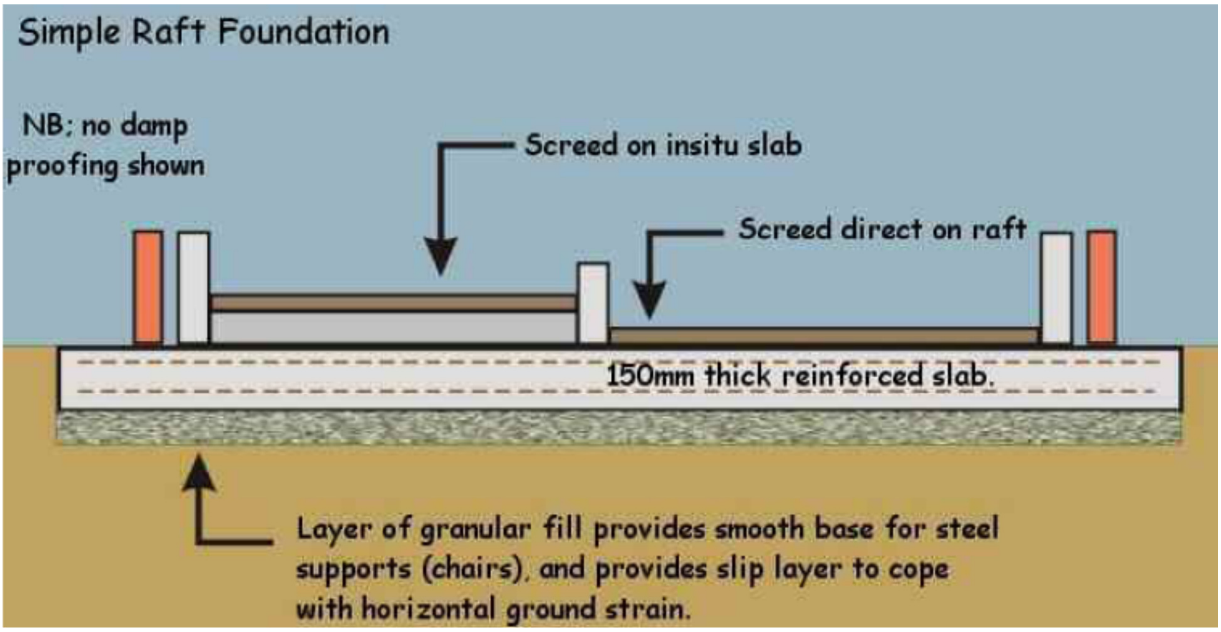


Figure 9: Simple Raft foundation (http://www.bne.uwe.ac.uk)

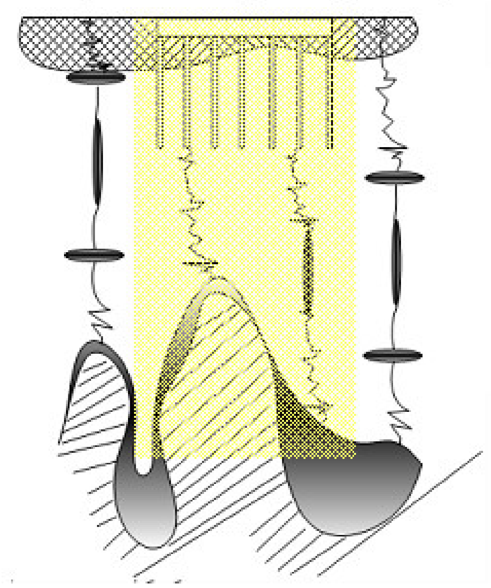


Figure 10: Piled raft foundation (www.gautrain.co.za)

According to (Cooke, 2007) where the subsoil is very weak the load needs to be spread over a greater area. This is achieved by casting a slab of concrete over the whole ground area and thickening the slab where walls are to be placed (Figure 11). Reinforcement is required where ground pressures are excessive during the different seasons. Mostly fabric reinforcement is used in a sheet mesh form (Type REF 395, etc). In stead of mesh reinforcement, one can make use of fibers, such as steel fibers and cryplon fibers which is a polypropylene fiber, as a means of reinforcement. This concept is relatively new, but it has a lot of advantages like less shrinkage cracks, no risk of the reinforcement moving during casting of the concrete, which means that the structure has a smaller chance of failing. This concept will be explained in chapter 5 where the costs of the different foundation types are compared.

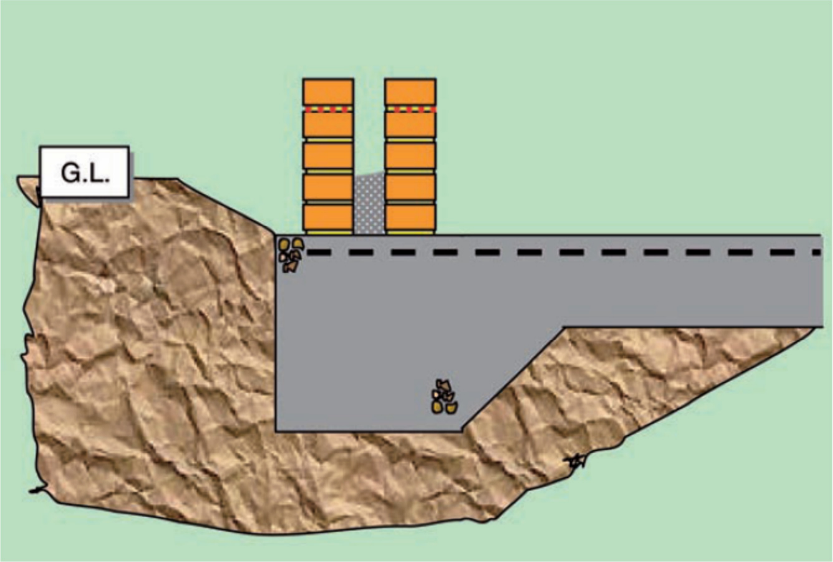


Figure 11: Simple raft foundation (Cooke, R. 2007)

3.3.4) Pad foundations

In areas where stronger strata, like bedrock, occur at a shallow depth, conventional pad footings with the use of a specially constructed mass concrete “mattress” are used. Foundation proofing done by means of small diameter probe drilling in selected areas is required to make sure that founding takes place on rooted bedrock in all instances.

Pad foundations are used when isolated loads need to be supported, such as columns or framed structures (Cooke, 2007). The load would be concentrated in fairly small areas of the pad with large expanses being either non-load bearing or having lightweight loadings, meaning that small slabs to spread the load from the skeletal structure can be cast. Figure 12 shows a simple pad below a steel stanchion. Steel reinforcement may be required for higher loadings. The type of skeletal frame will determine the pad foundation design. For example, a cast in-situ concrete column will require a kicker and continuity bars to be cast into the pad. Steel frame or precast concrete framed structures will require holding down bolts to be cast into the top of the pad or sockets to be formed.

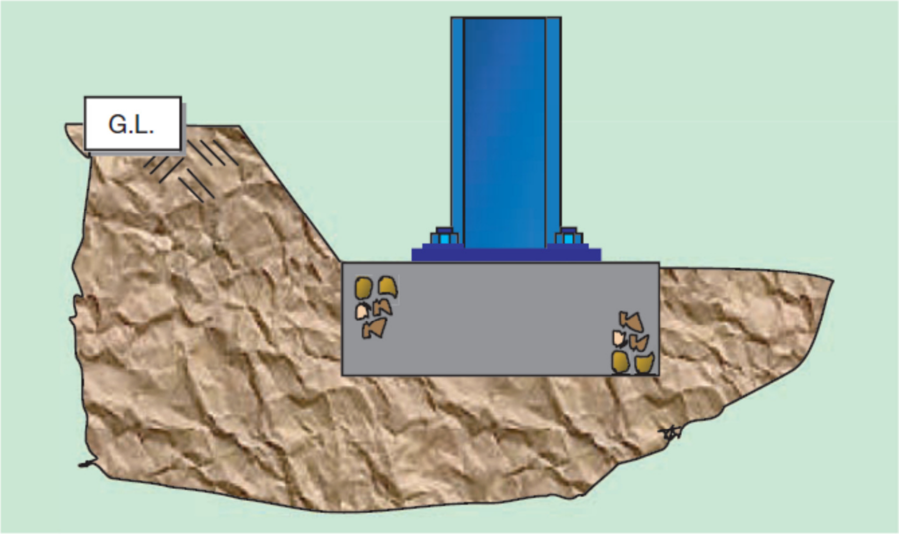


Figure 12: Simple pad below steel stanchion fixed with HD-bolts (Cooke, 2007).

3.3.5) Piles and beams

It is needed when:

- When the top layers of the soil are highly compressible and shallow foundations cannot support the structural loads effectively.
- A more economical design can be designed where the rock level is shallow enough for end bearing pile foundations.
- Where expansive and collapsible soils occurs on the site.
- Structures that are built off shore.
- To avoid problems caused by erosion where structures are built near flowing water in the case of bridge abutments, etc. (A. Prashant (n.d.)).

Types of Piles (A. Prashant (n.d.)).

Various types of piles can be used, for example:

Steel Piles

Pipe piles

Rolled steel H-section piles

Concrete Piles

Pre-cast Piles

Cast-in-situ Piles

Bored-in-situ piles

Timber Piles

Composite Piles

Concrete piles are the most commonly used types in South Africa. Concrete piles can be divided into pre-cast piles and cast in-situ piles. Pre-cast piles (10-45m) are used for deeper depths as cast in-situ piles (5-15m) (A. Prashant (n.d.)).

Concrete piles have several advantages and include the following:

- Concrete piles are relatively cheap to produce (cheaper than steel, timber, etc)
- If the superstructure is made of concrete it can be easily combined
- It is corrosion resistant
- Pre-cast piles can bear hard driving

Pre-cast concrete piles are difficult to transport and it is also difficult to achieve the desired cut-off (A. Prashant (n.d.)).

In areas where the ground conditions is not suitable to support strip foundations, it may be necessary to make use of a series of concrete columns, referred to as piles, that will reach down until it rests on a stronger strata. Piles are reinforced with steel where lateral forces are present, or just consist of concrete if all of the present forces are vertical.

At the top of every pile, referred to as the pile cap, a connection must be made to the ground beam which is the horizontal reinforced concrete section.

According to (Cooke, 2007) pile and beam foundations have the following advantages:

- To eliminate casting time on site, precast concrete beams can be used
- If piles are designed correctly, they are not affected by heave or shrinkage of clay soils
- When making use of piling as the foundation type, there is minimal ground disturbance and minimal spoil is produced
- Groundwater easily penetrate between piles
- Whilst piling, techniques to overcome groundwater are available so no de-watering is required
- The amount of concrete required is less than with the same depth of strip foundation

Disadvantages include the following:

- The high cost of pile and beam foundations (although the increasing cost of spoil removal and time savings can be offset against the extra expenses incurred by making use of piling foundations)

- Specialist plant and skilled labour is required.

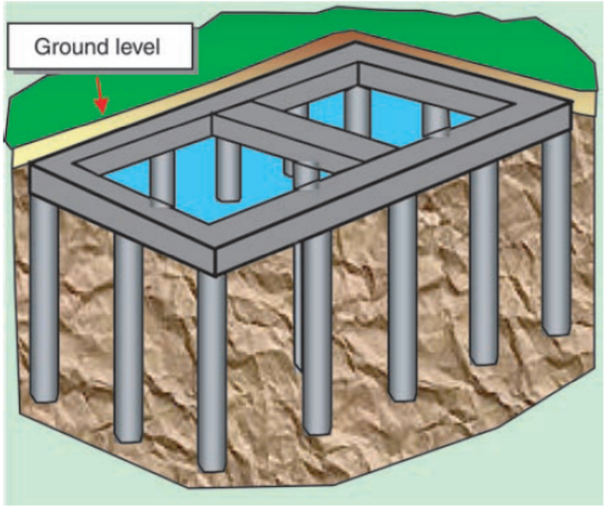


Figure 13: Isometric view of a pile and beam foundation (Cooke, 2007)

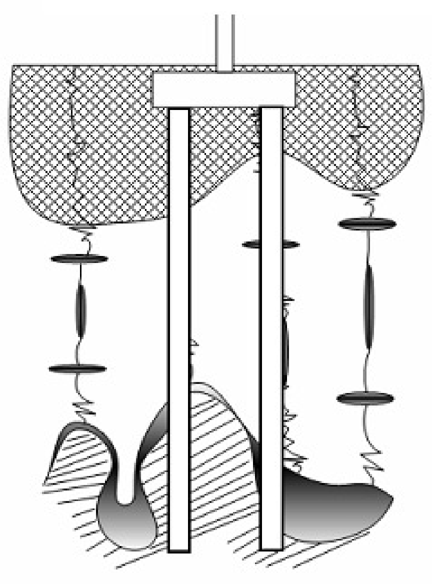


Figure 14: Piles to bedrock (http://www.gautrain.co.za)

Figure 15 shows a piling rig. An auger (long metal screw) is turned into the ground, working in almost the same way as a corkscrew. When the auger is brought to the surface the soil is removed. To clean off the spoil caught in the blade, a wire brush is located next to the auger.

