EDAT 3rd Year Project Report

The Effect of Fines in Sand for the Fabrication and Application of Concrete in Developing Countries

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Summary

This project focuses mainly on the needs of developing countries, where operations are basic and money is short. Good quality sand is available in developing countries but is in short supply and is expensive due to the high transportation costs. Poor quality sand, which consists of a significant proportion of clays and silts and is poorly graded, is readily available but needs to be improved if it is going to be used for building with.

After an insight into the aggregate industry had been gained, experimental laboratory work commenced and the first original objective of examining the effect of 'low quality' sand on mortar was investigated. During the third week of the project, a significant finding was made. It was discovered that when the seven day dry compressive strength tests of comparable concretes with identical water-cement ratios were measured, the strength of the concrete *unexpectedly increased* as the fraction of fines in the concrete increased. This was a fairly surprising result since the original aim of the project was to wash sand to remove the fines to make it a better quality. This result caused me to revise my original aims and the focus point of the project was changed to examining the properties of concrete made from sand with a high fines content.

The properties examined were strength, shrinkage and cyclic movements. Construction materials and processes were optimised and strength was measured using a destructive compressive strength test and the PUNDIT test. Drying shrinkage and cyclic movements were measured using point dial gauges.

It was discovered that despite the suitable dry compressive strength of the material with a large number of fines, that the use of this material will be hindered due to its large cyclic movements and drying shrinkage. This type of sand is only suitable for concrete and mortars in unconstrained applications such as block making and lintels and in situations where the material does not undergo cyclic movements, such as non water-proof rendering. If this material is used for applications such as bricklaying then the wall should be built in small sections, maybe one metre per day, without expansion joints.

There are many other properties of concrete, other than strength, drying shrinkage and cyclic movements that can be specified, but the duration of this project limited the amount of factors that could be examined. It is expected that other research in this field will be carried out to improve the quality of concrete made with 'high fines' sand, possibly by washing it, as the original project suggested.

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Acknowledgement

I am particularly indebted to Dr. T. H. Thomas, my project supervisor, for his help and encouragement throughout the duration of this project. I am also indebted to Mr. R. Bacon, the Production Manger at Gill Mill Quarry in Witney, Oxfordshire, for his time during my site visit to Gill Mill Quarry. It is also a pleasure to thank Mr. C. Banks, the Civil Engineering technician for all his patience and time spent helping me with my experiments; as well as my boyfriend, Mr. T Jenkin, for his advice and criticism on the draft report.

Notation

V	Compression wave velocity
E	Dynamic modulus of elasticity
P	Density
v	Dynamic Poisson's ratio
$\mathbf{f_c}$	Equivalent cube strength
A	Constant
B	Constant
e	Base of natural logarithms
x	Arithmetic mean
$\boldsymbol{\sigma}$	Standard deviation
$\mathbf{v_c}$	Coefficient of variation
n	Sample number
Z	Test Statistic
N	Normal distribution
$\mathbf{H_0}$	Null hypothesis
l	Length

1. Introduction

1.1 Background

This project focuses mainly on the needs of developing countries, where operations are basic and money is short.

"Sand is primarily used as an aggregate or bulking material, in the main for concrete and mortar, accounting for approximately 75% of total production", (Mineral Resources Consultative Committee, 1988).

Good quality sand is available in developing countries, but is in short supply and is expensive due to the high transportation costs. Poor quality sand, which consists of a significant proportion of clays and silts and is poorly graded, is readily available but needs to be improved if it is going to be used for building with. This project was originally established to identify an effective method of improving the quality of readily available poor quality sand to make it more fit for use in making concrete or mortar. This was to be done by exploring existing methods of washing poor quality sand, such as sieving and sedimentation and modern methods used in the commercial industry in the UK.

Within this overall aim, the original study had three specific objectives:

- To examine the effect of "low quality" sand on mortar to define a just satisfactory standard.
- To compare sieving and sedimentation techniques for manually washing poor quality sand up to that standard under artisanal conditions in a developing country.
- To develop an effective method of, or a machine for improving sand, possibly by washing it, to make it more fit for use in making concrete or mortar. The method should be compatible with the operations, finances and normal sand sources of an artisanal builder in a developing country, such as Africa.

The project was started with little knowledge about the aggregate and concrete industry. It was assumed alongside the general opinion of the aggregate industry in the UK and in accordance with the British Standard BS 812, that a high 'fines' (silts and clays) content in sand for fabricating concrete is unacceptable, and to improve the quality of concrete the majority of the fines should be removed. Gill Mill Quarry in Witney, Oxfordshire was visited to get a general feel of the sand and aggregate industry, and to examine the existing methods of sand washing to remove the fines, (The letters of correspondence for this visit are shown in Appendix A1). Removing these smaller particles from the sand is a very costly process in terms of energy and money, and the existing sand and aggregate plants in the UK do not deliberately remove the fines from the sand, but instead grade the different sizes of sand and gravel particles. When separating the larger sizes of particles, wet screening is used, which permits the sand, aggregate and water to fall through a various number of sieves of different sizes that are at 20° to the horizontal.

Figure 1.1: Wet screening at Gill Mill Quarry, Oxfordshire

Figure 1.2: A Hydro-cyclone

The remaining sand and water enters a hydro-cyclone, which imparts a rotational effect to the mix, with the resulting centrifugal force causing the heavier particles to be pushed against the inside surface of the hydro-cyclone. As a result of the continuing feed of material and the inverted cone shape, the heavier sand particles fall and the water and fines pass upwards into the overflow and are discharged away through an overflow pipe into a settling pond. The overflow pipe induces a syphon effect, which in turn creates a vacuum in the hydro- cyclone. This vacuum is sufficient to hold the discharge regulator closed thus trapping the majority of the water and fines, which are discharges via the overflow. When the weight of the solids inside the hydro-cyclone becomes sufficient to overcome the vacuum, the discharge regulator is forced open and allows discharge of the sand.

It was decided that this method of separating the different sizes of particles is too sophisticated and energy costly for developing countries to use, so either an alternative method for improving the quality of sand for concreting needs to be established, or it needs to be demonstrated that washing the sand is not essential.

1.2 The Project Report

The project report has been organised into the following chapters (after this introductory chapter 1):

- Chapter Two explains the aims and objectives of the research, and how the objectives were changed from the original ones
- Chapter Three includes the literature review, describes the purpose of the project and discusses the expected problems associated with using a high fines content in sand when making cementitious materials.

- Chapter Four details what materials were to be tested, what factors would be examined and methods of experimental testing were chosen.
- Chapter Five describes the methodology of each testing method and how the analysis of each result should be carried out.
- Chapter Six is the results section. Each factor has been divided into a sub section and discussed individually. Statistical analysis has been performed on applicable results, graphs have been drawn, and explanations of results have been given.
- Chapter Seven states what these results mean in terms of its use to builders in developing countries. It explains whether building with a material with a high fines content is advisable, and whether it would be suitable for some purposes, rather than others.
- Chapter Eight recommends future work, followed by conclusions in Chapter Nine.

2. Revision of Project

After an insight into the aggregate industry had been gained, experimental laboratory work commenced and the first original objective of examining the effect of 'low quality' sand on mortar was investigated. During the third week of the project a significant finding was made as it was discovered that when the seven day dry compressive strength tests of comparable concretes with identical water-cement ratios were done, the strength of the concrete unexpectedly increased as the number of fines in the concrete increased. This was a fairly surprising result since the original aim of the project was to wash sand to remove the fines to make it a better quality. This result suggested that washing sand prior to use, to remove the fines is unnecessary and indicated that further experiments needed to be done to determine the effect of a high fines content in concrete. This caused me to revise my original aims and objectives of the study.

The new main objective of this study was to test whether sand with a high fines content can be used in the fabrication and application of concrete. The purpose of this was to make a useful contribution to the living standards in developing countries through the development of appropriate technologies. In this case the 'appropriate technology' is the use of local sand 'as found' rather than the use of transported 'no fines' sand.

Within this new overall aim, the study had two specific objectives:

- To use the strength of concrete as a constraint to optimise water content, workability, vibration compaction time, the number of 'fines' and curing time, with respect to costs and skills related to developing countries.
- To determine the effect of the presence of 'fines' on shrinkage and swelling of concrete.

For the remaining duration of this project, laboratory based experiments have been conducted to satisfy the new objectives, and it is hoped that the research will be of use to artisanal builders in developing countries.

3. Fines in sand in cementitious materials

3.1 The Cement Literature

Books have provided little information on the actual effect of fines in concrete but have proved useful in the Properties of Concrete. As an overview on general aspects of concrete, A.M Neville and J.J Brooks provide a highly accessible and relevant text. J.M Illston also provides a very useful introductory section on the basics of concrete.

For concreting aspects related to developing countries, Spence and Cook provide an excellent section on the problems of skill, equipment and climate. This enabled a clear distinction between concrete technology in the UK and developing countries.

During the examination of the strength of concrete, Popovics book was very useful. It provided detailed descriptions with clear explanations, especially in the testing of concrete. Another book which proved useful on this area was "Testing of Concrete Structures" by J.H Bungey and S.G. Millard.

Statistical analysis was explored using various textbooks such as "Statistics and Experimental Design in Engineering and the Physical Sciences" by N. Johnson, but the clearest explanations were in "Statistics 2", written by G. Attwood and G. Dyer.

Due to the complexity of the analysis of shrinkage and swelling due to a high fines content, full descriptive analysis was not incorporated into this report. However, the basics of shrinkage and swelling are described in the general concrete books mentioned above, and additionally a detailed account of the behaviour of clay is given by J.K. Mitchell, "The Fundamentals of Soil Behaviour".

Other literature that was often consulted was the Building Research Establishment Report, 1998 and the British Standards. The British Standards were accessed through the World Wide Web at www.bsonline.co.uk. The main relevant standards that were consulted were:

- *BS 12: 1978*: Ordinary and Rapid Hardening Portland Cement.
- *BS 812: Part 1:1975*: Sampling, shape, size and classification.
- *BS 1881: Part 3: 1970*: Methods of Making and Curing Test Specimens.
- *BS 1881: Part 115*: 1983: Specification for Compression Testing Machines of Concrete.
- *BS 1881*: *Part 116: 1983*: Method for the Determination of Compressive Strength of Concrete Cubes.
- *BS 1881*: *Part 202: 1986*: Measurement of the Velocity of Ultrasonic Pulses in Concrete.
- *BS 5497: Part1: 1979*: Guide for the Determination and Repeatability and Reproducibility for a Standard Test Method.

3.2 Review of Issues

In the UK, it is stated in the British Standard BS 812, that it is considered unacceptable to make cementitious materials with a high fines content. It is thought that the reason for this is that fines interfere with the bond between the aggregate and the cement paste, causing abnormal and variable behaviour of the properties of concrete. This is suggested in Neville and Brooks (1987), but the exact reasons of why fines in sand should not be used could not be found in literature.

In the UK, the main properties of concrete that are considered and tested are wet and dry compressive strength, shrinkage, cyclic movements, permeability, durability, and resistance to freezing and thawing, (Neville & Brooks, 1987). The extra fines in the sand are likely to have some effect on all of these properties, and it was the aim of this project to examine certain properties, to discover how the changes in behaviour would affect the use of concrete in certain applications. It was expected that the strength, shrinkage and cyclic movements would be affected greatly by a high fines content in the sand. However since this project focuses on concrete for use in the (high-temperature) tropics, properties such as resistance to freezing and thawing did not need to be examined.

The application of cementitous materials in developing countries is mainly for bricklaying, rendering, and as reinforced concrete. There has been a trend in recent years to manufacture housing components such as lintels, roofing, and hollow core flooring units in an effort to reduce costs. In India, pre-cast concrete frames for doors and windows have been investigated because of the expense of conventional wooden frames, (Mohan and Rao, 1977).

The strength of the concrete is important for most of the applications stated above, but is not so critical for bricklaying and rendering. Concrete compressive strength is typically between 10-70MPa for most applications and is not generally used at strengths lower than 10MPa.

Concrete is strong in compression but weak in tension. Concrete in compression can withstand 2000 μ-strain and in tension approximately 200 μ-strain (Tensile stress is approximately 1/10 the compressive stress). Hence, cracks could occur due to tensile forces or strains exceeding the tensile capacity of the concrete. Tensile forces and strains can arise from many causes, including cyclic movements and shrinkage, and they give rise to many different forms of cracks.

For bricklaying, the concrete should not have large changes in volume, since if this happens unevenly around a building, cracking may appear in the brickwork. Consequently, if the brickwork if jammed between two rigid elements, it could cause the wall to bow. If the brickwork is in compression, it is expected that the wall can withstand about 600 μ-strains, so this magnitude of shrinkage can be tolerated. If the brickwork is in tension, then a much lower value can be tolerated, typically 200 μ-strains.

Typically renders use gypsum since it doesn't crack, but as a cheap alternative, cement renders can be used. Cracks can be dangerous if they occur in a wall between two points, but are also a nuisance and should not be visual. It is thought that waterproof renders can only tolerate small cyclic movements, generally <100 μ-strain, and non-waterproof renders should not shrink or expand more than 200 μ-strain. If renders are used for decorative value then a millimetre crack per metre is visible, and would be unacceptable.

Steel reinforcement in concrete is common in the UK, but structural steel is rarely used in developing countries for building because of its cost but steel is obviously essential for the reinforcement of concrete. As few countries have sources of iron ore suitable for steel making, they must resort to importing pig iron and processing it to make steel. When steel reinforcement is used, movement of a section in the concrete member should be prevented because a gradual transfer of load from the concrete to the reinforcement results. If there is an external constraint and the concrete expands, it is being prevented from moving and compressive stresses develop uniformly across the section. If large shrinkage occurs, typically over 600 μ-strains, the concrete is being prevented from contracting so that tensile stress is induced. In consequence, cracking will take place across the section.

Changes in concrete properties for the fabrication of lintels should not cause any problems, since it is common practice to leave a gap in the mortar of about 10mm at both ends to allow it to expand without cracking. If the cyclic movements are larger than 1000 μ-strain then the gap can be expanded.

This project examined the effect of fines in sand when making concrete to decide whether a high fines concrete can be used for the applications mentioned above, for the building industry in developing countries.

4. Choosing the Sand and Method for Testing

4.1 Sand chosen for testing

"Natural sand and aggregate is formed by the decomposition of rocks, and through the subsequent removal, transportation, sorting, deposition and weathering of the products of decomposition", (Spence & Cook, 1983).

In some areas, some or all of the products of weathering remain in place, in conjunction with the parent rock. These are typical of broad, flat, poorly drained upland areas such as Africa and Indian plateaux. In other areas, the products of weathering are transported, that is they are removed by water or ice, or sometimes wind. In the process of the transportation by water larger particles are further broken down, shaped and resorted, and then deposited in river terraces or lakes. Dissolved silicates react with the soluble salts of sodium, potassium and calcium to form new minerals with distinctive properties known as clay minerals.

Clay, those particles of less than 0.002mm in size, consists predominantly of the clay minerals. Clay may be present in sand in the form of surface coatings which interfere with the bond between the sand and the cement paste. In addition silt, which has a grain size between 0.002 and 0.06mm, may be present either as surface coatings or as loose material.

"It is assumed that clay particles should not be present in large quantities because, owing to their fineness and therefore large surface area, they interfere in the bond between the sand particles and the cement paste matrix", (Spence & Cook, 1983).

It is also thought that excess fines cause an increase in the water demand and as a result the strength of the concrete will decrease, (as a consequence of the water cement ratio rule, which is investigated later).