Figure 15: A piling rig (http://www.bne.uwe.ac.uk)

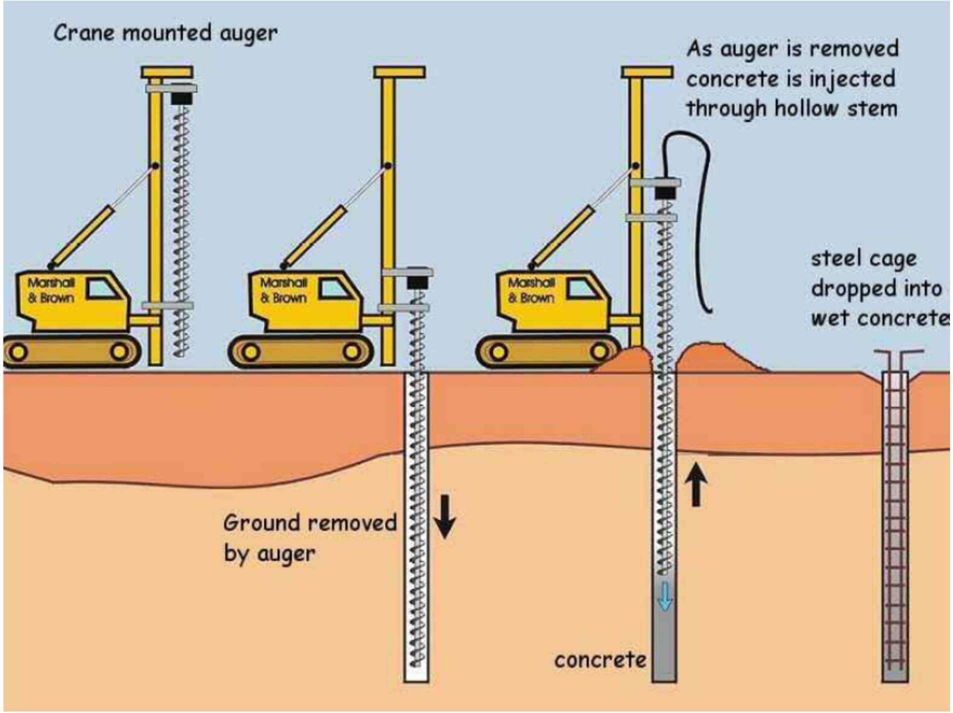


Figure 16: Demonstration of augered piles (http://www.bne.uwe.ac.uk)

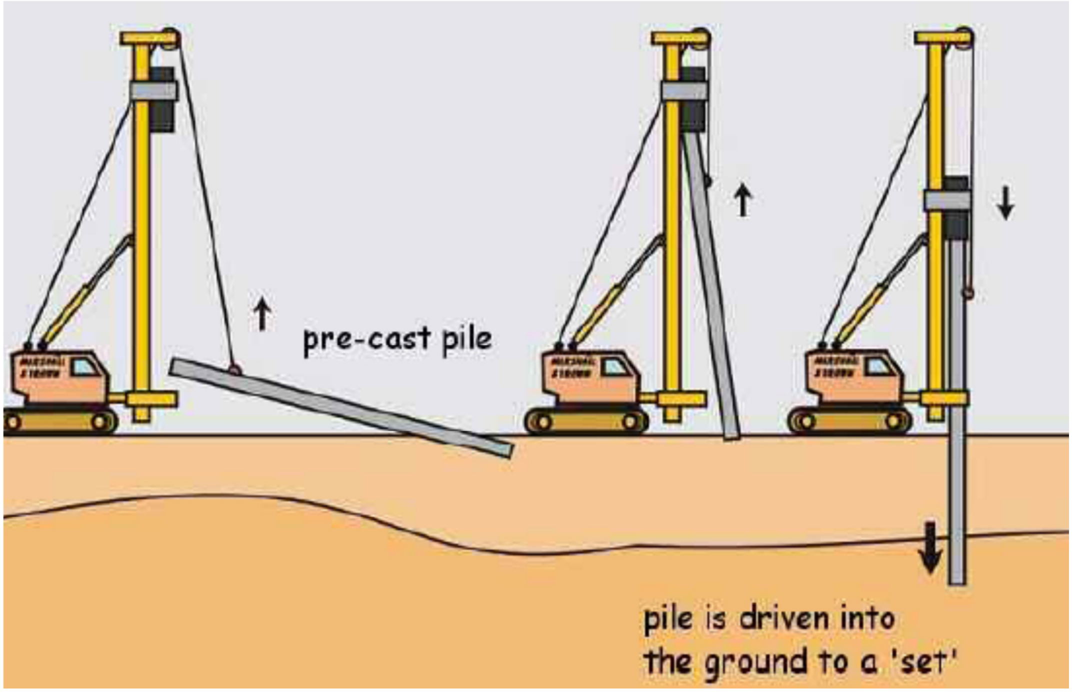


Figure 17: Demonstration of driven piles (http://www.bne.uwe.ac.uk)

3.4) SUMMARY

The most commonly used types of foundations used is spread footings, strip foundations, raft foundations, pad foundations and piling foundations consisting of piles and beams. Each type of foundation is used in different soil conditions.

3.5) CONCLUSION

Spread footings and strip foundations are the most basic type of foundations and are mostly and effectively used in good, stable soils where pad foundations, raft foundations and piling foundations are more complex foundation types and are mostly used in bad, unstable soils.

3.6) TESTING OF HYPOTHESIS

In some cases the soil is unsuitable to stabilize, or it will be too expensive to stabilize the soil, then one must look at alternative means of founding i.e. pad foundations, raft foundations and piling foundations just to name a few. One must look at all of the possible ways of founding either by considering one type of foundation in isolation, or by considering a combination of the foundation types.

CHAPTER 4 - THE IMPACT OF MINEROLOGY AND WET-DRY CYCLES ON THE STRENGTH AND DURABILITY OF STABILIZED SOILS

4.1) INTRODUCTION

Soil stabilization is faced with a number of limitations, particularly when the soil contains a considerable amount of chemical compounds, sulfates, nitrates, chlorides, etc. that may change the effects of the lime and cement used to stabilize the soil (Cuisinier et al., 2011). Temperature and moisture also have a significant impact on the material properties because these weather conditions will cause swelling and shrinkage of the soil (Little, 1999).

The design must take into account the effects of the temperature gradient within the stabilized layers. A critical component of the mix design for stabilized layers is to ensure that the stabilizer as well as the amount of stabilizer used effectively reduces the moisture sensitivity of the soil being stabilized (Little, 1999).

According to (Cuisinier et al., 2011) sulfates and organic matter are the most commonly known compounds to alter soil stabilized with cement and lime. Other compounds may be responsible, for these failures for example nitrates and phosphates found in agricultural fertilizers or chlorides found in the area of sea coasts (e.g., LCPC-SETRA, 2000) nevertheless, in literature there are limited information available about the actual effects of the above mentioned compounds on soil stabilization. If these compounds are likely to alter soil stabilization, it is necessary to determine the concentration of the compound present in the soil which may have a negative impact on the effectiveness of soil stabilization with lime and cements (Cuisinier et al., 2011).

Curing conditions influence both the physical and chemical (known as physicochemical) processes of soil stabilization and therefore it can be said that it has an influence of the mechanical performance as well as the swelling of the stabilized soil (Cuisinier et al., 2011).
According to (Cuisinier et al., 2011) the study was conducted on two soils namely; fine sand and silt. The presence of clayey particles in the silt can bee seen as the main difference between the two soils used (Cuisinier et al., 2011).

4.2) INFLUENCE OF SULFATES ON SOIL STABILIZATION

According to (Little, 1999) reactions between soil and lime as well as the stabilization process are not only affected by the mineralogy found in the soil, but also by the presence of other compounds such as salts and organic contents within the soil. According to (Little, 1999) as a general rule, where the soil contains organic contents exceeding one percent, it might be difficult to stabilize soil with lime, or uneconomical quantities of lime may be required to stabilize the soil.

Soil with high concentrations of salt may also affect or interfere with soil stabilization. The most important salts are sulfate salts, including magnesium, calcium and sodium sulfates. This is interference with the effectiveness of the stabilization due to high sulfate concentrations which can lead to deleterious reactions among the soil minerals, lime, sulfate ions and/or water (either water within the soil or of construction). These reactions can lead to heaving as well as loss of stability of the stabilized soil. Because of this, it is important to consider the presence of sulfate salts which can be done by investigating geotechnical reports or by performing soluble sulfate tests of the soil on the site. Where the total soluble sulfate level is greater than approximately 0.3% in a water/soil solution, where the solution is 10:1, then supplementary precautions such as swell test may be necessary to guard against sulfate reactions (Little, 1999).

Where sulfates are present, the stabilized soils may undergo dramatic volume changes which may cause the mechanical performance of the stabilized soils to decrease (Cuisinier et al., 2011).

According to (Cuisinier et al., 2011) the results of the experiments conducted showed that the presence of sulfates is not systematically associated with an alteration of the soil stabilization process, but that the impact of sulfates on the soil stabilization is directly related to the water content, temperature and the curing conditions of the stabilization process.

The nature of the soils being stabilized plays a very important role in the performance of the stabilization process, because as seen from the experiments conducted in (Cuisinier et al., 2011) the silt showed more swelling than the sand which can be related to the presence of clay present in silt. Clay particles contains aluminum which is essential for ettringite formation and thus for swelling.

4.3) INFLUENCE OF NITRATES ON SOIL STABILIZATION

To the knowledge of the publishers of (Cuisinier et al., 2011), there are not any references on the influence of nitrates on soils stabilized with cement and lime.

However, due to the fact that nitrates are likely to alter concrete structures, one can conduct an evaluation of their potential detrimental effects on soil stabilized with cement which can be inferred from cement chemistry.

The alteration of concrete structures is the result of the attack through an acidic–basic reaction on the cementitious compounds, which mainly involves ammonium nitrate. The attack provokes a reduction of the mechanical performance of concrete. Such deleterious reactions may occur in both cement or lime stabilized soil if a sufficiently high concentration of nitrate compounds is present in the soils to be stabilized (Cuisinier et al., 2011).

According to tests conducted by the authors of (Cuisinier et al., 2011) the results showed that nitrates, at concentrations which are representative of that which can be found in natural soils when conducting earthworks, appeared to lower the effectiveness of soil stabilization when the concentration of nitrate was high. The influence of nitrates is also highly dependent on the type of cement used for stabilization as well as the curing conditions.

4.4) INFLUENCE OF PHOSPHATES ON SOIL STABILIZATION

The same as for nitrates, it can be inferred from the literature available on concrete and cement chemistry that phosphates can affect soil stabilization. It is known that phosphates act as retarders of cement hydration, which delays the setting time robustly, while hardening during an early stage can be significantly lowered. The experiments conducted in (Cuisinier et al., 2011) shows that the results are very sensitive to the types of soil and cement used. Alteration of soil stabilization by phosphates is not directly related to the concentration of phosphates in the soil, but rather the combination of the characteristics of the soil and of the curing conditions.

4.5) INFLUENCE OF CHLORIDES ON SOIL STABILIZATION

According to (Cuisinier et al., 2011) calcium chloride and sodium chloride do not alter the mechanical improvement of lime-treated soils with high water contents. The strength of stabilized organic clay is higher when sodium chloride is used together with lime, rather than when lime is used on its own. It can be seen that the main effect of the chlorides is speeding up the kinetics of the setting reactions.

This effect of chlorides on soil stabilization is very similar to the effect of chlorides on cement or concrete hardening (Cuisinier et al., 2011).

4.6) WET-DRY CYCLES

As seen from the tests performed in (Parsons, & Milburn, 2002). As seen in Figure 18 performance of the clay soils was the poorest overall. Soils stabilized with cement performed the best on the sulfate bearing CH clays and lime performed better than fly ash and cement on the CL clays. The soil samples containing little clay which were stabilized with cement also performed well, while where fly ash was used as a stabilizing additive, only the SM soil performed well (Parsons, & Milburn, 2002). The soil samples treated with enzyme did not make it through the first soaking phase as indicated in Figure 19.

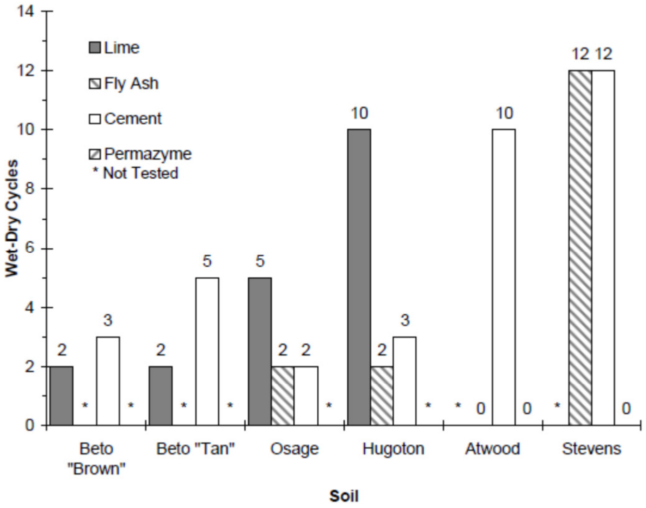


Figure 18: Number of wet-dry cycles completed (Parsons, & Milburn, 2002)

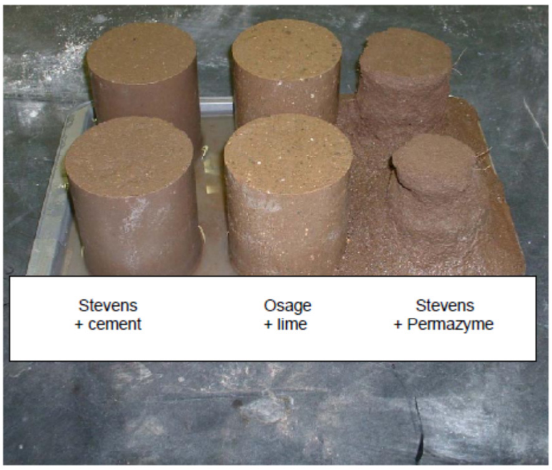


Figure 19: Failure of enzyme treated soil after first soaking cycle (Parsons, & Milburn, 2002)

4.7) OPTIMUM LIME CONTENT

The optimal lime content to be used when stabilizing soil is approximated by using the Eades and Grim pH test as explained in ASTM D 977. This test will identify the required lime content to satisfy instant lime-soil reactions which will still provide the level of calcium and the remaining high pH required to provide the proper conditions for the long-term pozzolanic reaction. This pozzolanic reaction is necessary for the stabilization of soil and the durability of stabilization. The lime content established by the pH test serves as an indicator of the optimum content. This must be verified by performing strength tests due to the fact that the optimum content according to the pH test is not necessarily the optimum content to be used when stabilizing the soil (Little, 1999).

4.8) WETTING-DRYING AND DRYING-WETTING TEST PROCEDURES

The effects of dry-wet and wet-dry tests on the compressive strength of the stabilized soils samples are shown in Figure 20. During the first four cycles there where an average increase in the compressive strength ranging between (10.6 to 18.1 %) for the samples subjected to the cycles started with drying and (4.7 to 9.4 %) for the samples subjected to the cycles started with wetting can be seen respectively (Al-Kiki et al, 2011).

The initial strength of the stabilized soil increases due to the continuous reactions between the lime and the soil. This is because due to the cycles the rate of strength gained is higher than the rate of deterioration. One can see a reduction in the compressive strength in the stabilized soil samples at the end of the 4th cycle. The compressive strength of the samples subjected to wetting first and then drying cycles decreased with a reduction ratio 42.2 % at the end of the 12th cycle, while compressive strength decreased with a reduction ratio of34.4% for the samples subjected to drying first and then wetting (Al-Kiki et al, 2011).

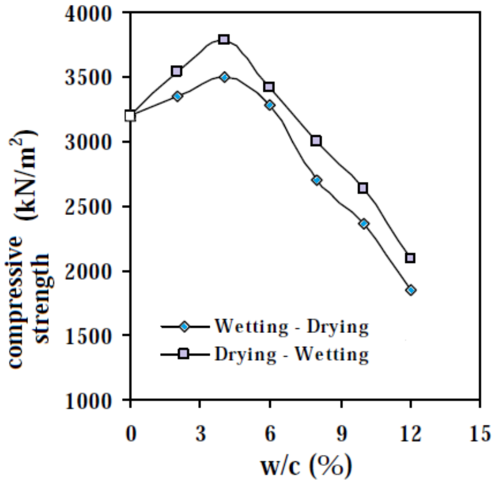


Figure 20: Effect of wet and dry cycles on the unconfined compressive strengh (Parsons & Milburn, 2002)

4.9) SUMMARY

There are various compounds found in soil which can alter the performance of the stabilized soil. Chlorides, phosphates, nitrates and sulfates were discussed in this chapter with regards to their effects on soil stabilization. There is not a lot of information regarding all of these minerals and in some cases assumptions were made. Not only does the concentration of the compound influence the performance of the stabilized soil, but several other factors plays a role like wet-dry and dry-wet cycles, the nature of the soil, the type of cement or lime used and the curing conditions, etc.

Chlorides, phosphates, nitrates and sulfates can have a considerable effects on the mechanical performance of stabilized soils, with some of the components effecting the stabilization negatively, i.e. the concentration of the sulfates and nitrates in the soil has an effect on the mechanical performance or effectiveness of the soil stabilization where the phosphates’ effect depends on the combination of the characteristics of the soil and of the curing conditions and some positively i.e. where chlorides speeds up the kinetics of the setting reactions when lime is used to stabilize soils where organic clay is present.

4.10) CONCLUSION

The influence of a compound on the soil stabilization processes, as well as the mechanical performance of the stabilized soil, is a combination of the nature of the soil, the type of cement or lime used and the curing conditions of the stabilized soil.

In some cases the performance of the soil after it has been stabilized is improved by the presence of the potential deleterious compound. According to (Cuisinier et al., 2011), some of the compounds can be used as secondary compounds in cements to control, or to delay the setting reactions.

Therefore, it is not only important to assess the type of soil and the presence of a substantial amount of a given compound in the soil to evaluate whether the soil is suitable for stabilization with lime and cements, but also the curing conditions like the temperature, humidity, etc.
According to (Parsons & Milburn, 2002), lime in general performed better when used to stabilize fine grained materials and cement performed better when used to stabilize coarse grained soils and did relatively well on the CH clays.

4.11) TESTING OF HYPOTHESIS

In the proposal of this thesis it was thought that in areas with extreme weather conditions e.g. high rainfall or where it is very hot and dry, the behavior of stabilized will be effected. The soil may expand in the case of wet weather and shrink in the case of warm or dry weather. The correct weather conditions will play a big role in compaction of soils to ensure the minimizing of expansion or shrinkage of the soils. Clay soils are harder to stabilize than the other soils because it expands and contracts more excessively than other soils when it gets wet or dry.

This statement tested true. Although the initial strength of the stabilized soil increases due to the continuous reactions between the additive (mostly lime or cement) and the soil, there is a reduction in the compressive strength in the stabilized soil after a few wet-dry or dry-wet cycles.

The influence of nitrates is also highly dependent on the type of cement used for stabilization as well as the curing conditions. It is known that phosphates act as retarders of cement hydration, which delays the setting time robustly, while hardening during an early stage can be significantly lowered. The strength of stabilized organic clay is higher when sodium chloride is used together with lime, rather than when lime is used on its own. It can be seen that the main effect of the chlorides is speeding up the kinetics of the setting reactions.

CHAPTER 5 - A COST COMPARISON OF VARIOUS TYPES OF FOUNDATIONS AND SOIL IMPROVEMENT

5.1) INTRODUCTION

Due to the high cost of construction, one needs to consider all of the available foundation options that can be used in order to obtain both the cheapest as well as the most structurally sound option to provide the client with a structure that is safe. In order to know which type of foundations is the best one to use the geotechnical engineers must first perform tests on the soil found on the site to see which type of soil or soils are going to be built on and then the structural engineer must specify the type of foundation(s) to be implemented accordingly. The civil engineer specifies any soil improvements to be done with the quantity surveyor doing a cost comparison of the foundation type or in some cases of several options, by making use of rates obtained from tenders or in a case where a contractor is not appointed yet the quantity surveyor can make use of rates from similar projects in size, in the same region and recently done.

5.2) PROJECTS USED

For this chapter two projects will be examined. The one project is still in planning stage (Green Gate Factories) and will be used to compare rates for bulk earthworks and foundation comparisons and the other one is being built at the time of this thesis (Kemach JCB factory). Some problems and the impact of these problems on the cost of the project will be looked at.

5.3) REPAIRING DAMAGES CAUSED BY THE FOUNDATION USED

In some instances the type of foundation chosen for a specific project may not produce the outcome that it was intended for, for example the raft may suffer from excessive cracking due to plastic or drying shrinkage. This was the case with the raft done for Kemach JCB. The cause of the cracks is being investigated and will be discussed further in Chapter 6. The cracks do not pose any risk on the structural integrity of the building, but it is visually unpleasant. In the case of Kemach JCB an inspection was done by a Company named Floorshield to determine a solution to improve the aesthetic impact of the cracks, this problem will be discussed in more detail in Chapter 6. The report done by Floorshield is based on a site inspection and tests to determine the hardness of the surface and the durability in terms of suitability for placing coating over the surface. The structural cracks in the floor will be injected, grinded and sealed to prevent the cracks form becoming an aesthetic eye sore.

After the cracks have been injected, grinded and sealed, a clear urethane will be applied to serve as a final floor finish and any required joints in the floor will be filled with a urethane joint sealer.

Repairing the cracked floor

Description	Unit	Quantity	Rate	Amount
Concrete grinding (to expose stone)	m2	1140.00	R 80.00	R 91,200.00
Apply 2 coats of Carboline 134 twin pack clear urethane	m2	1140.00	R 53.60	R 61,104.00
Cut & fill joints (if required)	m	275.00	R 32.00	R 8,800.00
Crack injection	m	1365.00	R 185.00	R 252,525.00
P & Gs	Item	1.00	R 7,600.00	R 7,600.00
Total (Excluding VAT)				**R 421,229.00**
			Rate per m2	**R 369.50**

Figure 21: Cost of repairing the cracked floor at Kemach JCB

5.4) SOLUTIONS TO PREVENT THE HARDSTAND FROM SUFFERING THE SAME UNPLEASANT AESTHETICS

The concrete hardstand around the building was originally designed by the structural and civil engineering company to consist of mesh REF. 395 supported by stools and 30MPa concrete. Several saw cut joints and construction joints would have been necessary to ensure that the hardstand would suffer from limited cracking. Due to the cracks in the raft, the contractor proposed that other alternatives must be considered to ensure that the concrete hardstand would not suffer from the same visually unpleasant cracks.

The contractor came up with an alternative, which they have used on several other projects, that includes the use of fibers as means of reinforcement. There are mainly two types of fibers, namely steel fibers and cryplon fibers which is a polypropylene fiber. Although the fibers acts a means of reinforcement have not been tested by the Cement and Concrete Institute (CCI), it has been used on several projects with great success.

The minimum thickness of the hardstand should be 180mm thick in all three cases as determined by the engineer. The comparison is based on the design done by the structural and civil engineering company for the hardstand reinforced with mesh REF 395. Due to the fact that the CCI has not yet tested the use of steel and cryplon fibers as a reinforcing material, the engineer did not want to take the risk to recommend the use of these fibers. The contractor felt comfortable using either fiber as reinforcement because of the huge amount of success they have experienced over quite some time using either fiber.

Because of the rate per m2 using cryplon fibres is cheaper (as seen below), it was decided to use it as reinforcement for the hardstand. According to the engineer, cryplon fibres have been reported to reduce plastic and drying shrinkage of concrete at fibre contents of 0,1 to 0,3% by volume.

The engineer suggested the contractor must limit the amount of construction joints in the hardstands as these joints create future problems such as excessive cracking and/or breaking off of the concrete at these joints. Saw cut joints are not problematic as they are horizontal. A curing liquid will also be used because of the slope of the hardstand.