Sand used for building purposes in the UK follow the recommendations in the British Standard BS 812, that only good quality sand is used with a minimal amount of fines. This is also shown on the U.S Bureau of Public Roads Classification System (for soil) which is based on particle size analysis. The chart is divided into 10% bands, with clay occupying the top third of the chart, sand and silt in the bottom corners, and sand-silt-clay mixtures between them. UK standards specify for use the material in the bottom left hand corner of the chart, usually between 90-95% sand, as shown in blue. In order to test a less well selected aggregate, a synthetic 'poor sand' "X" was devised comprising of 75% sand, 4.8% silt and 20.2% clay, as shown in red. This material will be tested against the same sand but without the large clay proportion, which is denoted as material "Y". Material "Y" is comprised of 95% sand, 4.8% silt and 0.2% clay, and is shown on the diagram in green.

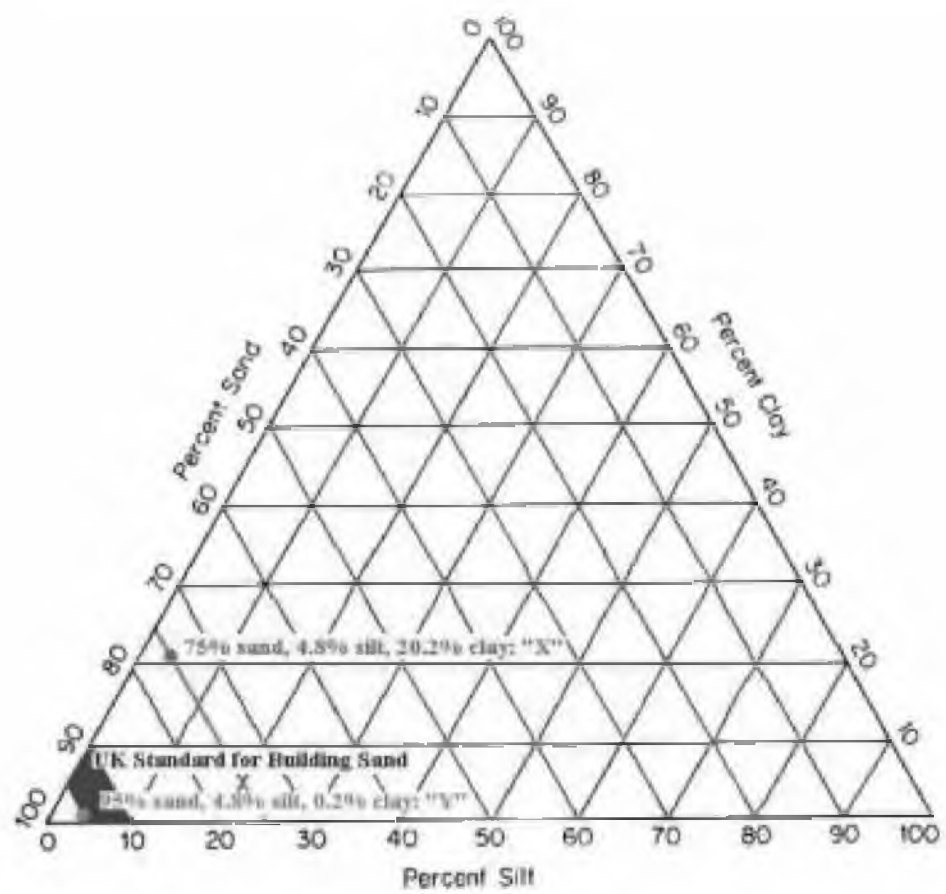


Figure 4.1: U.S Bureau of Public Roads Classification System

Ideally, the effect of a significant amount of silt as well as clay in concrete needs to be examined. Pure clay is readily available but it was not possible to find a source of pure silt, although several attempts were made. Material from a settling pond was collected to examine how much silt was present, but unfortunately the material contained 89% clay, with only the remaining amount being silt, (see Appendix A2 for the sedimentation test and result of the determination of silt content). It was decided that this material could not be used to represent silt, so the fines added to the sand to degrade it will be clay only.

The clay used was Kaolin as it is relatively inexpensive and easily available at the University. Degrading the sand to this quality is adjusting the sand so that it is of a "poor" but not "extremely poor" quality. It was decided that for the purpose of this project that this would be the only type of sand tested, as the project has time constraints with many other factors to be investigated.

Sand and aggregate used in the UK for the purpose of building is usually well graded, as the graduation of particles affects strength. This is because if there are voids present in the concrete due to the inability of the aggregate to fill the voids, then a high strength cannot be achieved. Figure 4.2 is a particle size distribution graph which shows a good sand and aggregate distribution, (drawn in blue), which lies within the limits (shown dashed) recommended by the British Standard BS 812 for medium sand. This good particle size distribution is represented by a shallow curve which slopes from left to right and meets the top of the chart at the size of the coarsest particles present. The builders "Y" sand that was used to make the very poorly graded sand "X" is shown in green. This was already outside the grading limits set by BS 812 as it had 5% more fines than recommended and 12.2% extra 0.6mm particles than the maximum allowed. It also had very few particles exceeding 2.36mm resulting in the sand being deficient in larger particles. Extra clay was added to this sand to give an even poorer distribution, increasing the fines content from 5% to 25% higher than the recommended limit. This material "X" is represented by the curve shown in red. Throughout the duration of this project sand "X" represented by the red curve and sand "Y" represented by the green curve have been used for experimental work.

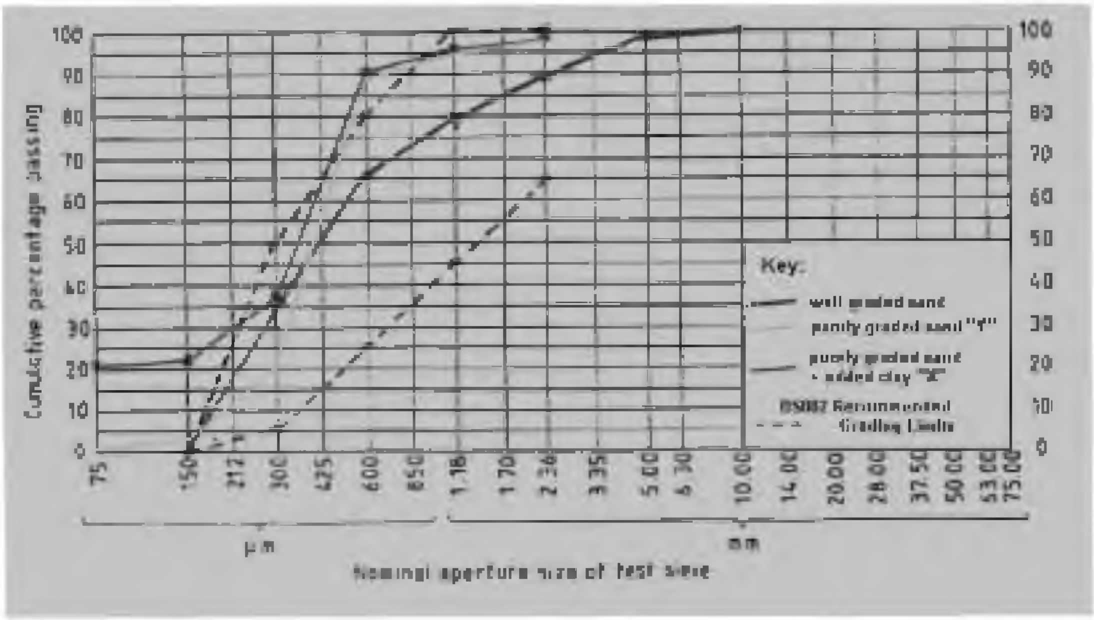


Figure 4.2: Particle Size Distribution Graph

4.2 Factors & method chosen for testing

4.2.1 Strength

Concrete is a structural material, so it is understandable that the most sought-after property of a concrete is strength. The strength of concrete is its resistance to rupture. Structural elements must be capable of carrying the imposed load and the maximum value of bearable stress is usually taken as the strength.

"Concrete strength appears to be a good index of a number of other technically important properties and routine strength tests in general are relatively simple to make", (Kesler, 1966).

Some of the many important properties of concrete that improve with an increase in strength are density, resistance to deterioration, porosity and permeability; hence strength may be used as a criterion of general quality.

It was therefore decided that strength would be an important factor to test, but the type of strength to be tested needed to be decided. In structural situations concrete is subject to one of a variety of types of loading, resulting in different modes of failure.

Knowledge of the relevant strengths is therefore important. There are 7 main different types of strength:

- *Compressive strength*: Required for columns or reinforced concrete beams.
- *Tensile strength*: Important for the cracking of concrete slabs. Tensile strength is about 10% of the compressive strength.
- *Shear strength*: Important in reinforced concrete beams to control the diagonal cracking of the beam. The pure shear strength is about 20% of the compressive strength.
- *Torsion strength*: Important for a reinforced concrete beam in pure torsion before cracking. The torsion strength of concrete is calculated by plastic theory and is usually higher than tensile strength.
- *Impact strength*: Important in concrete piles and in certain military establishments. Impact strength is approximately half of the compressive static strength.
- *Fatigue strength*: Has a practical significance since the majority of structures are subjected to repeated loading.
- *Multi-axial loading*: Important because concrete in structures is practically always subject to multi-axial combination of compression, tension, shearing and torsional stresses.

The two most common types of strength that can be tested for concrete are tensile strength and compressive strength. The tensile strength of concrete has a fundamental role in the fracture mechanism of hardened concrete. It is an accepted view that the fracture in concrete occurs through cracking caused by tensile stresses. This means that concrete fracture is essentially tensile failure regardless of whether the fracture is caused by compression, freezing, or other factors. Therefore, the mechanical properties of a hardened concrete are controlled to a great extent by the fact that its tensile strength is about one tenth of the compressive strength. To avoid undue cracking in structures such as concrete beams and slabs, the tensile strength is of special importance, despite its low magnitude. The case of uni-axial tension is rarely encountered in practice and in laboratory tests can only be obtained with care.

"The compressive strength of concrete is one of the most important technical properties. In most structural applications concrete is employed to withstand compressive stresses", (Popovics, 1998).

In those cases where other stresses (e.g. tensile stress) are of primary importance, the compressive strength is still frequently used as a measure of the resistance because this strength is the most convenient to measure. For the same reason, the compressive strength is generally used as a measure of the overall quality of concrete.

It was therefore decided that compressive strength would be tested, but a decision had to be made on whether the wet or dry compressive strength should be used. In the stabilised soils literature it can be seen that the compressive strength is mainly referred to as the wet compressive strength, but in the concrete literature the dry compressive strength is used.

It was expected that the sand being used would affect the wet compressive strength dramatically showing a cyclic loss of mass in the material as well a decrease in strength. It was decided that the shrinkage and swelling would be important factors to investigate due to the high fines content in the sand, so would be examined independently, and not combined with the strength test to form one single test. The wet compressive strength indicates what happens to the strength as well as taking into account the shrinkage and swelling, but the compressive strength indicates the strength only and was chosen to be tested.

According to Witmann, (1968) the dry compressive strength of concrete is higher than that of a comparable wet concrete because dryness decreases the volume of the hardened cement paste. The volume reduction is caused by surface tension that increases in the water filled small pores during drying, pulling adjacent grains of solid together: thereby reducing the average distance between surfaces in the hardened cement gel. This increases the secondary bonds between the surfaces, increasing the strength. Since rewetting the hardened cement paste causes volume increases, and therefore an increase in the average distance between surfaces of the cement gel, this would explain the lower strengths of wet cement paste and concrete specimens.

Compressive strength can be tested at various specific ages, where various ages only give a proportion of the final strength.

"The strength developed by a concrete made with given materials and given proportions increase for many months under favourable conditions, but in the majority of specifications the strength is specified at an age of 28 days", (Building Research Establishment Report, 1988).

Traditionally, concrete strength is determined 28 days after casting and rejection of a particular batch of concrete, or adjustment of the concrete production is delayed by the substantial time difference between casting and testing. It was therefore decided to test the specimens at an age of 7 days to begin with in order to get a respectable number of results to be analysed. After the main trends that the factors were following for 7 day tests, specimens were made to be tested after 28 and 56 days.

Numerous test methods have been recommended for the determination of concrete strengths. Some of these methods measure fundamental properties of the concrete whereas others do not. Also, various simplifying assumptions are used in the procedures of different test methods to convert a measured load to a calculated failure stress. Some of these procedures require more doubtful assumptions than others, which may considerably influence the relationships between various concrete strengths.

The principle laboratory test methods that could have been used were:

- *Destructive Compressive Strength Test*
- *PUNDIT Test*
- *Schmidt Hammer*
- *Penetration Resistance*
- *Pull-out Test*

A summary of the principle test methods are shown in the table below:

Method	Standard Number	Principle Applications	Principle Properties Assessed	Surface Damage	Type of Equipment	Remarks
Destructive Compression Test	BS 1881	Strength Measurement	Compressive Strength	Completely	Mechanical	Load rate should be of a few minutes
PUNDIT Test	BS 1881-203a	Comparative Surveys	Elastic Modulus	None	Electronic	Two opposite smooth faces preferably needed, strength calibration affected by moisture and mix
Schmidt Hammer	BS 1881-202	Comparative Surveys	Surface Hardness	Very Minor	Mechanical	Greatly affected by surface texture
Penetration Resistance	BS 1881-207a	In Situ Strength Measurement	Strength Related	Moderate / Minor	Mechanical	Specific calibrations required, surface zone test
Pull Out Test	BS 1881-207a	Quality Control (In Situ Strength)	Strength Related	Moderate / Minor	Mechanical	Pre-planned usage

Table 4.3: Summary of Principle Test Methods

It was decided that the compressive strength would be measured using the standard destructive *compressive strength test*, as recommended in the British Standard BS 1881, and the non-destructive *PUNDIT test*. Because the PUNDIT test is quick and non-destructive it allowed a large number of readings to be taken without damage to the blocks so as to retain some blocks to obtain further readings as the specimens aged. The detailed procedure of these two tests and problems associated with them are described in the research methodology.

The Schmidt hammer, also known as the rebound or impact hammer was also considered as a non-destructive test method that could have been used. The test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The spring loaded mass has a fixed amount of energy imparted to it extending the spring to a fixed position; this is achieved by pressing the plunger against a smooth surface of concrete which has to be firmly supported. This is illustrated in figure 4.4.

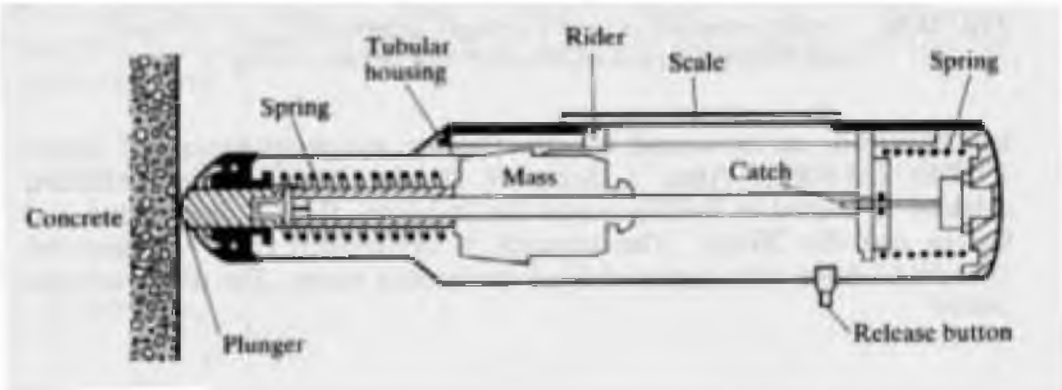


Figure 4.4: Schmidt Hammer

Upon release, the mass rebounds from the plunger, and the distance travelled by the mass, expressed as a percentage of the initial extension of the spring is called the rebound number; it is indicated by a rider moving along a graduated scale. The rebound number is an arbitrary measure since it depends on the energy stores in the given string and on the size of the mass. This test was rejected for this research as the concrete was not hard enough indicated by when the mass rebounded it indented the concrete.