The rate per m3 for the hardstand reinforced with the steel and cryplon fibers were calculated by the contractor and the rate per m3 for the hardstand reinforced with the mesh were detailed by the engineer and quantified by the quantity surveyor based on bill rates from the contractor.

5.5) EXTERNAL HARDSTANDS COST CAMPARISON

DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
REINFORCED CONCRETE				
30MPa/19mm Concrete				
External concrete hardstand	m3	602.10	R 1,083.41	R 652,321.16
MOVEMENT JOINTS ETC				
Saw cut joints reamer and sealed with Dow Corning 888 Silicone joint sealant				

10mm Joints	m	1411.92	R 53.45	R 75,467.12
REINFORCEMENT				
Type 395 fabric reinforcement in concrete surface beds, slabs, Etc	m2	3345.00	R 51.44	R 172,066.80
TOTAL (EXCLUDING VAT)				**R 899,855.09**

Material	Rate/m3
Mesh reinforcing	**R 1,494.53**
Cryplon fibers	**R 1,327.20**
Steel fibers	**R 1,502.20**

Figure 22: Comparison of the cost of reinforcing/m3 required for the external hardstand at Kemach JCB

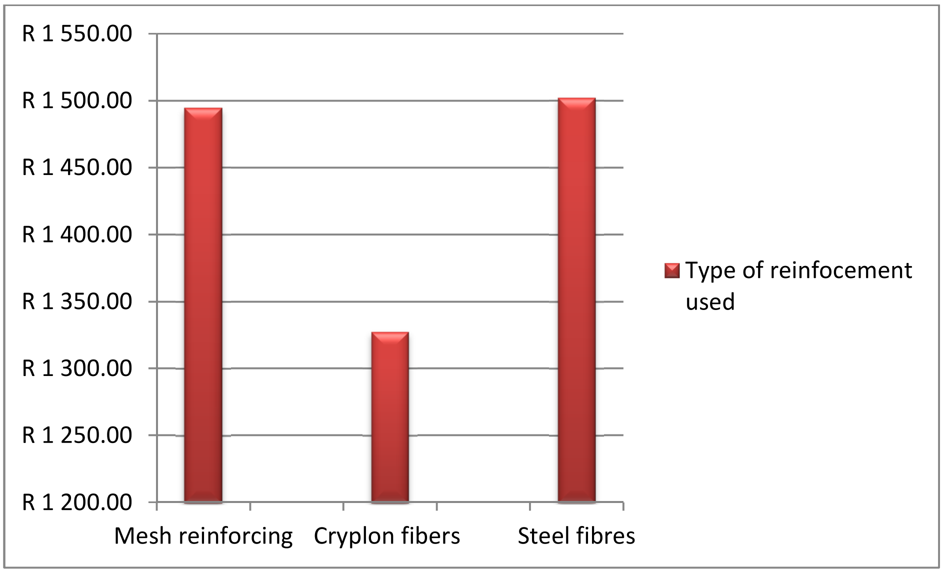


Figure 23: Reinforcing cost comparison

NOTE: The above rates exclude the rate for soil improvements.

5.6) COMPARISON OF FOUNDATIONS AND BULK EARTHWORKS OPTIONS

The Green Gate Factories project is located on a site where the erf are “split” in two if one looks at the type of soils found on the site. The one portion consists of siltstone and the other of dolorite. There will be two buildings constructed, one on the dolorite area (Building “A”) and one on the siltstone area (Building “B”). The foundation type comparison will be done for Building “B”. Building “A” will consist of piling foundations only. The amounts used for both of the comparison below, namely the foundations and the bulk earthworks are based on designs done by the civil and structural consulting engineers on the project, measurements done by the quantity surveyors on the project and the rates were based on a similar project, Kemach JCB (also used for this Chapter as per the above paragraphs), done on the site opposite the one where the Green Gate Factories will be built.

5.7) COST COMPARISON FOR RAFT VS PILES, STRIP FOOTINGS AND SURFACE BEDS

PILING OPTION

	GROUND FLOOR CONSTRUCTION					R 472,750.00
A	Establishment on site for Piling	Item	1	R 75,000.00	R 75,000.00	
B	Setting up at each position for installing Piles	No	30	R 1,500.00	R 45,000.00	
C	Piles 500mm diameter	No	30	R 10,000.00	R 300,000.00	
D	Main contractor's mark-up and attendance	5%			R 21,000.00	
E	1m Wide concrete apron	m	47	R 250.00	R 11,750.00	
F	Allowance for rock excavation	item	1	R 20,000.00	R 20,000.00	
	FOUNDATIONS					
A	Stair foundation, 1400mm x 650mm x 250mm	no	2	R 498.59	R 997.19	R 192,260.01

- Excavate	1.00	1.40	0.65	0.25	70.00	:	15.93
- R.o.c.	2.00	2.00	0.65	0.25	1.50	:	0.98
- Cart away/filling	1.00	1.40	0.65	0.25	85.00	:	19.34
- Cart away/filling G5	1.00	1.40	0.65	0.25	180.00	:	40.95
- Concrete	1.00	1.40	0.65	0.25	1,050.00	:	238.88
- Reinforcement (Kg)	65.00	1.40	0.65	0.25	10.74	:	158.79
- Sundries	0.05	1.00	1.00	1.00	474.85	:	23.74

B	Strip footing to external and internal one brick walls 650mm x 250mm, avg 750mm deep	m	191	R 746.87	R 142,890.74

- Excavate	1.00	1.00	0.65	0.75	70.00	:	34.13
- R.o.c.	2.00	1.00	1.00	0.75	1.50	:	2.25
- Cart away/filling	1.00	1.00	0.65	0.30	85.00	:	16.58
- Cart away/filling G5	1.00	1.00	1.00	0.45	180.00	:	81.00
- Concrete	1.00	1.00	0.65	0.25	1,050.00	:	170.63
- Reinforcement (Kg)	65.00	1.00	0.65	0.25	10.74	:	113.42
- Brickwork	1.00	1.00	1.00	1.00	290.00	:	290.00
- Brickforce	2.94	1.00	1.00	0.75	1.50	:	3.31
- Sundries	0.05	1.00	1.00	1.00	711.30	:	35.57

C	Strip footing to external and internal one brick walls 800mm x 250mm, avg 750mm deep	m	2	R 827.98	R 1,407.56

- Excavate	1.00	1.00	0.80	0.75	70.00	:	42.00
- R.o.c.	2.00	1.00	1.00	0.75	1.50	:	2.25
- Cart away/filling	1.00	1.00	0.80	0.30	85.00	:	20.40
- Cart away/filling G5	1.00	1.00	1.00	0.45	180.00	:	81.00
- Concrete	1.00	1.00	0.80	0.25	1,050.00	:	210.00
- Reinforcement (Kg)	65.00	1.00	0.80	0.25	10.74	:	139.59
- Brickwork	1.00	1.00	1.00	1.00	290.00	:	290.00
- Brickforce	2.94	1.00	1.00	0.75	1.50	:	3.31
- Sundries	0.05	1.00	1.00	1.00	788.55	:	39.43

D	Ground beams to external and internal one brick walls 450mm x 800mm	m		R 926.97	R 0.00

- Excavate	1.00	1.00	0.45	1.00	70.00	:	31.50
- R.o.c.	2.00	1.00	1.00	1.00	1.50	:	3.00
- Cart away/filling	1.00	1.00	0.45	0.40	85.00	:	15.30
- Cart away/filling G5	1.00	1.00	1.00	0.80	180.00	:	144.00

- Concrete	1.00	1.00	0.45	0.80	1,050.00	:	378.00
- Reinforcement (Kg)	65.00	1.00	0.45	0.80	10.74	:	251.27
- Brickwork	1.00	1.00	1.00	0.20	290.00	:	58.00
- Brickforce	2.94	1.00	1.00	0.40	1.50	:	1.76
- Sundries	0.05	1.00	1.00	1.00	882.83	:	44.14

E	Pile cap 800 x 800 x 800mm deep	No	28	R 1,106.77	R 30,989.58

- Excavate	1.00	0.80	0.80	0.80	70.00	:	35.84
- R.o.c.	2.00	1.60	1.00	0.80	1.50	:	3.84
- Cart away/filling G6	1.00	0.80	0.80	0.80	180.00	:	92.16
- Concrete in base	1.00	0.80	0.80	0.80	1,050.00	:	537.60
- Blinding	1.00	0.80	0.80	0.05	850.00	:	27.20
- Reinforcement (kg)	65.00	0.80	0.80	0.80	10.74	:	357.43
- Sundries	0.05	1.00	1.00	1.00	1,054.07	:	52.70

F	Pile cap 1200 x 1000 x 800mm deep	No	2	R 2,062.47	R 4,124.94

- Excavate	1.00	1.20	1.00	0.80	70.00	:	67.20
- R.o.c.	2.00	2.20	1.00	0.80	1.50	:	5.28
- Cart away/filling G6	1.00	1.20	1.00	0.80	180.00	:	172.80
- Concrete in base	1.00	1.20	1.00	0.80	1,050.00	:	1,008.00
- Blinding	1.00	1.20	0.80	0.05	850.00	:	40.80
- Reinforcement (kg)	65.00	1.20	1.00	0.80	10.74	:	670.18
- Sundries	0.05	1.00	1.00	1.00	1,964.26	:	98.21

G	Trimming of piles	No	30	R 395.00	R 11,850.00

GROUND FLOOR CONSTRUCTION R 243,099.30

A	Surface bed 100mm thick	m²	243	R 212.00	R 51,600.80

- Concrete	1.00	1.00	1.00	0.10	1,050.00	:	105.00
- DPM	1.00	1.00	1.00	1.00	12.00	:	12.00
- Powerfloat	1.00	1.00	1.00	1.00	25.00	:	25.00
- Saw cut joints	1.00	1.00	1.00	1.00	35.00	:	35.00
- Mesh 193	1.00	1.00	1.00	1.00	28.00	:	28.00
- Earthpoison	1.00	1.00	1.00	1.00	7.00	:	7.00

B	Surface bed 150mm thick	m²	853	R 224.50	R 191,498.50

- Concrete	1.00	1.00	1.00	0.15	1,050.00	:	157.50
- Powerfloat	1.00	1.00	1.00	1.00	25.00	:	25.00
- Saw cut joints	1.00	1.00	1.00	1.00	35.00	:	35.00
- Earthpoison	1.00	1.00	1.00	1.00	7.00	:	7.00

TOTAL PILING OPTION **R908,109.31**

RAFT OPTION

Raft as per Kemach	m²	1096	R 685.00	R 750,760.00
Main contractor's mark-up and attendance	5%			R 37,538.00
DPM Main Contractor	m²	1096	R10.00	R 10,960.00
Soil poisoning Main Contractor	m²	1096		R 7,672.00

R7.00

R 806,930.00

STRIPFOOTING FOUNDATIONS

Stair foundation, 1400mm x 650mm x 250mm	no	2	R 585.38	R 1,170.77	R 307,212.16

- Excavate	1.00	1.40	0.65	0.75	70.00	:	47.78
- R.o.c.	2.00	2.00	0.65	0.75	1.50	:	2.93
- Cart away/filling	1.00	1.40	0.65	0.25	85.00	:	19.34
- Cart away/filling G5	1.00	1.40	0.65	0.25	180.00	:	40.95
- Concrete	1.00	1.40	0.65	0.25	1,050.00	:	238.88
- Reinforcement (Kg)	85.00	1.40	0.65	0.25	10.74	:	207.65
- Sundries	0.05	1.00	1.00	1.00	557.51	:	27.88

Strip footing to external and internal one brick walls 650mm x 250mm, avg 750mm deep	m	191	R 746.87	R 142,890.74

- Excavate	1.00	1.00	0.65	0.75	70.00	:	34.13
- R.o.c.	2.00	1.00	1.00	0.75	1.50	:	2.25
- Cart away/filling	1.00	1.00	0.65	0.30	85.00	:	16.58
- Cart away/filling G5	1.00	1.00	1.00	0.45	180.00	:	81.00
- Concrete	1.00	1.00	0.65	0.25	1,050.00	:	170.63
- Reinforcement (Kg)	65.00	1.00	0.65	0.25	10.74	:	113.42
- Brickwork	1.00	1.00	1.00	1.00	290.00	:	290.00
- Brickforce	2.94	1.00	1.00	0.75	1.50	:	3.31
- Sundries	0.05	1.00	1.00	1.00	711.30	:	35.57