The *penetration resistance test* and the *pull out test* were rejected as they are partially destructive tests. The penetration resistance test estimates the strength of the concrete from the depth of penetration by a metal rod driven into the concrete by a given amount of energy generated by a standard charge of powder. The pull out test measures the force required to pull out a previously cast-in steel rod with an embedded enlarged end. Because of its shape, the steel rod assembly is pulled out with a lump of concrete in the approximate shape of a frustum of a come. The pull out strength is calculated as the ratio of the force to the idealised area of the frustum. As it was decided that all specimens would be crushed using the compression test after intermediate readings had been taken, using any of the partially destructive tests would damage the specimens. Damaging the specimens and the crushing them would result in an unrealistic low compression strength and since the destructive compression test is the most reliable and accurate test available, the compression test method was adopted.

It is expected that the concrete made with sand "Y", the good sand, will give a 7day dry compressive strength of approximately 12 MPa, which is within the range of a 'normal' concrete. The range of concrete strength is usually between 10-70 MPa, which means that the estimated value is nearer the lower value. This is because it is expected that the method for making the specimens is more basic than methods used in normal UK concrete making.

It is expected that concrete made with sand "X", will have a 20% lower dry compressive strength than sand "Y", at approximately 9.6MPa. This is explained in the literature by the extra fines interfering with the chemical reaction in the cement and the water. Concrete is not generally used at strengths lower than 10MPa, so it is expected that sand "X" will not be suitable for use in concrete.

4.2.2 Shrinkage / Swelling

As mentioned previously, due to the high fines component in the composition of the sand of the concrete, shrinkage and swelling were considered to be important factors to be investigated. This is because:

"The high fines fraction in the material being tested means there is a high proportion of small particles having surface electrostatic charges to which a layer of water becomes attached", (Spence and Cook, 1983).

The thickness of this layer depends on the normal pressure to which the soil mass is subjected, and this gives fines, especially clays, their characteristic ability to swell and shrink as they take on and lose moisture.

Shrinkage can be divided into three main categories. They are,

- *Plastic,*
- *Autogenous,*
- *Drying.*

Plastic shrinkage is the shrinkage which occurs before the concrete has set or has attained any significant strength. The principle cause of such shrinkage is the rapid evaporation of water from the concrete surface. The restraint of the mass of concrete will cause tensile strains to be set up in the near surface region, and as the concrete has near zero tensile strength, plastic shrinkage cracking may result. Any tendency to plastic shrinkage cracking will be encouraged by greater evaporation rates of the surface water which occurs.

Autogenous shrinkage results in volume change without the loss of moisture. The contraction is relatively small and of significance only in large structures. This type of shrinkage is not examined in this report.

Drying shrinkage occurs when concrete is hardened and cured and allowed to dry. First, the water saturating the voids in the concrete dries out. This continues until the total moisture content is reduced by about half. Further drying results in water being drawn out of the mass of small capillaries which permeate the cement gel. This process continues on an ever decreasing scale for a long time. The rate at which the shrinkage occurs depends on the speed of water loss and on the moisture movement through the concrete; therefore in hot, dry and windy climates rates of shrinkage will be high.

So, when cement, aggregate and water are mixed together the gross volume decreases as the finer particles arrange themselves in the interstices of the larger particles. The shrinkage continues as the concrete is being worked into place, i.e. when still plastic. Evaporation of water in the mix also decreases the volume of such concrete.

Shrinkage, when the concrete is in a fluid state, does not matter structurally because no internal stresses can be instigated. When the concrete changes from a fluid to a solid state, further shrinkage of the concrete will cause internal stresses and even cause cracks to occur. If a mass of concrete shrinks or expands uniformly and its movement is not restricted by any external forces, then no internal stresses can be induced in the concrete. This seldom happens in practice; usually any movement of the concrete is restricted internally by reinforcement imbedded in the concrete, and often externally by its surroundings. Also, the surface of the concrete will often dry out (and therefore shrink) faster than the internal particles of concrete. It was therefore decided that drying shrinkage would be measured during the curing period of 56 days.

Shrinkage after the concrete has solidified continues as and when further water evaporates. The chemical reaction of cement with water, and thus the shrinkage, continues in the concrete seemingly indefinitely. A gel is formed which contracts upon desiccation and becomes very hard. If the concrete is submerged in water the cement gel expands with considerable force, so that the whole mass of the concrete expands and swells. This expansion, however, can never equal the shrinkage which has already taken place. On drying the concrete in air shrinkage again occurs. Therefore, when concrete is subjected to continual wetting and drying, it experiences corresponding expansions and contractions, (shrinkage and swelling). This is illustrated graphically in figure 4.5. It was decided to measure these expansions and contractions to examine the effect of a high proportion of fines had on these movements as it was expected that the specimens would be susceptible to damage on exposure to wetting and drying cycles.

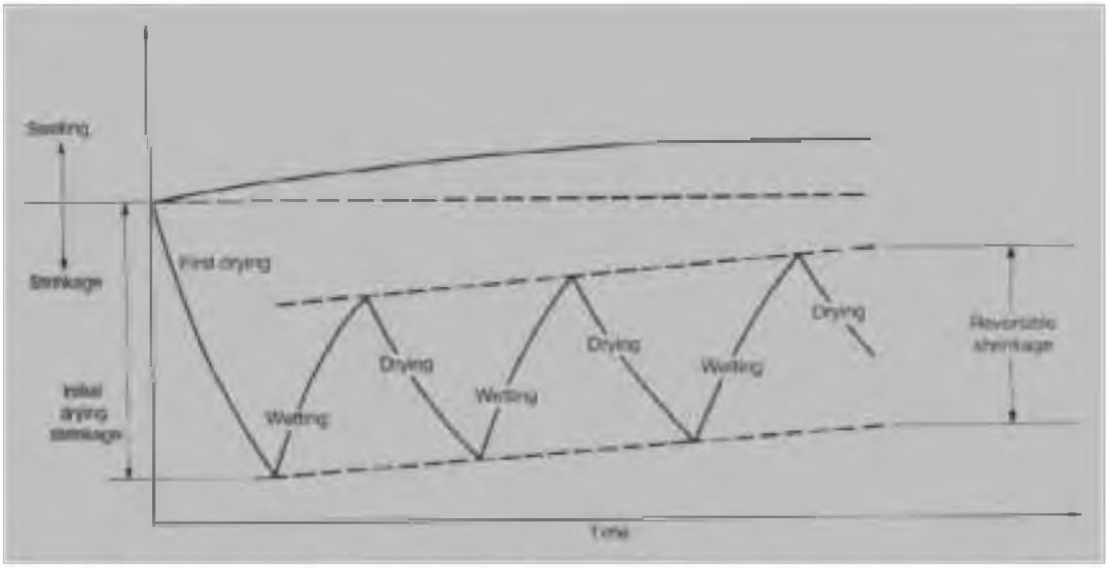


Figure 4.5: Schematic of volume changes in concrete due to alternate cycles of drying and wetting.

Maximum shrinkage occurs on the first drying, and a considerable part of this is irreversible; i.e. it is not recovered on subsequent rewetting. Further drying and wetting cycles result in more or less completely reversible shrinkage. The diagram also shows the continuous but relatively small swelling of the hardened cement paste (hcp) on continuous immersion of water. The water content first increases to make up for the self-desiccation during hydration and to keep the paste saturated. In principle the stronger the hcp structure, the less it will respond to the forces of swelling and shrinkage.

Shrinkage and swelling were measured using dial gauges that were set up on the specimen cubes. This was the only method considered as it is a cheap and effective way of measuring the volume changes with the specimens that had already been made for testing compressive strength. With a 100mm cube, strains could be measured to a resolution of ~ 100 μ-strains. Using the same specimens allowed better time management and enabled a larger range of results. The details of the procedure are described in the research methodology.

According to Illston, (1994), 'normal concrete' usually shrinks between 300-600 μ-strains in one year of drying. Therefore, it is expected that concrete made with the good sand, sand "Y", will have a drying shrinkage of approximately 600μ-strain, the upper limit, allowing for the 5% extra fines than recommended in BS 812. It is expected that concrete made with sand "X", will have a larger drying shrinkage, approximately 20% more shrinkage, of about 720μ-strain, since there is a larger proportion of fines. Cyclic shrinkage is thought to follow the usually pattern described above, but with increased shrinkage and swelling movements. Usually cyclic movements change between ±400μ-strain, so it expected that concrete made with sand "X" will have movements between approximately ±600μ-strain.

5. Research Methodology

5.1 General Approach

This project examined the factors affected by a high fines content when making concrete. This means that several iterations were used, each to change a factor, while holding all others constant to obtain a result. When a new result was obtained, a new understanding was gained and different avenues were explored. This structure led to most of the project being devoted to experimental work in the laboratory and analysing results. Alongside the experimental work, secondary data was collected to support the laboratory work and to justify the findings.

5.2 *Making the specimens*

The compressive strength test that was used uses a concrete cube and is the standard destructive test in the UK set out by the British Standard, BS 1881: 1983. The cube size tested was 100mm, as recommended for maximum aggregate sizes of 20mm or less. Some of these cubes were also used for the PUNDIT test and for the shrinkage and swelling measurements.

The mix components were chosen for experimentation was based on a soil-cement ratio of 4:1 by weight. This ratio was chosen because for high strength concrete a ratio of 3:1 is normally used, and for rendering, a ratio of 5:1 is commonly used. It was decided to use an in-between value in order to keep it constant throughout the duration of the project, so not to have another variable. The water content, vibration time, and mixing time were varied until the optimum, or best operating point was found, (this will be discussed in the analysis). The approximate density of the concrete to be tested was 2000kg/m^3, and the volume of the cube was 0.001m^3. Since:

Density (kg/m^3) = mass (kg) / volume (m^3), the mass needed for each block was approximately 2kg. That is, 1.6kg of aggregate and 0.4kg of cement.

The cubes were cast in lubricated steel moulds, accurately machined to ensure the opposite faces are smooth and parallel. A thin layer of lubricant was applied to the inside surfaces of the mould in order to prevent bond between the concrete and the mould. The concrete was placed and compacted using a vibrating table, as soon as the mix was made. This was so there would be no effect from the delay of moulding.

A vibrating table can be considered as a case of formwork clamped to the vibrator. A rapidly rotating eccentric weight makes the table vibrate with a circular motion but, by having two shafts rotating in opposite directions, the horizontal component of vibration can be neutralised, so that the table transmits a simple harmonic motion in a vertical direction only. The concrete was fully compacted by external vibration and filling the mould in two stages. The details of this procedure are prescribed by BS 1881: Part 108: 1983. When the mould was filled the surface was trowelled smooth.

The moulded specimens were stored for 48 hours at a temperature of 23 °C since curing at a higher temperature would result in a higher initial strength development, but a lower 28 day strength. If a much lower temperature was chosen, the concrete would also have a lower strength. Subsequently, the de-moulded cubes were stored at the same temperature in a polyethylene bag until the prescribed age of testing.

5.3 Compressive strength tests

5.3.1 Destructive compressive test

The cube testing machine has two heavy platens through which a uniformly distributed increasing axial compression load was applied to the concrete.

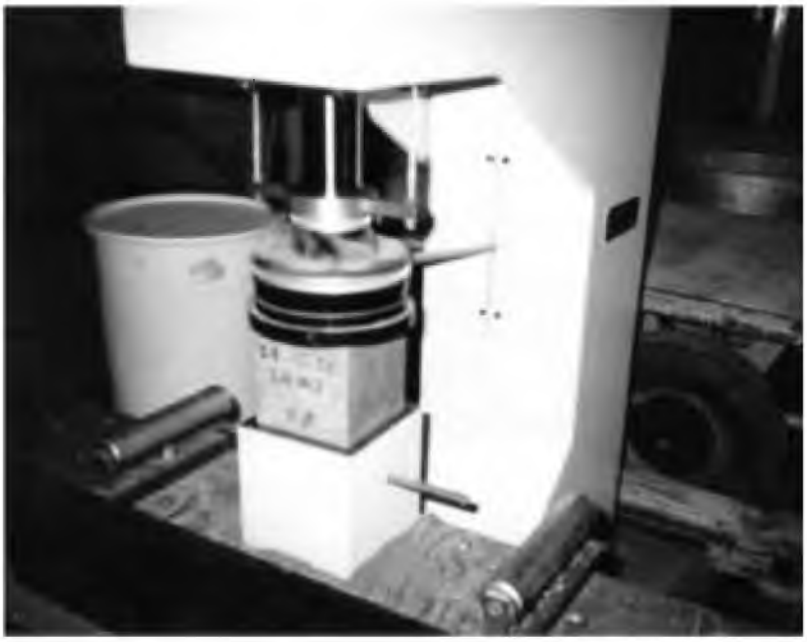


Figure 5.1: Compression Test Machine

The bottom platen is fixed and the upper one has a ball seating which allows rotation to match the top face of the cube at the start of loading. This then locks in position during the test. The load was applied to the pair of faces which were cast against the mould, i.e. with the trowelled face to one side. This ensured that there were no local stress concentrations which would result in a falsely low average failure stress.

The strength of concrete increases as the rate of loading increases so it is necessary to define the rate for testing purposes. McHenry and Shideler (1955) have shown that if the specimen is not subjected to impact or if the load is applied in a reasonable period of time, the rate of loading does not significantly influence strength. Therefore, a rate to reach the ultimate load in a few minutes is recommended, so a loading rate of 50kN/ Min was chosen. When the specimens had failed, the maximum load and type of failure was recorded.

The cracking pattern within the cube produced a double pyramid shape after failure, (see figures 5.2a & b).

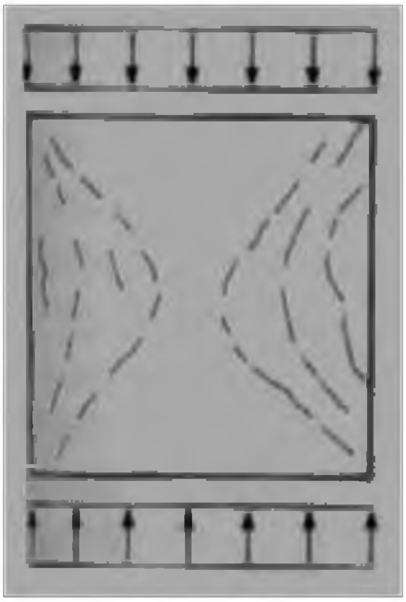


Figure 5.2a: Cracking Pattern Of a Cube

Figure 5.2b: Cube after failure

From this, it was immediately apparent that the stress within the cube was not uniaxial. The compressive load induced lateral tensile strains in both the steel platens and the concrete due to the Poisson effect. This mismatch between the elastic modulus of the steel and the concrete and the friction between the two resulted in lateral restraint forces in the concrete near the platen. The concrete cube was therefore in a triaxial stress state, with consequent higher failure stress than the true, unrestrained strength. This was the major objection to the cube test, but the test was relatively simple to perform and is capable of comparing different concretes.