Strip footing to external and internal one brick walls 800mm x 250mm, avg 750mm deep	m	2	R 827.98	R 1,407.56

- Excavate	1.00	1.00	0.80	0.75	70.00	:	42.00
- R.o.c.	2.00	1.00	1.00	0.75	1.50	:	2.25
- Cart away/filling	1.00	1.00	0.80	0.30	85.00	:	20.40
- Cart away/filling G5	1.00	1.00	1.00	0.45	180.00	:	81.00
- Concrete	1.00	1.00	0.80	0.25	1,050.00	:	210.00
- Reinforcement (Kg)	65.00	1.00	0.80	0.25	10.74	:	139.59
- Brickwork	1.00	1.00	1.00	1.00	290.00	:	290.00
- Brickforce	2.94	1.00	1.00	0.75	1.50	:	3.31
- Sundries	0.05	1.00	1.00	1.00	788.55	:	39.43

Column base 2500 x 1000 x 500mm deep	No	16	R 3,688.78	R 59,020.50

- Excavate	1.00	2.50	1.00	1.50	70.00	:	262.50
- R.o.c.	2.00	3.50	1.00	1.50	1.50	:	15.75
- Cart away/filling G6	1.00	2.50	1.00	1.50	180.00	:	675.00
- Concrete in base	1.00	2.50	1.00	0.50	1,050.00	:	1,312.50
- Blinding	1.00	2.50	1.00	0.05	850.00	:	106.25
- Reinforcement (kg)	85.00	2.50	1.00	0.50	10.74	:	1,141.13
- Sundries	0.05	1.00	1.00	1.00	3,513.13	:	175.66

Column base 1600 x 1600 x 400mm deep	No	28	R 3,247.87	R 90,940.36

- Excavate	1.00	1.60	1.60	1.50	70.00	:	268.80
- R.o.c.	2.00	3.20	1.00	1.50	1.50	:	14.40
- Cart away/filling G6	1.00	1.60	1.60	1.50	180.00	:	691.20
- Concrete in base	1.00	1.60	1.60	0.40	1,050.00	:	1,075.20
- Blinding	1.00	1.60	1.60	0.05	850.00	:	108.80
- Reinforcement (kg)	85.00	1.60	1.60	0.40	10.74	:	934.81

- Sundries	0.05	1.00	1.00	1.00	3,093.21	:	154.66					
Stub column 650 x 450 x 510mm high								No	16	R 736.39	R 11,782.23	
- Concrete in stub column	1.00	0.65	0.45	0.51	1,150.00	:	171.55					
- Formwork	2.00	0.65	0.45	0.51	350.00	:	392.70					
- Reinforcement (kg)	110.00	0.65	0.35	0.51	10.74	:	137.07					
- Sundries	0.05	1.00	1.00	1.00	701.32	:	35.07					
GROUND FLOOR CONSTRUCTION												R 243,099.30
Surface bed 100mm thick								m²	243	R 212.00	R 51,600.80	
- Concrete	1.00	1.00	1.00	0.10	1,050.00	:	105.00					
- DPM	1.00	1.00	1.00	1.00	12.00	:	12.00					
- Powerfloat	1.00	1.00	1.00	1.00	25.00	:	25.00					
- Saw cut joints	1.00	1.00	1.00	1.00	35.00	:	35.00					
- Mesh 193	1.00	1.00	1.00	1.00	28.00	:	28.00					
- Earthpoison	1.00	1.00	1.00	1.00	7.00	:	7.00					
Surface bed 150mm thick								m²	853	R 224.50	R 191,498.50	
- Concrete	1.00	1.00	1.00	0.15	1,050.00	:	157.50					
- Powerfloat	1.00	1.00	1.00	1.00	25.00	:	25.00					
- Saw cut joints	1.00	1.00	1.00	1.00	35.00	:	35.00					
- Earthpoison	1.00	1.00	1.00	1.00	7.00	:	7.00					
TOTAL STRIPFOOTING OPTION												**R550,311.46**

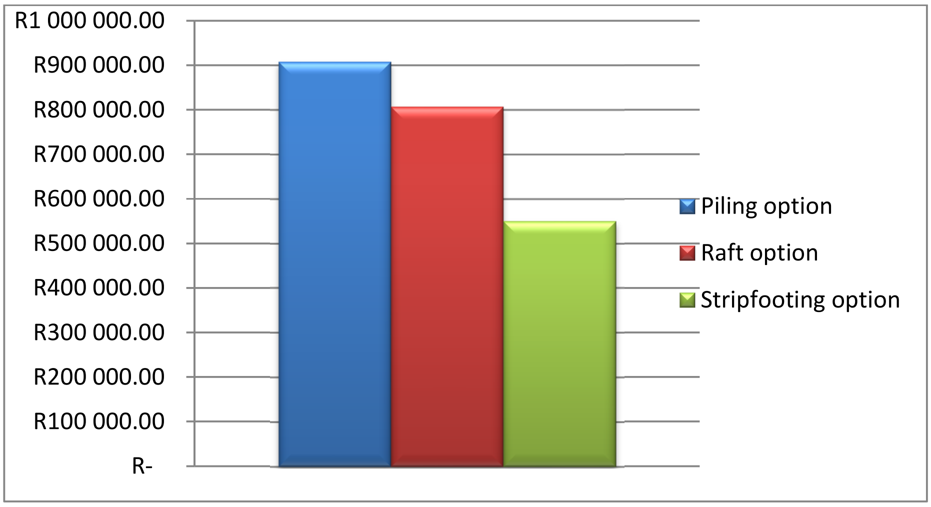


Figure 24: Cost comparison of raft vs piling vs strip footing option

The above estimates and graph shows the difference in cost of the three foundation options as designed by the structural and civil engineering company. Strip footings are the cheapest way of founding, provided that the soil being built on does not need soil improvements.

Because of the bad soil on the site, soil improvements will be necessary and the following comparisons were done based on designs done by the structural and civil engineering company.

The bulk earthworks are compared for two different foundation types for Building “B” only, namely Building “A” piling and Building “B” raft and the Building “A” piling and Building “B” strip footings, because the engineer on this project determined that piling in siltstone would not be the preferred means of founding.

	NEW FACTORY GREENGATE PROPERTIES	2938	Factory A	49.7%	
	ESTIMATE BULK EARTHWORKS	2973	Factory B	50.3%	**OPTION 1**
**	**BOTH SIDES Piling A, Raft B**	**5,911**	**m^2**		

	BULK EARTHWORKS					R 1,052,478.85
A	Clear site	m^2	5,911	R 3.00	R 17,733.00	
B	Remove topsoil off site 150mm	m^3	900	R 80.00	R 72,000.00	
C	Rip and compact 150mm to 93% MOD AASHTO to all areas	m^2	5,911	R 6.00	R 35,466.00	
D	Import dump rock to form 300mm thick pioneer layer in area "B"	m^3	200	R 350.00	R 70,000.00	
E	Cut top 500mm from area "A" and fill in area "B" in					
	150mm layers to 93% MOD AASHTO	m^3	3,000	R 120.00	R 360,000.00	
F	Cut/Excavate to spoil and remove material from site to spoil	m^3	2,000	R 80.00	R 160,000.00	
G	Import G7 material compacted in 150mm layers to 95% MOD AASHTO					
	to the appropriate levels	m^3	1,000	R 190.00	R 190,000.00	
H	Testing materials Allowance	item	1	R 10,000.00	R 10,000.00	
I	P&G Bulk Earthworks	15%			R 137,279.85	
J	Contingency Earthworks				*Incl. In summary*	
	5,911	**m2**		**R 178.05**	**R 1,052,478.85**	**R 1,052,478.85**

NEW FACTORY GREENGATE PROPERTIES	2938	Factory A	49.7%	**OPTION 2**
ESTIMATE BULK EARTHWORKS	2973	Factory B	50.3%	

**	**BOTH SITES**	**5,911**	**m^2**			
	Piling Factory A, Normal foundations Factory B					
	BULK EARTHWORKS					R 1,564,228.85
A	Clear site	m^2	5,911	R 3.00	R 17,733.00	
B	Remove topsoil off site 150mm	m^3	900	R 80.00	R 72,000.00	
C	Rip and compact 150mm to 93% MOD AASHTO to all areas	m^2	5,911	R 6.00	R 35,466.00	
D	Import dump rock to form 300mm thick pioneer layer in area "B"	m^3	400	R 350.00	R 140,000.00	
E	Cut top 500mm from area "A" and fill in area "B" in					
	150mm layers to 93% MOD AASHTO	m^3	1,500	R 120.00	R 180,000.00	
F	Cut/Excavate to spoil and remove material from site to spoil	m^3	3,000	R 80.00	R 240,000.00	
G	Import G7 material compacted in 150mm layers to 95% MOD AASHTO					
	to the appropriate levels	m^3	3,500	R 190.00	R 665,000.00	
H	Testing materials Allowance	item	1	R 10,000.00	R 10,000.00	
I	P&G Bulk Earthworks	15%			R 204,029.85	
J	Contingency Earthworks				*Incl. In summary*	
	TOTAL CARRIED TO SUMMARY	**5,911**	**m2**	**R 264.63**	**R 1,564,228.85**	**R 1,564,228.85**

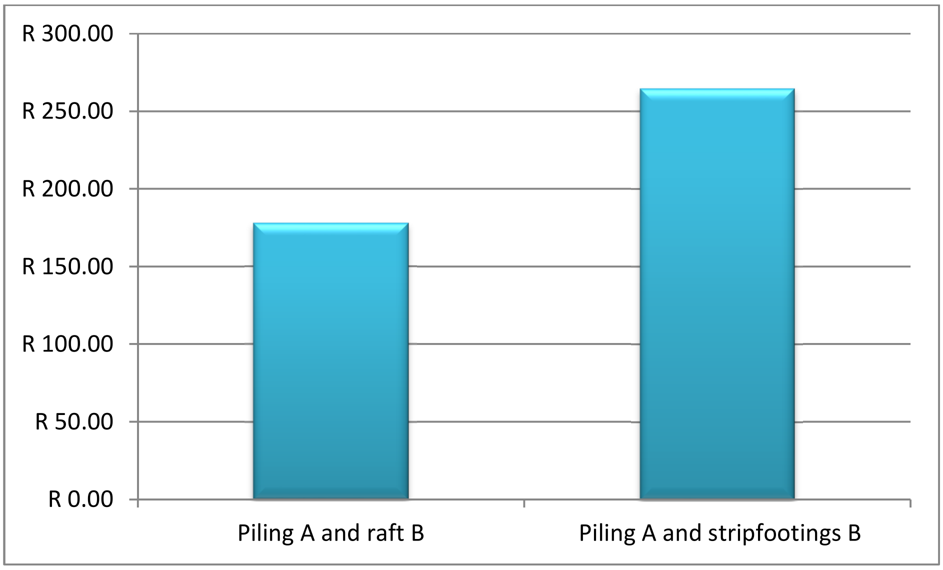


Figure 25: Bulk earthworks cost comparison

As seen from the above comparison of the foundation types it is cheaper to use the strip footing option when the soil is already in a good condition. In the case of bad soil conditions, some soil improvements would be necessary. One can see from the comparison done between the two foundation options namely piling and strip footings for building "B" that the total cost for the Bulk Earthworks and the Foundations it would be cheaper to use a raft foundation (which adds up to a total amount of R 1,859,408.85 as opposed to the strip footing foundation which adds up to the amount of R 2,114,540.31), but due to the risk of cracks in the raft as was the case of Kemach JCB, the client decided to go with the strip footing option because the effect of an unwanted cracked floor can be far more expensive that the saving when a raft foundation was to be used instead.

5.8) SUMMARY

Several elements have an influence on the type of foundation and the extend of soil improvements to be used. It must be determined which foundation types can be used on the site and then it must be determined what soil improvements will be necessary for the type of foundation. If more than one foundation type can be used, a cost comparison must be done taking into account both the cost of the foundation and the soil improvements for that type of foundation. It must also be borne in mind that the type of foundation used should not effect the aesthetics of the building in such a way that more money should be spent to hide the defects.

5.9) CONCLUSION

As seen from above the soil improvements needed for one type of foundation might be far less than the soil improvements needed for another type of foundation, but it might not always be the best choice to go with the cheapest option because it might cause problems that need to be repaired at a much higher cost than the saving the Client had by using that foundation.

5.10) TESTING OF HYPOTHESIS

It was stated that it is cheaper to stabilize the soil and to use strip footing foundation than using other foundation types. It depends on the amount of soil improvements needed and the design of the foundations.

As seen from the above comparisons it was cheaper to make use of a raft foundation which required less soil improvements than a strip footing foundation. A piling foundation could not have been compared to the two foundation types because it was not suitable for the siltstone found on the site. But in the case of Kemach JCB the raft foundation end up costing more due to the unpleasant aesthetics.

Therefore it cannot be said that one type of foundation will always be cheaper than another type of foundation because it will be different for every project. Factors having an impact of the cost are the type of soil, design of the foundation, amount of soil improvements needed, etc.

CHAPTER 6 – CASE STUDY – FARM DRIEFONTEIN

6.1) INTRODUCTION

Two independent reports were conducted for the cracking of the raft foundation slab of the office and warehouse on stand 6; portion 357 farm Driefontein also referred to as Kemach JCB. The first report was compiled by PDS civil and structural engineers, the engineers who designed the raft foundation, and the other report was compiled by the Cement & Concrete Institute as requested by the client.

The reports were conducted to describe the mechanism which has caused the shrinkage cracks to form on the foundation slab.

According to PDS civil and structural engineers after observing the concrete cores taken by the main contractor, they confirmed that the cracks are shrinkage cracks and not structural cracks.

6.2) BACKGROUND INFORMATION

The following information was made available to the two respective companies who conducted the reports:

- Because of the expansive nature of the siltstone and the potentially highly compressible/collapsible dolerite founding conditions (the site is partially on both types of soil), the buildings at Erf 6 Jet Park had been built on concrete raft foundations
- Rafts with ribbed beams had been used comprising of beams between 550 and 850mm deep at approximately 3.5 m centers in two directions, which is also known as a grillage of beams
- The slab portion of the raft is 150mm thick

- The rafts had been constructed on engineered fill. Excavations for the raft beams had been made into the fill

- 25MPa concrete had been specified for the rafts

- The slabs and beams had top and bottom reinforcement in both directions and the reinforcement was continuous through the construction joints

- Y8 at 200mm centres were used for top reinforcing and Y8 at 300mm centres were used for bottom reinforcing, in both directions had been specified in the slab

- The beams and the slabs were casted simultaneously

- The rafts had been cast during the period between 25 and 30 March 2012

- Ready-mixed concrete, supplied by Afrisam, had been used in the rafts. Afrisam's SS25F5FC mix had been used and the concrete had been pumped into position

- The mix that had been used contained 181 liters of water, 228 kg of CEM II A-M (V,L) 42,5N, 93 kg of Ground Granulated Blastfurnace Slag (ggbs), 22-mm dolerite stone, 13- mm andesite stone, dolerite crusher sand, a filler sand and a water reducing admixture. The extender content accounted for circa 43% of the total binder

- The concrete had been placed, vibrated, struck off, covered with plastic sheeting and after a waiting period, powerfloating had started. After the power floating had been completed the rafts were ponded with water directly on top of the plastic sheeting for about seven days

- It was relatively windy during the period the rafts had been cast

- Most of the rafts had been cast in the open, i.e. not under a roof

- The slump of the concrete delivered to site had been measured by the contractor and was between 150mm and 170mm

- Cracking had not been noticed until about four to six weeks after the concrete had been cast

6.3) STRUCTURAL RAFT FOUNDATION

According to the report done by the C&CI the concrete floor slabs rest on the subgrade and distribute the loads to the subgrade. Joints are provided in concrete floors to control cracking resulting from restrained contraction and the effects of restrained warping and traffic loads; to divide the floor into practical construction increments; and to accommodate floor movements. A raft foundation is similar to a floor slab in that it is also used to distribute the building pressure over a large area so that the stresses on the supporting soil are low, therefore the soil improvements will be less extensive when making use of a raft foundation than it will be when making use of strip footings. However a raft foundation may also be required to act as a structural element and span across possible ground settlements, swelling or possible sinkholes, which would limit the use of joints.

C&CI advises that careful consideration is advised with use and detailing of joints in rafts. Structural continuity is required in order to limit differential movements and, in extreme situations, a structural collapse. With the use of a relatively large slab with ground beams, substantial restraint to drying shrinkage movements would have been provided by friction and earth pressures on the bottoms and sides of the beams and by the heavily reinforced beams between the slabs. Thin members with a large surface area such as slabs are particularly vulnerable to this type of cracking. These cracks were repaired with a low viscosity epoxy, towards the end of July 2012. The longer the delay of the repair of the cracks the more shrinkage would have occurred. After about four months the majority of the shrinkage would have occurred and hopefully the shrinkage would have stabilized.

When designing and detailing a concrete raft with ribbed beams the designer has two options:

- A raft that is structurally continuous in order to limit differential movements. The raft should be designed with sufficient reinforcing and constructed using appropriate techniques to limit cracks. Should the raft crack due to restraint caused by the ribbed beams, then these cracks should be repaired as late as possible to allow most of the shrinkage to occur. One way to eliminate horizontal earth pressures on the sides of beams is to cast the raft on to compacted engineered fill and use void formers (C&CI).

- A raft that is subdivided with joints that will allow movement at the joints. This could result in excessive horizontal and vertical movements. Joints that open up excessively could break up under traffic loads and brickwork or brittle partitioning on such a raft would move and crack (C&CI).

6.4) SURFACE DEFECTS

Generally, finishing of a concrete floor consists of floating and toweling the surface. These operations are carried out after a delay period of a few hours after placing of the concrete. The delay is to allow the concrete to stiffen, for bleeding to cease and for bleed water to evaporate and/or to be removed. Failing to wait for these conditions to be met before finishing can result in delamination (as per figure 26), crazing and dusting of the surface. The timing of finishing is critical and is dependent not only on an experienced finisher but on concrete properties and the prevailing conditions during finishing.

6.5) VISUAL OBSERVATIONS

PDS Civil and Structural Engineers conducted the first report on 01 June 2012 and at that stage cracks were observed on the ground floor slab mainly in the workshop area of the building. The total area of the workshop is 1136m^2 which is divided into 3 areas by construction joints. The largest floor area between construction joints is 500m^2. Cracking occurs throughout the slab as indicated in figure 27. The width of the cracks varies from approximately 0.3mm to 0.8mm wide as measured by PDS Civil and Structural Engineers. Top and bottom reinforcement was installed in the slab portion of the raft giving a combined percentage of 0.28% reinforcement in the slab.

After C&CI were requested to conduct another report on the cracking of the raft the writer made the following observations on site on 25 July 2012

- The cracks observed had been repaired with a low viscosity epoxy about one week prior to the site visit of the C&CI and surplus epoxy on the surface was still in place, making for easy identification of the crack patterns, but it was not possible to measure crack widths as was the case with PDS Civil Engineers.

- In all of the areas relatively straight cracks parallel to each other and to the short side of the raft were observed, some directly coinciding with the top reinforcing bars, others close to the interface where the depth between the slab and beams changes.

- Random cracks were also evident.
- Some isolated surface delamination of the surface was observed (Figure 26)

Figure 26: Delamination of the concrete surface (Photo taken at Kemach JCB by the main contractor)

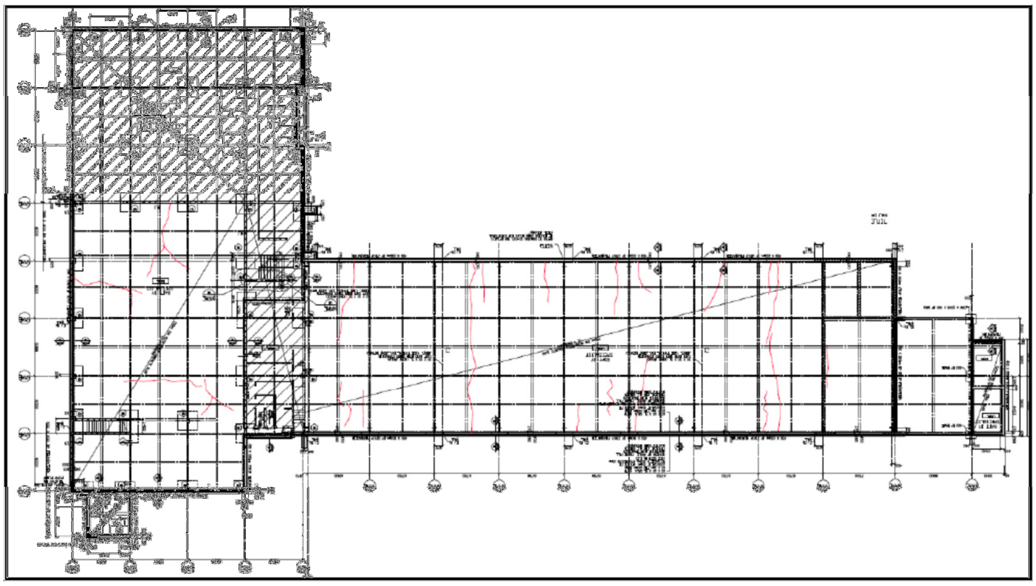


Figure 27: Cracks on raft indicated as per red lines (done by PDS)

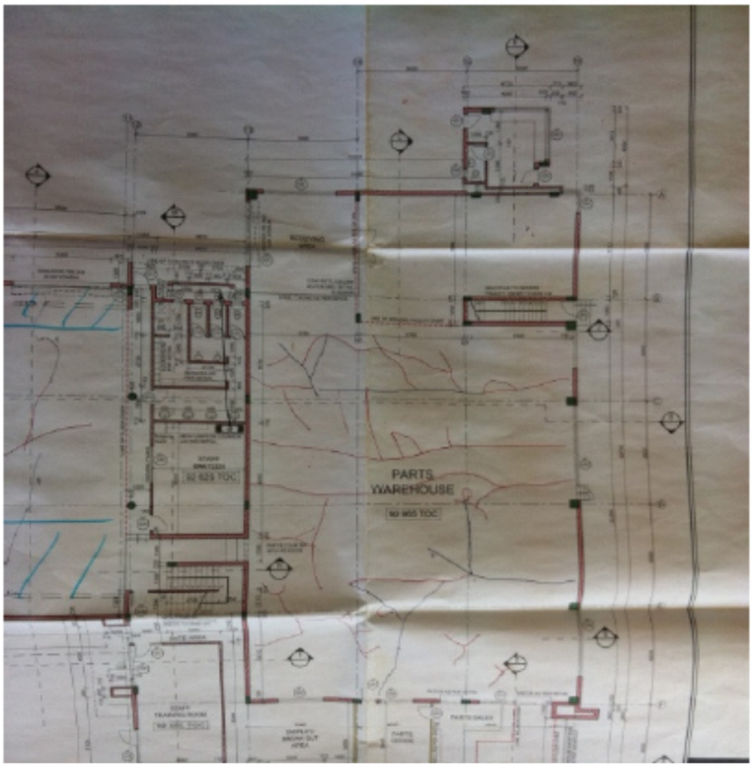


Figure 28: Cracks on raft indicated as per coloured lines (done by C&CI)

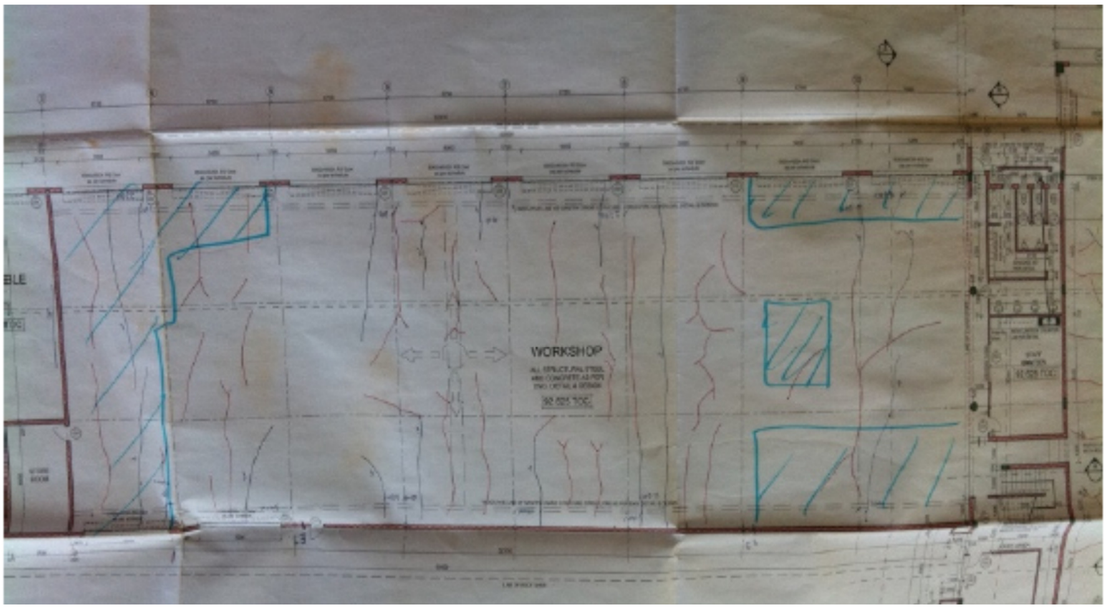


Figure 29: Cracks on raft indicated as per coloured lines (done by C&CI)

Figure 30: Cracks in the raft as indicated on cores taken form the raft (done by the main contractor)

6.6) SYNOPSIS

PDS civil and structural engineers concluded that the cracks in the concrete raft foundation are as a result of a combination of plastic shrinkage, autogenous shrinkage and drying shrinkage as explained below. The cracks in the raft are not structural and do not have an influence on the structural performance of the raft foundation.