The strength was expressed as the ultimate compression load per cross sectional area. This reading was converted into MPa for a reading of strength. This type of test is a destructive test and was applied to the cubes after seven days. No other results from the specimens tested could be obtained. Therefore, in order to obtain more results during the project time, it was decided to use an in-situ test which is a type of non-destructive test up until an age of 56 days and then crush them.

5.3.2 PUNDIT test

The PUNDIT test (Portable Ultrasonic Non-destructive Digital Indicating Tester), was used to indirectly test the compressive strength of the cubes made as described above.

Figure 5.3: PUNDIT in laboratory

Three types of waves are generated by an impulse applied to a solid mass. Surface waves having an elliptical particle displacement are the slowest, whereas shear or transverse waves with particle displacement at right angles to the direction of travel are faster. Longitudinal waves with particle displacement in the direction of travel are the most important since these are the fastest and generally provide the most useful information. Electro-acoustical transducers provide waves primarily of this type; other types generally cause little interference because of their lower speed.

The underlying principle of this PUNDIT is the recognition that factors that increase the concrete strength usually increase the velocity of the acoustic wave propagations in the material as well. The PUNDIT generates low frequency ultrasonic pulses and measures the time taken for a wave to propagate through the specimen of length 100mm. This enables the velocity to be determined from:

Pulse Velocity = Path length / Transit time

Path lengths and transit times were measured to an accuracy of $\pm 1\%$. This is because the pulse velocities for most concrete mixes lie within a narrow range so it is therefore necessary to measure both the transit time and path length to this accuracy. To acquire a high accuracy of transit time, good acoustic coupling between the transducer face and the concrete is needed. This was achieved by covering the transducer face with medium grease. A zero control is incorporated in the instrument since the zero is likely to change when different transducers are used. The instrument indicated the time taken for the earliest part of the pulse to reach the receiving transducer measured from the time it left the transmitting transducer when these transducers were placed on opposite surfaces of the specimen, (see figure 5.4). It was important that the readings were repeated by complete removal and re-application of transducers to obtain a minimum value for the transit time.

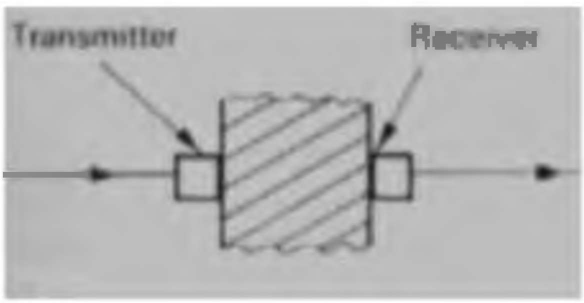


Figure 5.4: Diagram of PUNDIT on specimen

This arrangement for taking readings was the direct transmission arrangement, and is the most satisfactory method of taking readings since the longitudinal pulses leaving the transmitter are propagated mainly in the direction normal to the transducer face. Pulses were not transmitted through large air voids in a material, and if such voids existed directly in the pulse path, the instrument would have indicated the time taken by the pulse which circumvents the void by the quickest route.

It can be shown theoretically that the wave velocity depends upon the elastic properties, and hence if the mass and velocity of wave propagations are known it is possible to assess the elastic properties. The compression wave velocity is given by:

$$V = \sqrt{\frac{K.E}{\rho}}$$

Where V = Compression wave velocity (km/s)

$K = \dfrac{(1-v)}{(1+v)(1-2v)}$, (typically K = 1.3)

E = dynamic modulus of elasticity (kN/mm^2)

ρ = density (Kg/m^3)

v = dynamic Poisson's ratio, (typically 0.3).

In practice the velocity of such pulses travelling in concrete is very closely related to the elastic modulus since changes in the density or Poisson's ratio give rise to proportionately greater changes in elastic modulus.

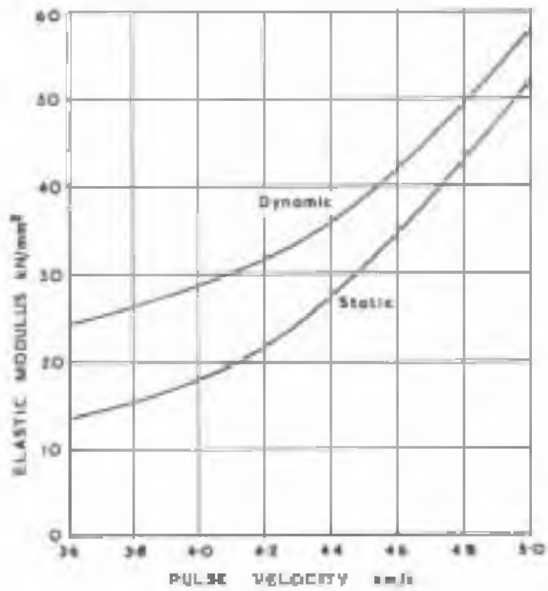


Figure 5.5: Curves relating Pulse Velocity with Static and Dynamic Elastic Modulus

The elastic modulus of concrete increases as its mechanical strength increases so that pulse velocity can be related empirically to cube strength. The exact relationship cannot be defined simply by consideration of the properties and proportions of individual constituents. This is because of the influence of the aggregate particle shape, efficiency of the aggregate, matrix interface and variability of the particle distribution, coupled with changes of matrix properties with age. There is no single curve which relates concrete strength to pulse velocity although, for a given cement content and aggregate type, a reasonable correlation exists between velocity and cube strength when this is varied by changing either the water cement ratio or the age at test. This correlation could not be used in the experimental work since the aggregate type is different to the "norm". In order for the Pundit Test results to be related to compressive strength, experimental collaboration of the specimens was necessary. Strength calibration was attempted as readings were taken between both pairs of opposite faces of cubes, which were then crushed in the usual way. Ideally, at least 10 sets of three specimens should be used, but time constraints did not allow this, so only 3 blocks for each type of specimen were crushed at 7 and 56 days. 6 pulse velocity readings were taken for each cube, and each individual reading was within 5% of the mean for that cube.

Although the precise relationship is affected by many variables, the curve is usually found to be of the general form:

$$f_c = Ae^{B\nu}$$

Where f_c = equivalent cube strength

e = base of natural logarithms

ν = pulse velocity

and A and B are constants.

Hence, a semi-logarithmic plot of pulse velocity against cube strength is linear for a particular concrete. It is therefore possible to use a curve derived from reference specimens to extrapolate from a limited range of results. This process is done in section 6.1.8.

5.4 Shrinkage & swelling measurements

Shrinkage and swelling measurements were done on the cubes made for the PUNDIT test. During the curing process, once the specimens had been removed from the moulds, the blocks were set up as shown in the photograph in figure 5.6.

Figure 5.6: Specimen during the curing process

Point dial gauges were set up on the side face of the specimens, and readings were taken at 7, 14, 28, and 56 days respectively. This allowed measurements of the drying shrinkage to be made. As it can be seen from the photographs, the blocks were covered in a polyethylene bag to keep the curing conditions the same for each specimen. Because of stick and hysterisis in the dial gauges, measurements were always approached from one side (above), so that the friction in the spring could be ignored. At 56 days, the specimens were measured using callipers and were then placed in a drying oven at 105°C and left to dry out for 7 days. After this period of time the cubes were re-measured, then submerged in water with a dial gauge set up on it. The movement in the specimen was recorded after 7 days, and the drying wetting cycle was carried out again.

The point dial gauges measure to an accuracy of ± 0.005mm and the callipers to an accuracy of ± 0.05mm. It was necessary to use the callipers for the drying part of the cycle, since the drying oven was not large enough to set up a dial gauge. This meant that the accuracy of the shrinkage measurements during the cycle were much less accurate than the swelling measurements.

6. Results & Analysis

6.1 Strength

The first property of the concrete that was tested was the dry compressive strength, after a curing period of 7 days. When the strengths of comparable concretes, (i.e. the sand with a high fines content, and the one without), with identical water-cement ratios were made, the strength of the concrete unexpectedly *increased* as the fines content increased. This is shown in table 6.1 below.

		Maximum load (kN)				
	Water-cement Ratio	Block 1	Block 2	Block 3	Mean Maximum Load (kN)	Mean Pressure (MPa)
Sand "X" Cube	0.95	122.2	120.1	121.1	121.1	12.1
Sand "Y" Cube	0.95	79.9	79.3	79.2	79.5	7.9

Table 6.1: Comparable concretes with identical water-cement ratios after 7 days

This was an unexpected result since it was expected that the fines would interfere in the bond between the hardening cement paste and the aggregate. The strength of concrete originates from the strength of the hardening cement paste, which originates from the hydration products in the form of a rigid gel, the cement gel.

"It is reasonable to assume that the bonds of the gel particles to each other, to the sand particles, and to other bodies in the concrete are responsible for strength", (Popovics, 1998).

A likely explanation as to why the compressive strength was higher for the cubes with more fines is that the bond to the hardening cement paste to aggregate particles of larger sizes is weaker than the bond to smaller sizes because of the specific surface of the former. Also, the 'fines' are siliceous substances of high surface area that react with the excess alkali in the cement to form additional 'pozzolanic' gel.

The strength being discussed is this research is the strength of small samples. The strength of these small samples is generally higher than that of core samples taken from a structure and there are several reasons for this:

1. The cube specimens were compacted, cured and tested under controlled conditions; a structure (or core samples taken from it) is not subjected to the same controlled conditions. Compaction and curing in a structure is generally less than the optimum that would be achieved with the test specimens.
2. The concrete is a structure is subjected to restraint stresses due to the reinforcement member geometry and other factors, and this pre-test load will influence strength of a core taken from a structure.

Interpretation of the Strength Readings

The strength of the concrete samples made from the same mix and tested in the same manner are variable and if a population (or large sample) of results are considered, the variation follows a normal distribution. The characteristics of a normal distribution are the arithmetic mean (x), which is the sum of the strength results divided by the number of results, the standard deviation (σ), which is the root mean square deviation of a set of results from their arithmetic mean, and the coefficient of variation ($v_c = (\sigma/x) \times 100$), which is a measure of the relative variability of a set of results. The results are said to follow a normal distribution if they are equally spaced about the mean value and if the largest number of cubes have strength close to the mean value, the number falling off as the results are much greater or less than the mean value. In some cases it may be considered doubtful as to whether actual results lie within a normal distribution, but for the purpose of statistical analysis they are considered to do so. The range of a set of strength results will be reflected in the values of standard deviation and coefficient of variation; the higher these values the greater the range. The variability of concrete is a reflection of the manner in which it was made and tested, i.e. the degree of quality control.

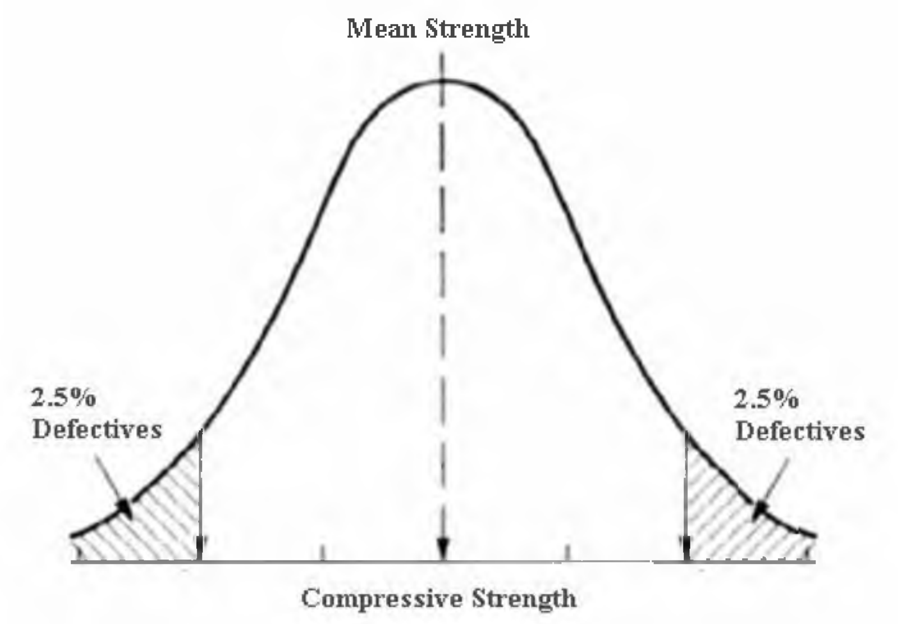


Figure 6.2: Normal distribution for concrete strengths

The mean value of a number of results gives no indication of the extent of variation of strength. The extent of variation can be determined by relating the individual strengths to the mean strength and determining the variation from the mean. The variations which occur in compressive strength test results, even when testing all the concrete from one batch, are not due to faulty workmanship but are inherent in the making and testing of concrete. The amount of scattering is in itself a measure of quality; where the sampling of concrete is not restricted to one batch but is spread over a number.

The variability of the properties of concrete can only be determined by testing, but testing itself can introduce error. Precision is the general term used for the closeness of agreement between replicate test results, and two terms are relevant: repeatability and reproducibility.

BS 5497: Part 1: 1979 defines repeatability as the value below which the absolute difference between two single test results, obtained with the same method on identical test material under the ‘same’ conditions (i.e. same operator, same apparatus, same laboratory, and a short interval of time), may be expected to lie within a specified probability (usually 95%). On the other hand, reproducibility is defines as the value below which the absolute difference between two single test results, obtained with the same method on identical test material under ‘different’ conditions, (i.e. different operators, different apparatus, different laboratories, and/or different times), may be expected to lie within a specified probability (usually 95%).

Values of repeatability and reproducibility are applied in a variety of ways, e.g.

- to verify that the experimental technique of a laboratory is up to requirement;
- to compare the results of tests performed on a sample from a batch of material;
- to compare test results obtained by a supplier and by a consumer on the same batch of material.

Using this statistical analysis, it can be shown that the results from comparable concretes with identical water-cement ratios can be proved to be statistically significant:

Testing for a difference between two normal distributions

	Result number	Water-cement Ratio	n	x	σ_{n-1}
Sand “X”	X_1	0.95	3	12.1	0.105
Sand “Y”	X_2	0.95	3	7.9	0.038

Table 6.3: Data on the 2 different batches of concrete for significance testing

If two sets of results, X_1 and X_2, have independent normal distributions with means of x_1 and x_2 and standard deviations σ_1 and σ_2 respectively then the difference Δ between two populations is another normally distributed entity

$$\Delta = X_1 - X_2 \sim N(x_1 - x_2, \sigma_1^2 + \sigma_2^2)$$

Since X_1 and X_2 are based on sample sizes of n_1 and n_2, respectively from the above two normal populations then

$$\overline{X}_1 - \overline{X}_2 \sim N\left(x_1 - x_2, \frac{\sigma_1^{\ 2}}{n_1} + \frac{\sigma_2^{\ 2}}{n_2}\right)$$

and the statistic $\overline{X}_1 - \overline{X}_2$ can be used to test hypothesis about the values of x_1 and x_2.

If $X_1 \sim N(x_1, \sigma_1^2)$ and the independent random variable $X_2 \sim N(x_2, \sigma_2^2)$ then a test of the null hypothesis H_0: $x_1=x_2$ can be carried out using the test statistic

$$Z = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}\right)}} \sim N(0,1^2)$$

So, the null hypothesis is

$H_0 : x_1 = x_2$ $\qquad H_1: x_1 \neq x_2$

In this comparison of strength of cubes made with sand "X" and sand "Y" respectively:

$\sigma_1 = 0.105$, $n_1=3$, $\sigma_1 = 0.0.38$ and $n_2=3$

$x_1 - x_2 = 12.1 - 7.9 = 4.2$, where σ and x are measured in MPa.

Thus, for this experiment, the test statistic Z has the value:

$$Z = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}\right)}} = \frac{4.2}{\sqrt{\left(\frac{0.105^2}{3} + \frac{0.038^2}{3}\right)}} = 65.15$$

The 5% (two tailed) critical values for z are $Z_{95} = \pm 1.96$

Hence 65.15 is a statistically significant value (i.e $z >> z_{95}$) and H_0 can be rejected. It can be concluded that there is significant evidence of a difference in means of the two results.

This statistical analysis was applied to all relevant results, and is used in later sections of the analysis. The main factors which affect strength are taken to be quality of water, cement, mixing time, vibration compaction time, curing conditions, workability, water-cement ratio and curing age. Each of these factors will be looked at it in turn.

6.1.1 Water Quality

Water is one of the main constituents of concrete. It has various functions; it reacts with the cement powder, causing it to set and harden, and it is a lubricating liquid which enables the concrete to be placed as a semi-fluid and so facilitates compaction.

"It is generally accepted that water which is fit for drinking is suitable for mixing concrete", (Neville & Brooks, 1987).

In this country it is doubtful whether there is any justification for using anything other than water supplied for domestic purposes. In some situations, however, it is necessary to use sea water. Sea water contains sodium and magnesium chlorides and sulphates. The action of the chloride ions is to accelerate early strength development while the sulphate ions reduce the later age strength. Mindless and Young (1981), indicate that the 28 days strength can be reduced by as much as 20% if sea water is used as mix water. Also, the addition of chloride ions to concrete increases the risk of corrosion of the reinforcing steel. Hence, because of the generally poor standard of concrete construction in the Third World countries, it is considered that sea water should, as far as it is practical, not be used. For the purposes of this study, only tap water was used for mixing.

6.1.2 Cement quality

Cement is the most important and expensive ingredient of concrete, on a price per tonne basis. It was patented by J.Aspdin in the UK in 1824 and he called his product Portland cement because of the 'artificial stone' (concrete) made with it resembled Portland stone.

The chemical composition of Portland cement consists essentially of four main elements; lime, silica, alumina and iron oxide. These elements interact with one another in the kiln to form a series of more complex products. Of these, four of the products are considered to be the major constituents of cement:

- Tricalcium silicate, C_3S
- Dicalcium silicate, C_2S
- Tricalcium aluminate, C_3A
- Tetracalcium aluminoferrite, C_4AF

Each grain of cement consists of an intimate mixture of these compounds.

There are several types of Portland cement available commercially, but the most common type used in concrete construction is Ordinary Portland Cement. Its related British Standard is BS 12:1978. Over the years, there have been changes in the characteristics of ordinary Portland cement: modern cements have a higher C_3S content and a greater fineness than 40 years ago. In consequence, modern cements have a higher 28 day strength than in the past, but the later gain is smaller. For the purposes of this research ordinary Portland cement was used to make the cubes since it is the cheapest and most widely available cement for builders in developing countries to use.

6.1.3 Mixing time

"For onsite mixing or in the laboratory, the essential requirement in mixing concrete is to produce a uniform mixture in as short a time as possible", (Spence and Cook, 1983).

The mixing operation consists of essentially of rotation and stirring, the objective being to coat the surface of all the aggregate particles with cement paste, and to blend all the ingredients of concrete into a uniform mass. Mixing can be achieved in pan or drum type mixers, or it can mixed by hand which is generally less effective in achieving the objective above. Nevertheless, hand mixing was used to make the concrete mix since this is the most likely method to be used in developing countries.

It is essential to mix the concrete well since the strength of concrete is also affected by the efficiency of mixing. Poor mixing results in a bad distribution of the coarse and fine aggregates through the mix, so that some parts are lean and some parts are rich in cement. The lean parts are not fully compacted, whilst the rich parts may be over compacted, resulting in some wet segregation.

Mixing time is considered to have an asymptotic effect, so provided it was 'very high' its actual value would not affect the strength of the concrete. However, in case this assumption was unreliable, some attempt was made to hold the mixing time constant. It was decided to hold the mixing time constant at 5 minutes for a mix of 5 kg. This time was chosen not in relation to the optimum mixing time, but instead was chosen due to the time constraints on a builder in a developing country. Although mixing for a much longer period increases the strength it is not done in practice, so an arbitrary value was chosen.

6.1.4 Vibration compaction time

The compaction of concrete is the process whereby the amount of voids is reduced to a minimum and the particles of aggregate are constrained to pack more closely together so as to achieve the minimum potential density and strength from the concrete.

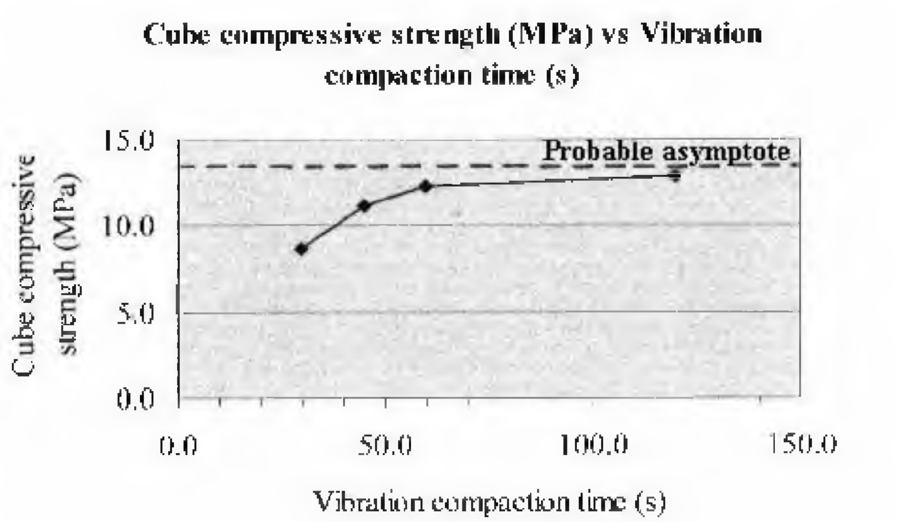
Vibration does not increase the workability of concrete and can be detrimental by causing segregation of the constituents of the concrete, the gravel particles tending to sink to the bottom, and the sand and cement to float to the top of the concrete. The vibration employed should *only just be sufficient* to make the concrete flow into the sharp corners of the mould and around the reinforcement.

Four batches of three specimens were made to test the effect of vibration time on compressive strength when using a high fines content concrete. The batches were vibrated for 30 seconds, 45 seconds, 1 minute and 2 minutes respectively.

It was discovered the compressive strength increases with vibration time in the form of an asymptotic relationship. The difference of 2 minutes vibration time compared to 1 minute gave a 5% increase in strength, whereas between 45 and 60 seconds, there was a 10% increase in strength. Therefore in terms of costs, one minute vibration time was considered sufficient, as this time is nearing its probable asymptote. This is shown in figure 6.5.

	Maximum Load (kN)					
Vibration Time (seconds)	Block 1	Block 2	Block 3	Mean Maximum Load (kN)	Mean Pressure (MPa)	Load Normalised to Max. Load
30	87.5	87.2	87.4	87.4	8.7	0.68
45	111.2	111.4	111.7	111.4	11.1	0.86
60	122.8	122.7	123.4	123	12.3	0.95
120	129.4	129.1	128.9	129.1	12.9	1.00

Table 6.4: Vibration compaction time against Cube compressive strength



Graph 6.5: Vibration compaction time against Cube compressive strength

6.1.5 Curing Conditions

Curing is the name given to procedures used for promoting the hydration of cement, and thus, the development of strength of concrete, the curing conditions being control of the temperature and of the moisture movement from and into the concrete.

Although there are several ways to cure concrete, including curing under water, the project focuses on methods used in developing countries.

In tropical and subtropical countries, the temperature during the day can regularly exceed 30°C and special precautions have to be taken, otherwise the concrete may crack and its strength will be impaired.

"Curing in developing countries means that there is a difficulty with fresh concrete because the temperatures are above 'normal', meaning that the concrete can stiffen bëfore it is compacted and finished", (ACI Committee 305, 1982).

The specific harmful consequences of this on the fresh concrete are:

- Increased water demand
- Increased rate of slump loss
- Increased rate of setting resulting in greater difficulty of handling and curing
- Increased tendency for dry shrinkage
- Decreased durability
- Increased creep.

During placement the concrete temperature should be kept low. The optimum temperature range for the setting and early hardening of concrete is between 10 to 20°C. Control of concrete temperature through the temperature of ingredients can only be done at the point of batching and mixing. According to Popovics (1998), since the greatest portion of concrete is aggregate, reduction in aggregate temperature brings about the greatest reduction in concrete temperature. This can be done by shading the supplies.

These hot climate conditions have not been simulated, since it would be too expensive to do so, but it is assumed that the aggregate is kept well shaded, at a temperature of approximately 18°C.

At present, many builders in developing countries do not understand the consequences of curing concrete at high temperatures, and wrongly assume that leaving the concrete to cure in the sun is acceptable. In fact, a higher temperature maintained throughout the life of a concrete will result in higher short term strengths but also, lower long term strengths. A temperature of fresh concrete higher than normal results in a more rapid hydration of cement and leads therefore to accelerated setting and to a lower long-term strength of hardened concrete since a less uniform framework of gel is established.

Also, as water is relatively scarce, so it is unlikely that artisanal builders would be willing to adopt under-water curing methods. It has therefore been suggested that concrete should be cured in tightly sealed polyethylene bags in developing countries. This method has been adopted for the purposes of this study.

6.1.6 Workability

The strict definition of workability is the amount of useful internal work necessary to produce full compaction. The useful internal work is a physical property of concrete and is the work or energy required to overcome internal friction between the individual particles in the concrete. In practice, however, additional energy is required to overcome the surface friction between the concrete and the formwork. Also, waste energy is consumed by vibrating the form and in vibrating the concrete that has already been compacted.

More usefully, workability means the ease at with which the concrete can be handled from mixing to its final fully compacted position. Workability is influenced by the type of aggregate, its maximum size, shape and grading. Since the sand being tested contained a large number of fines, more water was needed to increase the workability to an acceptable level. A higher workability of concrete means it is easier to place and handle, but if the workability exceeds a certain limit for a particular type of material, a lower strength and durability will result. A balance needed to be made between the workability and water content in order to produce an optimum mix. The water content was optimised to obtain "the highest strength compatible with acceptable workability", and will be discussed in the next section.

Therefore, the workability chosen was the lowest workability consistent with efficient handling and placing of the concrete into the moulds. The workability was deemed acceptable if the fresh concrete was able to be mixed relatively easily by hand, and as a general rule the workability was considered optimised when the mix was just about to reach its plastic limit, as judged by eye.

6.1.7 Water-cement ratio

"The water cement ratio is defined as the ratio of the mass of free water to the mass of cement in the fresh concrete", (Newman, 1959)

The quantity of water and cement are expressed in kilograms, which provides the water-cement ratio by mass. The total water in a concrete mix divides between the water absorbed by the aggregate to bring it to a "saturated surface dry" condition, and the free water available for the hydration of the cement and for the workability of fresh concrete.

The basis of the concrete strength versus water-cement ratio relation is that an increase in the water-cement ratio produces more capillary pores in the matrix portion of concrete. The higher the water cement ratio, the more diluted the cement paste becomes; therefore the weaker it will be at any stage of hydration. But, this relationship between concrete strength and water-cement ratio is only approximate because it may be affected by secondary factors.

A high strength concrete requires to be as free from voids as possible. If water in excess of the amount required for the chemical reaction with the cement is present in the mix, the water remains in a free state and the concrete sets around the drops of water. Such particles of water form pores and voids in the concrete, resulting in weakness and permeability. Dependent on curing conditions, they may freeze and expand, causing corrosion and / or eventually evaporating into the atmosphere.

The water cement ratio was altered in the experiments by changing the water content while keeping the cement content constant. When the cement content is kept constant and the water content is changed, the concrete consistency changes dramatically. When the consistency of a concrete is already so stiff that its workability is just barely suitable for the available method of compaction, any reduction in the water cement ratio caused by a decrease in the water content will lead to an overly dry consistency. The consequence of this is a reduction in the concrete strength because the impaired workability will result in incomplete compaction. By contrast, if the consistency is fluid, it is difficult to achieve a homogeneous, cohesive concrete without significant segregation.

Therefore, experiments were carried out in the laboratory to find the optimum water-cement ratio in relation to dry compressive strength using sufficient workability as discussed previously. The results are shown in figure 6.6 and 6.7.

Before the water was added to the mix, a soil moisture test was carried out on the sand with the extra fines to see how much water is already within the material. If the amount of water already in the material was considered significant it would be added onto the water content when calculating the water-cement ratios.

80g of sand "Y" & 20g of Kaolin was placed in a heat proof dish. (This is the composition of sand "X"). The combined dish and material was weighed to an accuracy of ± 0.005g and then placed in a drying oven which maintained a temperature of 105°C. After 7 days the combined dish and material was re-weighed. The difference in weights between these two readings is the amount of water, in grams, that the material contained. This amount excludes those water molecules bonded so tightly to solid surfaces that even a temperature of 105 °C will not detach them.

Soil Moisture Test Results

Sand "Y" and Kaolin = 100g
Dish = 157.78g
Combined weight before drying = 257.78g
Combined weight after 7 days in drying oven = 257.14g
Amount of water loss = 257.78g – 257.14g = 0.64g = 0.64%

Kaolin was also tested for moisture on its own, and showed no decline in weight, hence it contained no water. It can therefore be concluded the sand contained 0.64% of water. It was decided to take this value into account when working out the water-cement ratios, so 0.64% of water was deducted from every amount of water added to the concrete.

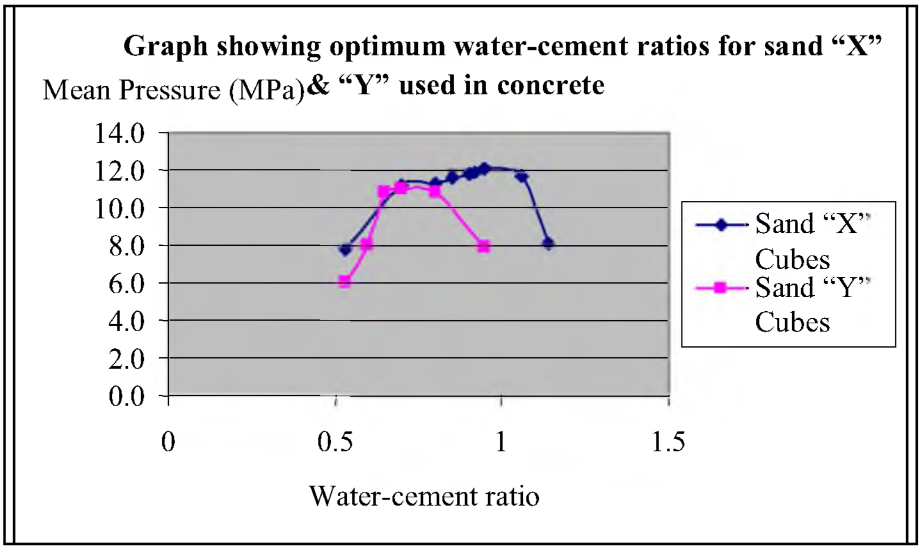
Optimum Water-cement Ratio Results

Sand "X"		Maximum load (kN)					
Water normalised to optimum	Water-cement Ratio	Block 1	Block 2	Block 3	Mean Maximum Load (kN)	Mean Pressure (MPa)	Load normalised to max. load
0.56	0.53	78.2	78.1	78.4	78.2	7.8	0.64
0.74	0.7	112.1	112.6	112.4	112.4	11.2	0.92
0.85	0.8	113.4	113.5	113.2	113.4	11.3	0.93
0.9	0.85	116	115.8	116.2	116	11.6	0.95
0.95	0.9	117.8	117.5	117.4	117.6	11.8	0.97
0.97	0.92	119.1	119.5	119.3	119.3	11.9	0.98
1	0.95	122.2	120.1	121.1	121.1	12.1	1
1.11	1.06	117.5	117.3	117.2	117.3	11.7	0.96
1.2	1.14	80.9	80.5	80.7	80.7	8.1	0.68

Table 6.6: Water-cement ratios versus compressive strength of Sand "X" cubes, (75% sand, 4.8% silt and 20.2% clay).