The C&CI drew a similar conclusion that the cracking observed on the rafts was either random cracks or long straight cracks often coinciding with the slab/rib interfaces as explained below.

6.6.1) Random cracking

The random cracking observed was typical of that due to plastic shrinkage (also observed by PDS Civil and Structural Engineers). Plastic shrinkage cracking in concrete slabs is caused by rapid loss of moisture when the rate of evaporation exceeds the rate at which the concrete water rises to the surface of the concrete by capillary action referred to as bleeding (C&CI).

This will occur during the period before curing begins, usually within the first six hours after casting; this causes differential shrinkage, which results in cracks of up to 1m or more in length. The cracks may be parallel to one another, ranging from about 100mm to 700mm apart, but often occur in a random, irregular pattern (C&CI).

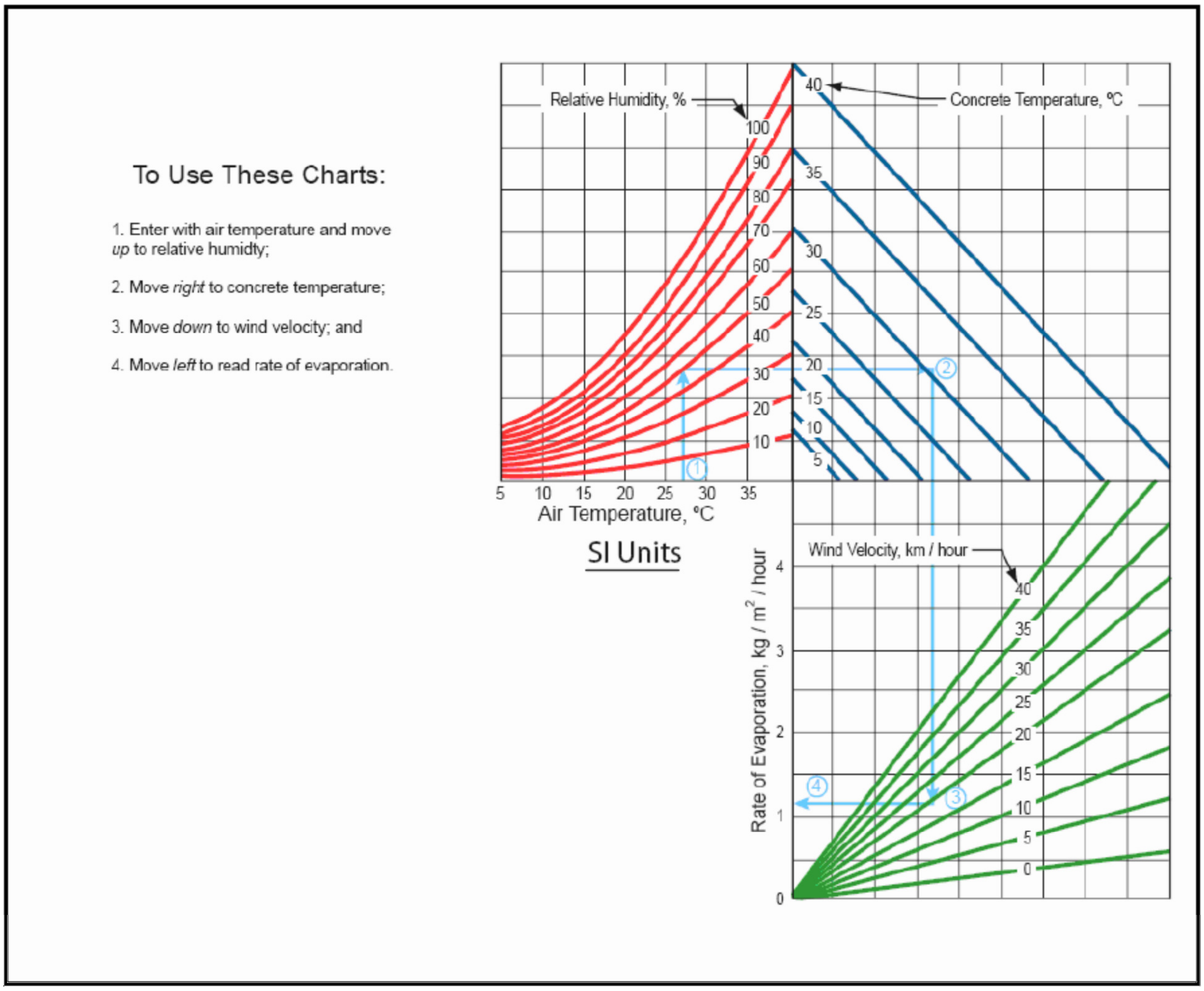
Crack formation begins at the surface of the slab and continues downward for some distance, with cracks becoming narrower towards the bottom. The cracks are usually only about 25 to 75 mm deep but may go all the way through the slab. Plastic shrinkage is influenced by factors such as wind velocity; the relative humidity of the atmosphere and the temperatures of the air and concrete. This type of cracking is usually associated with insufficient protection of the concrete in hot, dry or windy weather (C&CI).

According to (PDS) Delmar Bloem of the National Ready Mixed Concrete Association (USA) developed a Nomograph (Figure 31) that related the air temperature, relative humidity, concrete temperature and wind velocity parameters, which are relatively easy to measure, to predict the evaporation rates for a concrete surface with bleed water. These Nomographs have been published by many sources such as ACI, “Hot Weather Concrete” (ACI 305) and the PCA, “Design and Control of Concrete Mixtures.” In the United States of America (USA), two values of evaporation rates are used to provide guidance to the contractors on when plastic shrinkage cracks will form.

When the evaporation rates exceed 1.0 kg/m2/hr plastic shrinkage cracks are expected, when it is between 0.5 and 1.0 kg/m2/hr plastic shrinkage cracking may occur and when it is 0.5 kg/m2/hr or less plastic shrinkage cracks are not expected.

According to (C&CI) the following preventative measures are recommended to avoid plastic shrinkage cracks:

- Cover the concrete with plastic sheeting, or use a fine mist water spray to maintain a water sheen immediately after placing the concrete.
- Provide wind breaks or sun shades in hot, dry or windy conditions.
- Reduce the water content in the concrete (reduce the slump).
- Placing concrete at night.
- Re-vibrate the wet concrete. Care should be exercised to prevent segregation in very flowable mixes. Plastic shrinkage cracks can be eliminated by re-vibration whilst the concrete is still in a plastic state. Re-vibration is typically carried between one and two hours after initial placement of the concrete. Observing the rate of closure of the void left when removing a poker vibrator, can be used to give guidance of the optimum re-vibration timing.



To Use These Charts:

1. Enter with air temperature and move *up* to relative humidty;
2. Move *right* to concrete temperature;
3. Move *down* to wind velocity; and
4. Move *left* to read rate of evaporation.

Figure 31: Nomograpgh relating the air temperature, relative humidity, concrete temperature and wind velocity parameters

6.6.2) Long Straight Cracks

These cracks appeared to have occurred as a result either of plastic settlement or restrained drying shrinkage, or a combination of both.

6.6.3) Plastic settlement

Plastic settlement cracking is directly related to the bleeding of concrete. Bleeding is the upward migration of water and settlement of aggregate and cement particles occur simultaneously. If downward settlement is restrained, cracks may form. Restraint is usually present in the form of reinforcement, friction between concrete and formwork in narrow sections and differences in depths of adjacent parts (as is the case with rafts with ribbed beams). If restraint is due to reinforcement, cracks will typically follow the outline of the reinforcement (C&CI).

The casting technique used in this case, together with the high slump and high extender content allowed for varying degrees of settlement between slab and ribbed beams. An alternative casting technique would have been to use a lower slump concrete (a slump of 100mm is recommended) and to cast and compact the ribbed beams first, followed by the slab after a short delay. Re-vibration of the concrete is a suitable way to reduce the occurrence of such cracking (C&CI).

6.6.4) Restrained Drying Shrinkage

Substantial restraint to drying shrinkage movements would have been provided by friction and earth pressures on the bottoms and sides of the beams and by the heavily reinforced beams between the slabs. Thin members with a large surface area such as slabs are particularly vulnerable to this type of cracking. These cracks normally appear several weeks or months after the concrete were cast. In this case it is likely that cracks initially formed due to plastic settlement were widened and extended due to restrained drying shrinkage (C&CI).

Drying shrinkage cracks are usually approximately at right angles to the direction of restraint. (The cracks parallel to the short sides of the narrow strip cast in the workshop raft) Concrete Society Technical Report No. 54 states, “Because the (drying shrinkage) cracks form after the concrete has gained full strength, the cracks can pass through weak aggregate.” The observations of the cores indicated that the crack at the top of the slab formed around the aggregate but lower in the slab tended to pass through the aggregated. This supports the feeling that these cracks were a combination of plastic settlement and restrained drying shrinkage (C&CI).

Usually this type of cracking is controlled, but not necessarily prevented, by placing appropriate reinforcement close to the top surface of the slab and by carefully positioning the joints. Reinforcement near the top surface of the slab is more effective for controlling crack widths at the surface (C&CI).

Suggested preventive methods as per the C&CI are:

- Prevent rapid drying of the concrete after placing.
- Early and effective protection and curing.
- Optimise the positions of construction joints and the casting sequence to minimise the effects of drying shrinkage.
- Check that appropriate amounts of reinforcement have been detailed, taking into account the positions of construction joints and the sequence of casting. (More reinforcement provides more restraint and inappropriately high amounts of reinforcement may make cracking more likely)
- Maintain the position of top reinforcement to achieve specified cover.
- Cast the raft beams onto compacted engineered fill and use void formers to eliminate horizontal earth pressures on the sides of beams.

6.6.5) Autogenous shrinkage

According to PDS civil and structural engineers the autogenous shrinkage were also causing cracks in the slabs.

Autogenous shrinkage is defined as a concrete volume change occurring without moisture transfer to the environment. It is merely a result of the internal chemical and structural reactions of the concrete components. Previously it was thought that autogenous shrinkage only occurs in concrete with low water cement ratios however recent research has shown that autogenous shrinkage occurs in all concrete however more significantly in modified high strength mixes (PDS).

6.7) GENERAL

- Both plastic shrinkage and plastic settlement are exacerbated by cold weather and high extender content. The high extender content is likely to have delayed the setting of the concrete and exposed the concrete for a longer period to plastic shrinkage and plastic settlement (C&CI).

- Any moisture finding its way to the slab would have direct access to the top reinforcing via the plastic settlement cracks, exposing the reinforcing to corrosion (C&CI).
- Both plastic shrinkage and plastic settlement cracks are unlikely to be movement cracks and should not affect the structural integrity of the slab (C&CI).

6.8) REQUIRED REINFORCEMENT FOR EFFECTIVE CRACK CONTROL

Reinforcement steel

According to PDS and C&CI the reinforcing provided in the slab was 0.28% of the cross section area of the 150 mm thick slab.

Clause 5.2.2 of "Concrete Industrial Floors on the Ground" by Louis R Marais & Bryan D Perrie recommends the following formula to determine the amount of reinforcement required (P) to control cracking due to restrained drying shrinkage where the restraint is primarily in the form of friction under the slab.

P = 1.18 fL/Ss

Where:

f = 2 coefficient of friction for a rough subbase

L = distance between free edges of slab, in meters

Ss = allowable working stress in steel, in MPa

P = 1.18x2x60/450 = 0.32 %

This does not take into account the fixed edges or the restraint provided by earth pressures on the bottoms and sides of the beams and by the heavily reinforced beams between the slabs.