Sand "Y"		Maximum load (kN)					
Water normalised to optimum	Water-cement Ratio	Block 1	Block 2	Block 3	Mean Maximum Load (kN)	Mean Pressure (MPa)	Load normalised to max. load
0.76	0.53	62.1	61.1	57.1	60.1	6	0.55
0.86	0.6	80.2	80.5	80.4	80.4	8	0.73
0.93	0.65	107.7	107.3	107.9	107.6	10.8	0.98
1.00	0.7	110.1	109.9	110.5	110.2	11	1.00
1.14	0.8	108	107.8	108.1	108	10.8	0.98
1.36	0.95	79.9	79.3	79.2	79.5	7.9	0.72

Table 6.7: Water-cement ratios versus compressive strength of Sand "Y" cubes,(95% sand, 4.8% silt and 0.2% clay).



Graph 6.8: Graph showing optimum water-cement ratios for sand "X" and sand "Y" used in concrete.

Statistical analysis, similar to the method used in 6.1, was carried out on these results and is shown in Appendix A3.

As it can be seen by the figures shown in red, it was found that the concrete made from sand "Y" had an optimum water-cement ratio of 0.7, compared to a water-cement ratio of 0.95 for the sand "X" concrete. These optimum water-cement ratios were determined using compressive strength after seven days of curing.

"The ratio of water to cement for concrete made from 'good quality' concreting sand usually varies between 0.36 and 1.0 depending on the richness, and is usually approximately 0.4", (Akroyd, 1962).

The water-cement ratios for the materials used in this project are higher than the water-cement ratio recommended in the literature. This is because the concreting sand that was used had a poor grain distributions and a large amount of fines. Fines cause an increase in the water demand by the concrete to produce a specific workability. As a result, the strength of the concrete *should* decrease, as a consequence of the water-cement ratio rule. The reasoning associated with this is described below.

The important effect of the water-cement ratio, by weights, on the strength of concrete was published in 1918 by D. Abrams of Chicago, who stated that the strength of any workable concrete, of constant materials other than water, was dependent on the water-cement ratio alone, assuming the same cement, and degree of compaction are used and the conditions of curing and age at comparison of strengths are constants. The concretes compressive strength is inversely proportional to the water-cement ratio. This means that as the amount of water increases above that necessary for complete hydration of the cement it produces a more porous structure and results in a decrease in strength.

But, as can be seen from the results, *a higher water-cement ratio produced higher compressive strengths*. This was probably due to the fines "stealing" water from the cement and hence more water was needed to allow the full chemical reaction to occur with the cement. Once the chemical reaction had occurred with a sufficient amount of water, the bond of the hardened cement paste to the aggregate particles of larger sizes was weaker than the bond to the smaller sizes because of the smaller specific surface of the larger particles, hence increasing the compressive strength. But, the results also show that if the water cement ratio increased to 12% over the ideal, the decrease in dry compressive strength is large, approximately 68% of the strength for the optimum water cement ratio. This implies that the fines have "stolen" the water they need and too much is available for the chemical reaction, diluting the cement water paste and hence decreasing the compressive strength.

6.1.8 Curing age

It is experienced that the strength of a concrete increase with the progress of the hydration, that it, with age. When the hydration process stops, the strength development also stops. Hydration stops when any of the following three conditions occur:

- No more un-hydrated cement is available in the concrete.
- There is not enough free water.
- Diffusion can no longer take place.

Regardless of the hydration process, no retrogression in strength is permitted at any age. Such retrogression is always the warning sign of deterioration of the concrete due to some attack from the outside, faulty cement, reactive aggregate, or other cause.

Experiments were undertaken in the laboratory to verify this relationship. The two different concreting sands were used to make 12 cubes of each type. 7 day dry compressive strengths had previously been noted, so PUNDIT readings were taken at 7, 35 and 56 days. Ideally, readings should have been taken at 14 and 28 days but the timing of the Christmas vacation did not allow this. The full PUNDIT results tables for the two different types of specimens are shown in Appendix A4. The blocks were then crushed, and a calibration curve was drawn. The calibration results table is shown in Appendix A5 and graphs are shown in figures 6.9a and 6.9b below.

As mentioned previously, the precise relationship between the Pulse velocity and Compressive strength if affected by many variables, but the curve usually takes the general form:

$$f_c = Ae^{B\nu}$$

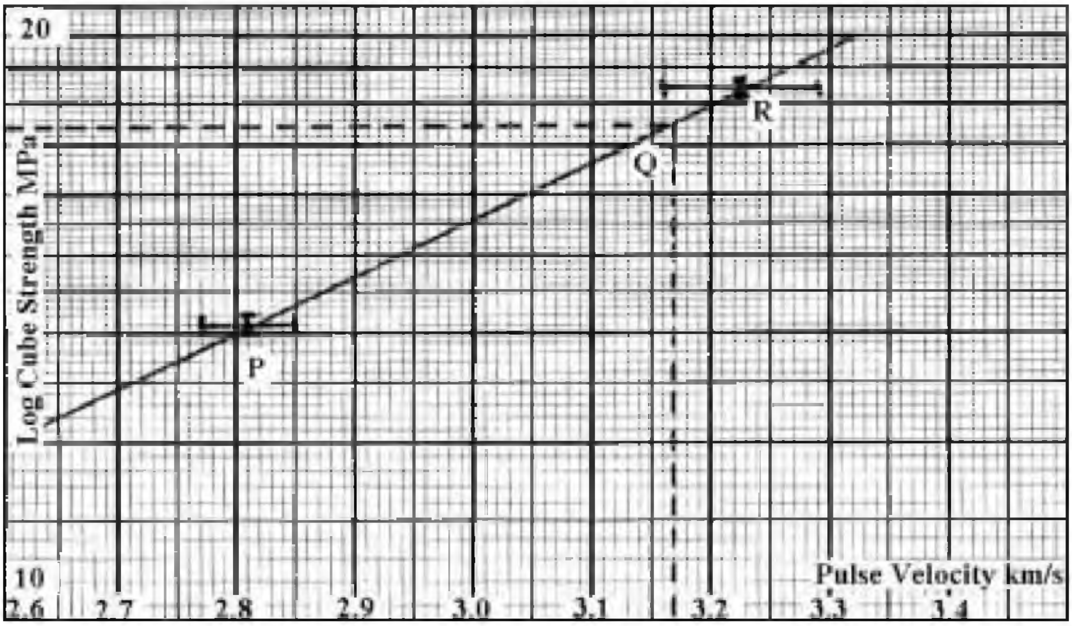
Where f_c = equivalent cube strength

e = base of natural logarithms

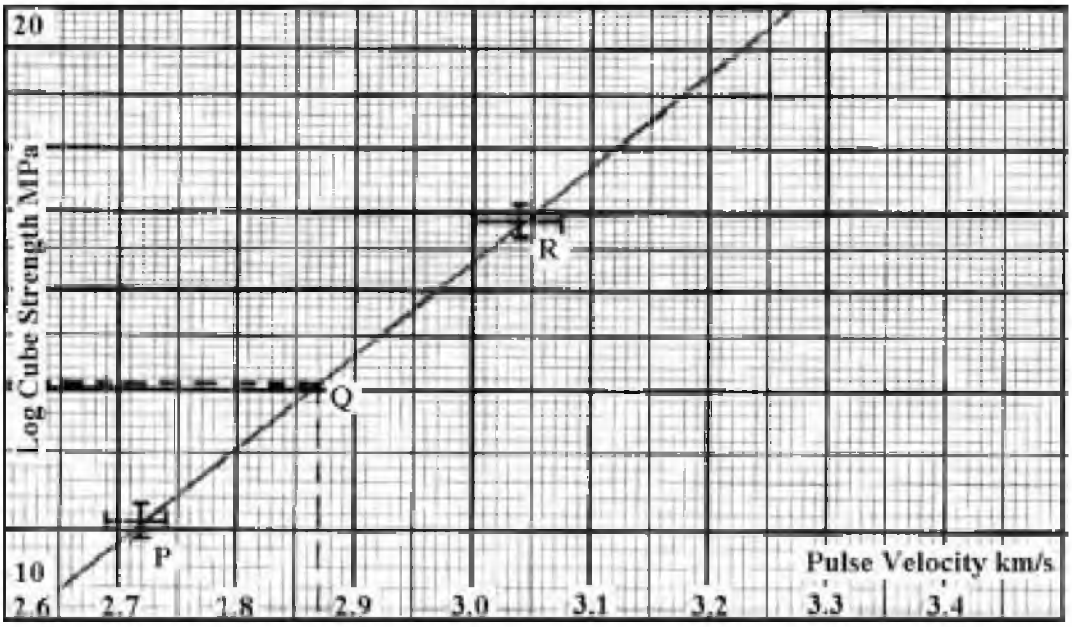
ν = pulse velocity

and A and B are constants.

Hence, a semi-logarithmic plot of pulse velocity against cube strength was plotted, and a straight line was achieved.



Graph 6.9a: Calibration graph of Cube Strength against Pulse Velocity for Sand "X" Cubes.



Graph 6.9b: Calibration graph of Cube Strength against Pulse Velocity for Sand "Y" Cubes.

In graphs 6.9 a & b;

Point P represents strength-velocity calibration with 7 day specimens.

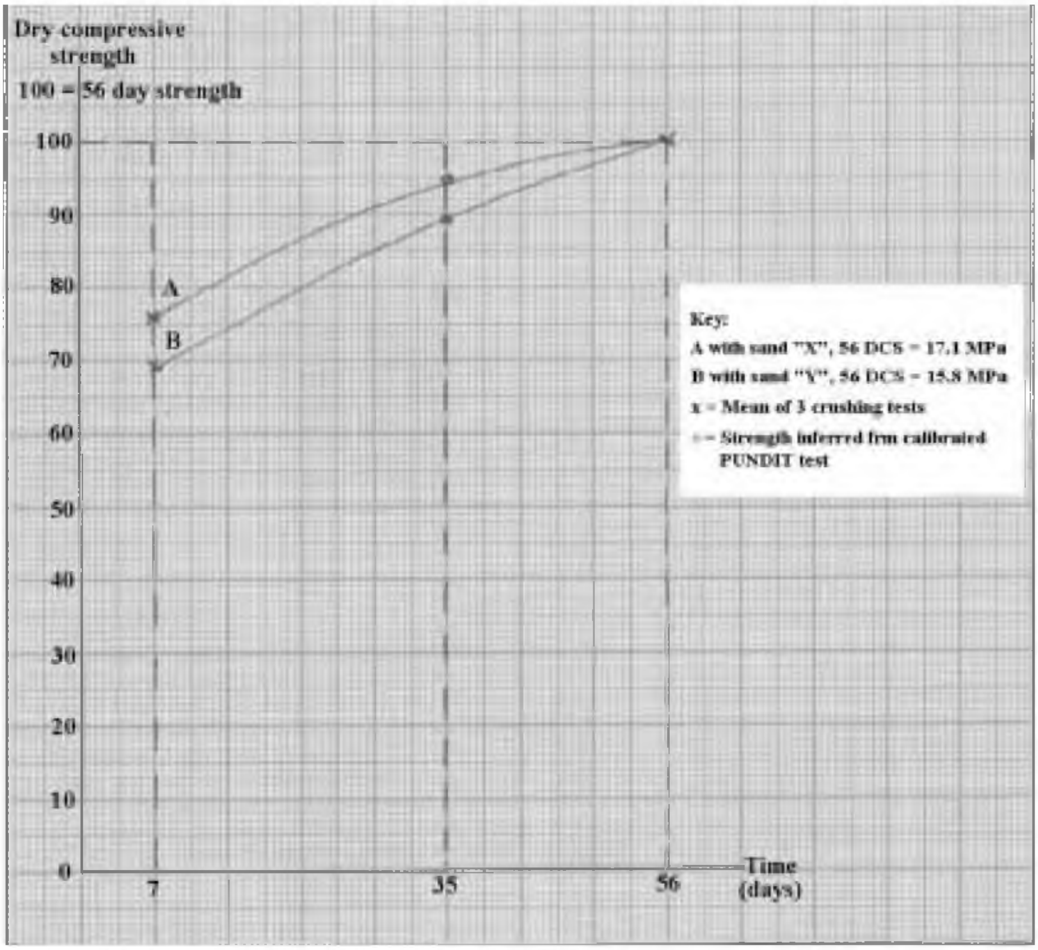
Point R represents strength velocity calibration with 56 day specimens.

Point Q is the inferred strength from the velocity measured at 35 days.

The graphs show the range of results so the line could have been drawn at any angle through the plotted lines. This shows there is some variation in results, especially in the pulse velocities, so the line of best fit has been drawn. The dotted lines on the graphs show the pulse velocity readings at 35 days, where no cube strength was measured. The predicted cube strength at this age is 16.4 MPa for the Sand “X” cubes and 13.1 MPa for the Sand “Y” cubes.

As it can be seen from both sets of results the degree of hydration increases with age, leading to the effect of age on strength. But, the hydration reactions are never complete, and in the presence of moisture, concrete will continue to gain strength for many years, although the rate of increase after such times will be very small.

The following graph, figure 6.10, shows the dry compressive strength development over a period of 56 days. Curve A shows the strength development of the concrete made with the poor sand “X”, and curve B is plotted for the good sand “Y”.



Graph 6.10: Graph showing the development of dry compressive strength over time

This graph shows that concrete made with sand "X" has a higher initial strength at 7 days, but has a slower development of strength to 56 days than sand "Y". Concrete made with sand "Y" has a greater development of strength over a period of 56 days. This implies that if both types of concrete were left for many years, it could be possible that concrete made with sand "Y" could eventually develop a higher dry compressive strength than sand "X".

This graph can also be used to obtain a factor by which to multiply the 7 day dry compressive strength results to obtain 'standard' 28 day characteristics. In concrete literature, it is more usual to specify the 28 day strength rather than 35 days, but as stated previously vacation timing did not allow the 28 day readings to be taken. The graph implies that for concrete made with the good sand "Y", the 28 day strength is a 1.16 times more than the 7 day strength, implying that the 28 day strength is 12.64

MPa. For the concrete made with sand "X", the 28 day strength is 1.06 times more than the 7 day strength, implying that the 28 day strength is 13.78 MPa.