However this friction value does not cater for raft foundations since the raft slab is fully restrained from shrinking by the raft beams as well as the columns of the superstructure above. The amount of restraint provided by the raft beams and structural columns is a function of their spacing, i.e. the closer they are spaced and the stiffer they are, the more restraint they offer the slab. Another consideration is the stiffness of the soil into which the beams are cast. In this case the soil mattress was very stiff and thus offers more restraint than normal (PDS).

According to PDS important information regarding restrained shrinkage can be summarised as follows:

a) Cracking due to restrained shrinkage will always occur even with high percentages of reinforcement

b) The more reinforcement provided the more cracks will form at a closer spacing (but smaller)

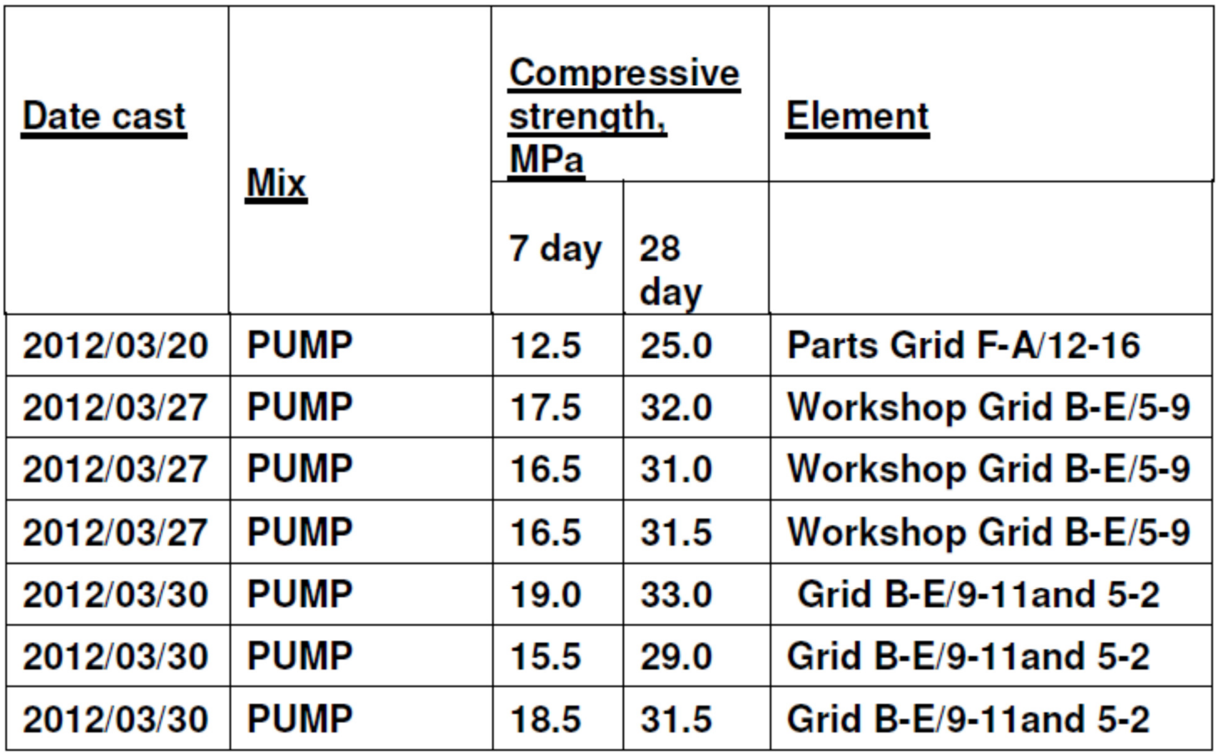
c) Larger bars lead to fewer cracks but the crack widths will be wider.

High volume to surface ratio structures such as dam walls shrink less than thin slabs spread over a large surface. Total shrinkage strain is the sum of plastic shrinkage, autogenous shrinkage and long term drying shrinkage. Typical values of total shrinkage can range from 0.0003 to 0.0006 depending on environmental factors, type of cement and measures taken to reduce shrinkage of the concrete (PDS).

Concrete Compressive strengths

The concrete compressive results met the requirements for a 25 MPa concrete as per the results from the concrete test cubes.

The concrete cube results from Concrete Proficiency Investigations were as follows:



Date cast	Mix	Compressive strength, MPa		Element
		7 day	28 day	
2012/03/20	PUMP	12.5	25.0	Parts Grid F-A/12-16
2012/03/27	PUMP	17.5	32.0	Workshop Grid B-E/5-9
2012/03/27	PUMP	16.5	31.0	Workshop Grid B-E/5-9
2012/03/27	PUMP	16.5	31.5	Workshop Grid B-E/5-9
2012/03/30	PUMP	19.0	33.0	Grid B-E/9-11and 5-2
2012/03/30	PUMP	15.5	29.0	Grid B-E/9-11and 5-2
2012/03/30	PUMP	18.5	31.5	Grid B-E/9-11and 5-2

Figure 32: Concrete compressive strength results

6.9) CONCLUSION

According to PDS it is believed that the cause of the cracks is largely due to early plastic shrinkage of the concrete where the concrete lost moisture faster than the bleed water rose to the surface through capillary action. The cracks then opened up due to additional drying shrinkage due to the raft being exposed to a dry and windy atmosphere for a prolonged period of time. PDS recommended that cracks wider than 0.4mm and those that are aesthetically unacceptable should be repaired using an approved low viscosity epoxy which is able to flow into the crack and, when set, bond the concrete (this was done in the period after the report conducted by PDS (2 July 2012) and the period before the report was conducted by the C&CI (14 August 2012). The repairs must be undertaken in strict accordance with the supplier's instructions. PDS conclude that the phenomenon of restrained shrinkage cracking in concrete is intricate.

As per the C&CI it would appear that the cracking was caused by one or more or a combination of:

- Inadequate protection of fresh concrete while casting in exposed conditions
- Lack of, ineffective or late application of curing
- Substantial restraint to drying shrinkage of slab concrete
- Reinforcement details that possibly did not take into account the substantial restraint to drying shrinkage movements, construction joint positions and the sequence of casting
- Casting technique with high extender and high slump concrete, resulting in settlement cracks

And it would also appear that the surface defects were caused by premature finishing of the concrete surface relative to the prevailing conditions and the materials.

CHAPTER 7 – CONCLUSION AND RECOMMENDATIONS

7.1) STATEMENT OF THE MAIN PROBLEM

Stabilization of soils is widely accepted as an effective means of improving soil properties. For some soils a single stabilization agent may provide superior performance, while for many soils more than one material may be effective and financial considerations or availability may be the determining factor on which to use.

(Parsons & Milburn, 2002).

However, soil stabilization faces a number of limitations, especially when the soil contains a significant amount of chemical compounds that may alter the effects of the additives (Cuisinier et.al, 2011).

In theory it is cheaper to stabilize soil than using alternative foundation types e.g. piling or raft foundations. This is because soil is cheap and readily available, but if the stabilized soil becomes weaker and starts to change due to the expansion, shrinkage or deterioration, it can have a significant impact on a building's integrity and durability and can result in higher future costs resulting from the attempts to repair or hide the physical/visual effects this will have on a building.

7.2) CONCLUSIONS OF THE SUB-PROBLEMS

7.2.1) How can soil be stabilized?

In certain areas soil of poor quality can be found. Due to the poor quality of soil a geotechnical engineer should test the soil(s) and a civil engineer should look at ways to alter the soil. This can be done by means of stabilization or modification of the soil or one can replace the poor quality soil with good quality soil. This soil improvements or replacement will have an impact on the construction cost therefore one should consider various options like the cost of stabilization versus the replacement of the poor quality soils before one decides what to do. The soil will need to be tested in order to determine the properties of the soil and these tests must be preferably performed in a laboratory. The geotechnical engineer will then make a recommendation regarding the method, materials to be used, etc. based on the outcome of the results or reports.

7.2.2) If soil can not be stabilized or it is too expensive to stabilize, what other foundation options are available?

The most basic types of foundations are spread footings and strip foundations and are mostly and effectively used in good, stable soils. Other foundation types like pad foundations, raft foundations and piling foundations are more complex foundation types and are mostly used where the soils are of poor quality or unstable.

7.2.3) what is the impact of mineralogy and wet-dry cycles on the strength and durability of stabilized soils?

Mechanical performance of stabilized soil as well as the influence a compound has on the soil stabilization processes, is a combination of the nature of the soil, the type of stabilization compound used e.g. cement or lime and the curing conditions of the stabilized soil.

In some cases the presence of the potential deleterious compound can improve the performance of the soil after it has been stabilized. According to (Cuisinier et al., 2011), some of the compounds can be used as secondary compounds in cements. These compounds can assist in controlling or delaying the setting reactions.

Therefore, it is not only important to assess the type of soil and the presence of a substantial amount of a given compound in the soil to evaluate whether the soil is suitable for stabilization with lime and cements, but also the curing conditions like the temperature, humidity, etc.

It’s found that in general lime performs better when used to stabilize fine grained materials and cement performs better when used to stabilize coarse grained soils as well as CH clays.

7.2.4) A cost comparison of various types of foundations and soil improvements for one specific project as well as repairing costs

As seen from the comparisons done in chapter 5 the soil improvements needed for one type of foundation might be far less than the soil improvements needed for another type of foundation, but it might not always be the best choice to go with the cheapest option because it might cause problems, like cracks in slabs, that might need to be repaired at a much higher cost than the saving there would have been by using that specific foundation.

7.2.5) Case study

According to the case study it was found that the cause of the cracks in the slab were largely due to early plastic shrinkage of the concrete where the concrete loses moisture faster than the bleed water rises to the surface through capillary action. The cracks then opened up due to additional drying shrinkage due to the raft being exposed to a dry and windy atmosphere for a prolonged period of time.

It was recommend that cracks wider than 0.4mm and those that are aesthetically unacceptable should be repaired using an approved low viscosity epoxy which is able to flow into the crack and, when set, bond the concrete

It would appear that the cracking was caused by one or more or a combination of:

- Inadequate protection of fresh concrete while casting in exposed conditions
- Lack of, ineffective or late application of curing
- Substantial restraint to drying shrinkage of slab concrete
- Reinforcement details that possibly did not take into account the substantial restraint to drying shrinkage movements, construction joint positions and the sequence of casting
- Casting technique with high extender and high slump concrete, resulting in settlement cracks

And it would also appear that the surface defects were caused by premature finishing of the concrete surface relative to the prevailing conditions and the materials.

7.3) TESTING OF HYPOTHESIS

The hypothesis stated that the strength and durability of stabilized soils are affected by mineralogy and wet-dry cycles and this may results in higher future costs due to the unplanned and unforeseen physical and visual effects this will have on a building.

After compiling the sub-problems it was found that soil can be improved/stabilized in various different ways and that the compound used to stabilize the soil can be affected by various deleterious compounds found in the soil. Temperatures and curing conditions can also have an influence on the strength of the stabilization. Not only do curing conditions have an influence on the soil improvement itself, but inadequate protection as well as a lack of ineffective or late application of curing of fresh concrete while casting in exposed conditions can lead to cracking of the foundations.

If the soil cannot be improved or it is financially unviable to improve/stabilize the soil in such a way that one can make use of a simple strip footing foundation, there are various other ways to provide a stable foundation for the structure for example raft foundations, piling foundations, etc. where the extend of soil improvements needed for that structure will be limited.

It can now concluded that not only the soil and things that influence it's strength like deleterious compounds in the soil or stabilizing agent and wet-dry cycles, but also the design of the foundation and other external conditions like temperature, weather, curing conditions, etc will have an influence on the physical and visual effects on a structure.

7.4) RECOMMENDATIONS FOR FURTHER STUDIES

There have been limited tests performed on the influence of chemicals in the ground on the stability of soil stabilization. There can also be more tests done on a wider variety of chemicals, as well as the influence on a wider variety of soil types.

There is also not a lot of information on the influence of freeze thaw on the stability of soil stabilization in South Africa. Even though the climate in South Africa is not as extreme as in some other countries, freeze thaw might still have an impact in certain areas where it gets very cold in the winter such as Molento and Sutherland.

The cost analysis was done on the circumstances of one project only. More comparisons can be done on different types of buildings such as factories, high and low rise office buildings, high and low rise residential buildings, etc. Comparisons on projects in different geographic areas can also be done to get more accurate outcomes.

The thesis hasn't explained all of the different compounds that can be used to stabilize soils.

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