6.2 Shrinkage / Swelling

6.2.1 Drying Shrinkage

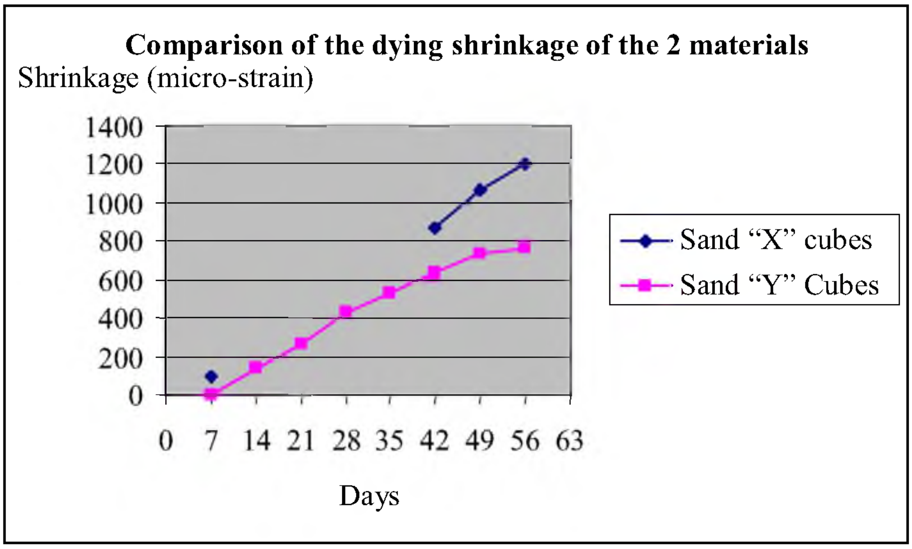
During the curing period of 56 days the shrinkage was measured. The specimens that were tested were ones that were made using the optimum water-cement ratio and using all other suitable conditions as described earlier. These specimens produced the following results:

		Total Curing Shrinkage (in μ-strains) after								
Sand "X" Cubes	Block Number	7 days	14 days	21 days	28 days	35 days	42 days	49 days	56 days	Direction of Movement
Dry cured	3	100	holiday	holiday	holiday	900	1100	1200	1300	Shrinkage
Dry cured	6	100	holiday	holiday	holiday	600	800	900	1000	Shrinkage
Dry cured	9	100	holiday	holiday	holiday	600	700	1100	1300	Shrinkage
Wet cured	16	-100	holiday	holiday	holiday	-500	-600	-700	-800	Swelling

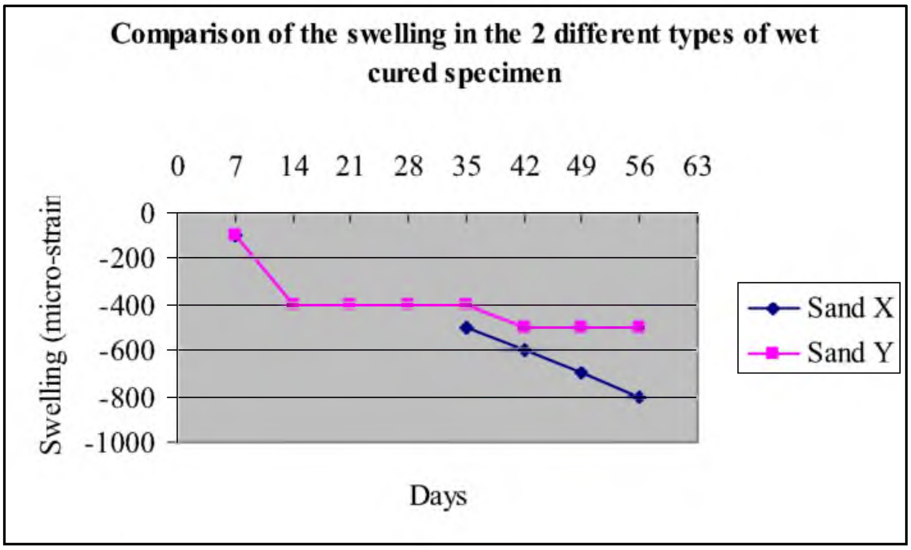
Table 6.11a: Drying Shrinkage during Curing in Sand "X" Cubes

		Total Curing Shrinkage (in μ-strains) after								
Sand "Y" Cubes	Block Number	7 days	14 days	21 days	28 days	35 days	42 days	49 days	56 days	Direction of Movement
Dry cured	3	0	100	200	400	500	600	700	700	Shrinkage
Dry cured	6	0	200	300	500	600	700	800	800	Shrinkage
Dry cured	9	0	100	300	400	500	600	700	800	Shrinkage
Wet cured	16	-100	-400	-400	-400	-400	- 500	-500	-500	Swelling

Figure 6.11b: Drying Shrinkage during Curing in Sand "Y" Cubes



Graph 6.11c: Graph showing the drying shrinkage of the dry cured specimens for the two materials.



Graph 6.11d: Graph showing the comparison of the swelling for the two different wet cured specimens.

Measurements have been converted into micro-strain using:

$\mu\text{-strain} = \frac{\delta l}{l} \times 10^6$, l is in millimetres

Measurements to the nearest 10 microns

Only four dial gauges could be set up for each type of concrete, since the department did not have any others that could have been used over a long period of time. This means that there could be some error in the wet cured specimens, as there were no other results to compare them with. Some measurements for the Sand "X" cubes were missed due to the Christmas vacation, and unfortunately, this could not have been avoided.

Analysing these results shows that the dry cured concrete made with sand "X" has shrunk 56.7 % more than the concrete made with sand "Y". The wet cured specimens *unexpectedly* swelled upon curing, visibly absorbing the water that it was curing in. The concrete made with sand "X", the poor quality sand, swelled 300μ-strain more than material "Y".

Shrinkage is influenced by the aggregate, which restraints the amount of shrinkage of the cement paste that can actually be realised in the concrete. The maximum size of grading of aggregate does not influence the magnitude of shrinkage of the concrete with a given volume of aggregate and a given water-cement ratio. However, larger aggregate permits the use of a leaner mix at a constant water-cement ratio, so that larger aggregate leads to lower shrinkage. This is a likely explanation of the results, since the Sand "X" cubes consisted of a larger amount of smaller particles and more water, hence shrunk more upon dry curing than the Sand "Y" cubes.

The likely mechanism that could explain these results involves complicated soil mechanics theory, and more detailed information can be found in Mitchell, 1993, "The Fundamentals of Soil Behaviour". A basic explanation of the results is provided below.

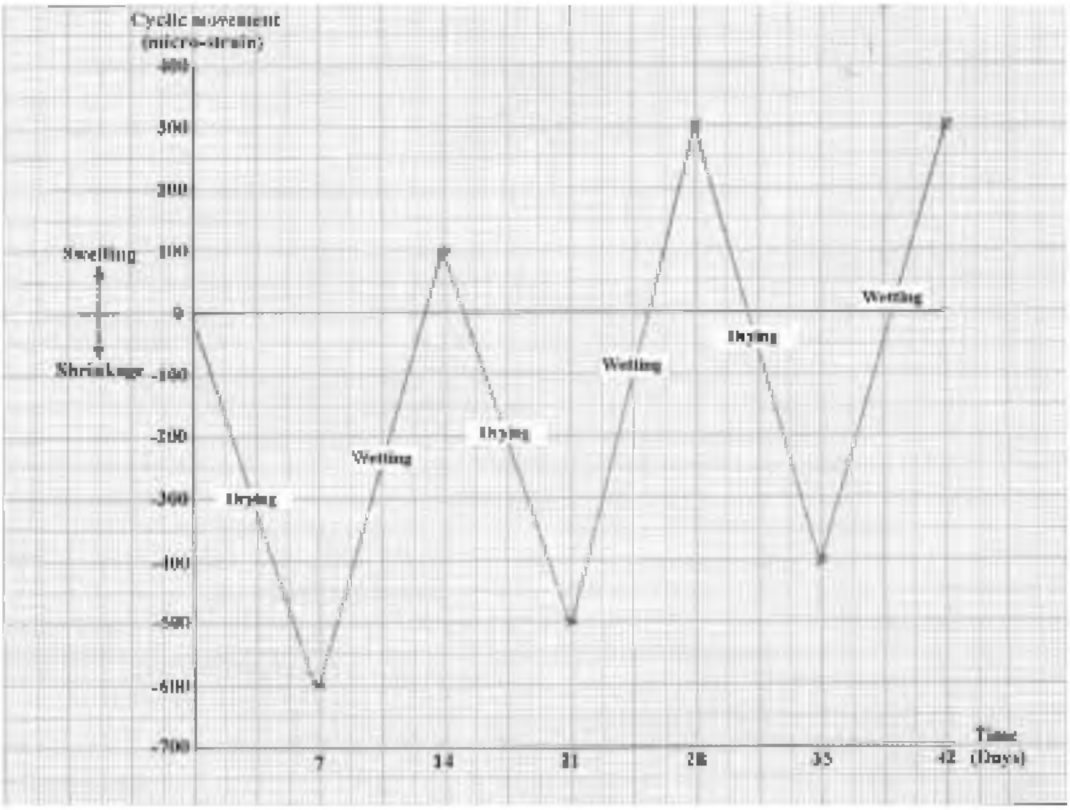
"The high clay fraction in the material being tested means there is a high proportion of small particles having surface electrostatic charges to which a layer of water becomes attached", (Spence and Cook, 1983).

As the saturated clay in the concrete is dried it shrinks, with capillary tension in the pore water balancing the pressure between the clay particles, and the friction caused by the pressure gives the clay a degree of cohesion. The difference in pressure between the pore water and the surrounding atmosphere is balanced by surface tension which can be considerable if the diameter of the pores is very small. Beyond a certain point, further drying causes no reduction in volume because the bulk of the water is removed, but the particles are held tightly together by small water droplets at their points of contact. When such a dried concrete is then wetted, water is absorbed into empty pores in the body of the clay and the capillary suctions are reduced, allowing the clay to soften rapidly as the pressure between the soil grains is reduced, and also to swell.

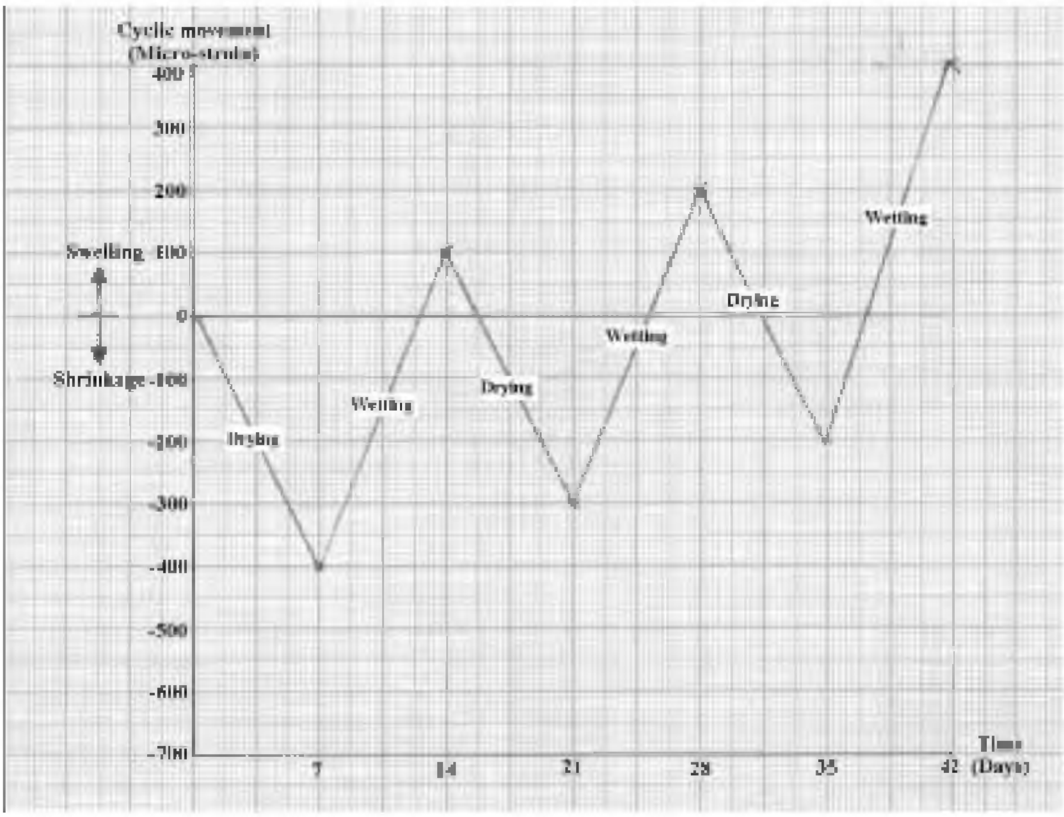
These results are not conclusive for this type of concrete since there is a considerable complication in interpreting and comparing drying shrinkage measurements. Although all the specimens tested were of the same size, the actual size of the specimen will affect the result. Water can only be lost from the surface and therefore the inner core of the specimen will act as a restraint against overall movement; the amount of restraint and hence the measured shrinkage will therefore vary with specimen size.

6.2.2 Cyclic Movements

After 56 days, the cubes were wetted for 7 days, then placed in a drying oven for 7 days, and underwent this cyclic process for three cycles. This was done on both types of concrete, and the results are shown in figures 6.12a and 6.12b.



Graph 6.12a: Cyclic shrinkage of concrete made with sand "X".



Graph 6.12b: Cyclic shrinkage of concrete made with sand "Y".

The results show that drying and wetting cycles result in more or less completely reversible shrinkage. Shrinkage after the concrete has solidified continues as and when further water evaporates. The chemical reaction of cement with water, and thus the shrinkage, continues in the concrete seemingly indefinitely. A gel is formed which contracts upon desiccation and becomes very hard. If the concrete is submerged in water the cement gel expands with considerable force, so that the whole mass of the concrete expands. This expansion, however, can never equal the shrinkage which has already taken place. On drying the concrete in air shrinkage again occurs. Therefore, when concrete is subjected to continual wetting and drying, it experiences corresponding expansions and contractions.

The concrete made from the good sand, sand "Y" has smaller cyclic movements than that of the concrete made with sand "X". Sand "X" has movements of ± 800 μ-strains, whereas sand "Y" has movements of ± 500 μ-strains. These results were expected since the extra fines in sand "X" were expected to absorb water every time the concrete was submerged in water, as well as the cement gel expanding.

7 Discussion

The high fines content in the concrete produced with sand "X" *enhanced* the dry compressive strength implying that fines in sand for fabricating concrete is not problematic. A higher strength of 12.1 MPa indicates that this type of concrete would be suitable for many applications of building in developing countries. Typically the range of concrete strengths is between 10-70MPa, so although the concrete made with sand "X" has a strength of 12.1 MPa, it is at the lower end of the range. Care should be taken when using this material for high strength applications, such as reinforced concrete columns in tall buildings.

Although this type of material seems advantageous as a building material due to its strength, shrinkage experiments produced contradictive results. 'Normal concrete' usually shrinks between 300-600 μ-strains in one year of drying, but the concrete made from sand "X" shrunk 1300 μ-strain in 56 days. This drying shrinkage was larger than an estimated value of 720 μ-strains, probably due to a bigger effect of the fines. This is not necessary a problem in itself since concrete in compression can withstand 2000 μ-strains. The major problem occurs when the concrete is in tension as it can only withstand 200μ-strains and material "X" expanded by 800μ-strains, four times greater than the tolerable amount.

So, when determining whether this material is suitable for applications of concrete, these shrinkage movements need to be considered. For pre-made concrete blocks, providing the drying shrinkage has already occurred, it is expected that these concrete blocks can be used. Care needs to be taken if they are expected to experience continual wetting and drying since the cyclic movement is ± 800μ-strains, and cracks are likely to occur.

Brickwork in compression is expected to withstand about 600 μ-strains and in tension 200 μ-strains. It is therefore not advisable to use this material for brickwork as the movements are too great despite the good strength value. If it is necessary to use this material "X" for bricklaying, then the wall should be built in small sections, maybe one metre per day, without expansion joints.

This material is suitable for non water-proof renders since the drying shrinkage of 1200 μ-strains can be tolerated as concrete in compression can withstand up to 2000 μ-strains. If the cracks are about one metre apart and unrelieved the rendering will look acceptable. It is not advisable to use this material as a water-proof render since when the material is in tension it will fail. The material can only withstand 200μ-strains in tension whereas the cyclic movement is $\pm$ 800μ-strains.

Shrinkage in steel reinforcement concrete can be a maximum of 600μ-strains which indicates that it would not be advisable to use this material. Large cracking would occur, causing a dangerous structure. Fortunately, this material "X" can be used for lintels since it is common practice to leave a gap in the mortar at both ends to allow it to expand and contract with cracking. Therefore, the gap can be made large enough to accommodate the cyclic movement of $\pm$ 800μ-strains in material "X".

8 Future Work

This report concentrates on two main factors only, strength and shrinkage. There are many other properties of concrete that can be specified, but the duration of this project limited the amount of factors that could be investigated. Although the large shrinkage and swelling movements of the concrete tested limits its use in the building industry, it does have a better compressive strength, so other research could be carried out on this 'low quality' concrete to identify other properties that can be improved. It is expected that the examination of 'poor quality' sand in concrete and how to improve the quality will be carried out by other third year project students in the future.

9 Conclusions

The purpose of this project was to investigate the affect fines have on the properties of concrete. Initial results showed that making concrete with sand with a ‘high fines’ content *unexpectedly* increases the strength of concrete. Material “X”, made with poor quality sand, was tested for its dry compressive strength and its optimum water-cement ratio of 0.95, mixing time of 5 minutes and vibration compaction time of one minute. This material exceeded the expectation that its seven day dry compressive strength would be approximately 9.6MPa, and was instead 12.1MPa. Since concrete strength used for building purposes lies within 10-70MPa, material “X” has a suitable dry compressive strength.

Despite the suitable dry compressive strength, it has been discovered that the use of this material will be hindered due to its large cyclic movements and drying shrinkage of approximately $\pm 800\mu$-strains and 1300μ-strains respectively. Due to the restricted sample sizes the accuracy of the results from the material testing may be limited. The purpose of testing was to get approximate values for the strength and the shrinkage, since testing under conditions in the developing world may produce different results.

This project supports the statement published in British Standard, BS 812, that sand with a ‘high fines’ content is unsuitable for making good quality concrete, but sand “X” is suitable for some applications in developing countries where operations are basic and money is short. It can be used for concrete and mortars in unconstrained applications such as block making and lintels and in situations where the material does not undergo cyclic movements, such as non water-proof rendering. If this material is used for applications such as bricklaying then the wall should be built in small sections, maybe one metre per day, without expansion joints.

There are many other properties of concrete, other than strength, drying shrinkage and cyclic movements that can be specified, but the duration of this project limited the amount of factors that could be examined. It is expected that other research in this field will be carried out to improve the quality of concrete made with ‘high fines’ sand, possibly by washing it, as the original project suggested.

10 List of References

Attwood, G. & Dyer, G., *Statistics 2*, 1st Edition, Heinemann, 1995, pp. 47.

Akroyd, T. N. W., *Concrete: Properties and Manufacture*, 1st Edition, Pergamon Press Ltd., 1962, pp. 100 & 177.

BS 12: 1978: *Ordinary and Rapid Hardening Portland Cement.*

BS 812: Part 1:1975: *Sampling, shape, size and classification.*

BS 1881: Part 3: 1970: *Methods of Making and Curing Test Specimens.*

BS 1881: Part 115: 1983: *Specification for Compression Testing Machines of Concrete.*

BS 1881: Part 116: 1983: *Method for the Determination of Compressive Strength of Concrete Cubes.*

BS 1881: Part 202: 1986: *Measurement of the Velocity of Ultrasonic Pulses in Concrete.*

BS 5497: Part1: 1979: *Guide for the Determination and Repeatability and Reproducibility for a Standard Test Method.*

Bungey, J. H. & Millard, S.G., *Testing of Concrete Structures*, 3rd Edition, Blackie Academic and Professional, 1996, pp. 49.

Elvery, R.H., *Ultrasonic Testing of Concrete – Te Use of the PUNDIT,* 1972, pp. 13.

Illston, J.M., *Construction Materials*, 2nd Edition, Chapman and Hall, 1994, pp. 155-157, 129-132.

Kesler, C. E., *Significance of Tests and Properties of Concrete and Concrete Making Materials*, ASTM STP No. 169-A, Philadelphia, 1996, pp. 1044-1052.

Lydon, F. D., *Developments in Concrete Technology*, 1st Edition, Applied Science Publishers Ltd., 1979.

Mitchell, J. K., *Fundamentals of Soil Behaviour*, 2nd Edition, John Wiley and Sons, 1993, pp. 177, 302-303.

Neville, A. M. & Brooks, J. J., *Concrete Technology*, 2nd Edition, Longman Group Ltd., 1990, pp. 74, 179.

Popovics, S., *Strength and Related Properties of Concrete: A Quantitative Approach*, 1st Edition, John Wiley and Sons, 1998, pp. 2, 221.

Spence, R. J. & Cook, D. J., *Building Materials in Developing Countries*, 1st Edition, John Wiley and Sons, 1983, pp. 36, 191-206.

Stulz, R. & Mukerji, K., *Appropriate Building Materials: A Catalogue of Potential Solutions*, 3rd Edition, Skatt Publications & IT Publications, 1988, pp. 6-8.

Teychenne, D. C, Franklin, R. E., & Erntroy, H. C., *Design of Normal Concrete Mixes*, 1st Edition, Building Research Establishment Report, 1988, pp. 1-11.

Young, J. F. & Gray, R. J., *The Science and Technology of Civil Engineering Materials*, 2nd Edition, Prentice Hall, 1998, pp. 194-197.

11 Glossary

Many terms have different meanings for different applications. The definitions used in this report are:

Aggregates: A granular material obtained by processing natural material.

Clay: It is the fraction of a soil composed of particles smaller than 0.002 mm in size.

Concrete: The essential ingredients of concrete are cement, aggregate (sand and gravel), and water. When mixed in carefully prescribed proportions, they produce a workable mass, which can take the shape of any formwork into which it is placed and allowed to harden in.

Fines: Any solid material passing a 75µm sieve.

Grading: Particle size distribution.

Sand: The fraction of soil composed of particles between the sizes of 2mm and 0.06mm, i.e. the smallest grain size than can be discerned by the naked eye.

Silt: The fraction of a soil composed of particles between the sizes of 0.06mm and 0.002mm.

Appendix A1
Letters of Correspondence

62 Kingsway,
Leamington Spa,
Warwickshire,
CV31 3LE.

Smith and Sons (Bletchington) Ltd.,
Enslow,
Kialington,
Oxon.
OX5 3AY

29.9.01

Dear Sir / Madam,

I am a penultimate year student at Warwick University studying Design Engineering. This year of study involves me undertaking a large project in which I will be developing an effective method of, or a machine for improving sand, possibly by washing it, to make it more fit for use in making concrete or mortar.

Although the design task I face is looking at a method that will be compatible for operations, finances and normal sand sources of a builder in Africa, it would be useful to find out about the current methods in the UK as research for this project. It could also be interesting to find out whether the current methods in the UK could be improved in terms of cost and efficiency. I was hoping that your company would be able to assist me in this process. I would be very grateful if I could visit your company for part of a day in the near future for a brief discussion with somebody concerning the methods that are used.

Due to this project only running over the course of one academic year, the time scale for me to develop my ideas is short. I would therefore appreciate it if you could contact me as soon as possible if you are able to help. If this is not possible, it would be very much appreciated if you could send me some names and addresses of other companies that may be able to assist me.

My email address is vicky.fernandes@vizzavi.net and my telephone number is 07833 970966.

Thank you very much for your time in reading this letter, and I hope to hear from you in the near future,

Yours Faithfully,

MISS VICKY FERNANDES
3rd Year Engineering Design Student, Warwick University.

SMITHS
BLETCHINGTON

Smith and Sons

Miss Vicky Fernandes,
62 Kingsway,
Leamington Spa,
Warwickshire,
CV31 3LE

Our Ref: rsb/gm/sitevisit001

Tuesday 2nd. October 2001

Dear Miss Fernandes,

Re: <u>Site Visit to Gill Mill Quarry, Witney.</u>
<u>Study of Sand Plant Operations.</u>

I am in receipt of your letter to our Head Office of 29th. September and it has been passed to me to see if I can assist you. This site has a 200 tonnes per hour sand and gravel washing plant and has recently installed a new sand recovery plant which is highly efficient in addition to having a sand cyclone tower for fine sand production.

However, I have considerable experience with which I may be able to advise you. I am an Engineer with HNC's in Marine and Mechanical Engineering, I am a Fellow of the Institute of Quarrying and I have spent a considerable period of my life working overseas in Africa, the Middle East and the Pacific and am very familiar with Third World conditions and materials.

I am enclosing an Indemnity Form which I would be obliged if you could fill in and return to me as soon as possible. Perhaps you would call me on 01993 779514, Fax 01993 779383, to discuss a timetable. The site address is on the top of the Indemnity Form.

I am looking forward to hearing from you.

Yours Sincerely,
Smith and Sons (Bletchington) Ltd..

Robert S. Bacon
Production Manager

62 Kingsway,
Leamington Spa,
Warwickshire,
CV31 3LE.

Smith and Sons (Bletchington) Ltd,
Mr. R. Bacon,
Gill Mill Quarry,
Standlake Road,
Ducklington,
Nr. Witney,
Oxon. OX8 7PP.

17.10.01

Dear Mr. Bacon,

Thank you very much for your knowledge and time spent helping me on my research project. It really helped my understanding of the processes you use to improve the quality of your sand, and your added experiences of developing countries has given me a better idea of what type of cleaning methods I will need to develop.

Thank you again for all your help and advice, it was very much appreciated.

Yours Sincerely,

MISS VICKY FERNANDES.

Appendix A2
Sedimentation Test (Syphon)

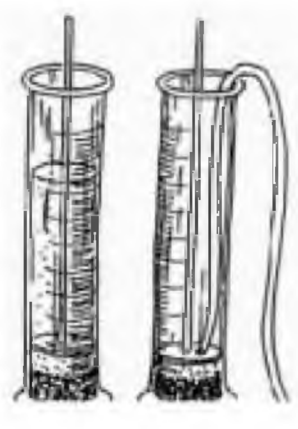
Sedimentation Test (Syphon)

A material from Gill Mill Quarry in Witney in Oxfordshire was tested for its silt content. This was done to see whether the material contained enough silt, to represent a silt content for the sand chosen to be tested.

The test used was adapted from a similar test described in the University of Warwick's working papers. The working paper used was number 38, written by Mr. D.E. Gooding called "Soil Testing for Soil-Cement Block Preparation, 1993".

Equipment: 1 Flat bottomed glass jar, approximately 1 litre capacity.
1 Flat circular disk on a stem such that it may be lowered into the cylinder.
1 Flexible rubber siphon tube to remove suspended material from the cylinder.
1 Stopwatch or clock.
1 Weighing balance accurate to at least 0.1g, preferably 0.01g.
1 Heat proof container to receive the syphoned suspension.

Method: Weigh out a representative 60g sample of dry soil and place it in the cylinder. Add clean water to 200mm. Close the cylinder with a rubber bung and shake vigorously end over end to produce a uniform suspension of soil. Once a uniform suspension has been formed place the cylinder on a flat steady level surface and begin to time 20 minutes.



At the end of 20 minutes slowly lower the disk to cover the settled material, taking care not to disturb it. The top layer of material is silt. (It the disk is allowed to rest on the surface then some silt will be forced up around the edge of the disk. Any silt forced back into suspension will give a misleading low value for the silt fraction). The remaining suspended material can be siphoned off with the rubber siphon tube. The siphon operation is simpler to perform if the tube is tied to the stem just above the upper face of the disk. This stops the tube from floating or curling.

The material remaining in the jar is the silt fraction, so is put in a heat proof dish, and is dried. It is then weighed and recorded as the silt and sand fraction. These two materials are further separated by dry sieving. The material passing the 0.063mm sieve is the silt fraction.

Results: Mass = 60g

Clay fraction = (weight of container + clay) – weight of container

= (313.03 - 275.07) + (268.25 – 257.86)

= 49.12g

Sand and Silt fraction = (weight of container + silt) – weight of container

= 324.60 + 314.49

= 10.88g

After dry sieving:

Sand fraction = 4.90g

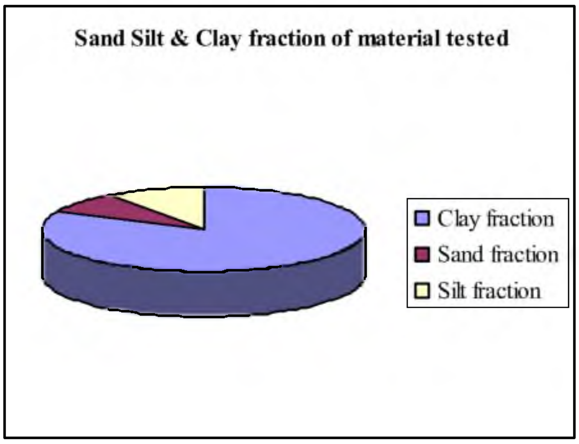
Silt fraction = 5.98g

Results as a percentage:

Clay fraction = 81.9%

Sand fraction = 8.2%

Silt fraction = 9.9%



These results showed that there was only 9.9% of silt present in the material, and hence not a good source of silt to use for my project. This material was rejected, and it was decided that Kaolin, a type of clay, would be used to represent fines, and no other silt would be added.

Appendix A3

Statistical Analysis on Water-Cement Ratios

Statistical Analysis on Water-cement Ratios

Sand "X" Mix	Maximum load (kN)								
Water-cement Ratio	Block 1	Block 2	Block 3	Mean Maximum Load (kN)	Mean Pressure, x (MPa)	n	σ	x_1-x_2	z
0.53	78.2	78.1	78.4	78.2	7.8	3	0.0152	-3.4	-200.69
0.7	112.1	112.6	112.4	112.4	11.2	3	0.0251		
0.8	113.4	113.5	113.2	113.4	11.3	3	0.0153	-0.3	-20.64
0.85	116	115.8	116.2	116.0	11.6	3	0.02		
0.9	117.8	117.5	117.4	117.6	11.8	3	0.0208	-0.1	-6
0.92	119.1	119.5	119.3	119.3	11.9	3	0.02		
0.95	122.2	120.1	121.1	121.1	12.1	3	0.105	0.4	6.53
1.06	117.5	117.3	117.2	117.3	11.7	3	0.0153		
1.14	80.9	80.5	80.7	80.7	8.1	3	0.02		

Sand "Y" Mix	Maximum load (kN)								
Water-cement Ratio	Block 1	Block 2	Block 3	Mean Maximum Load (kN)	Mean Pressure, x (MPa)	n	σ_{n-1}	x_1-x_2	z
0.53	62.1	61.1	57.1	60.1	6.0	3	0.2646	-2	-13.07
0.6	80.2	80.5	80.4	80.4	8.0	3	0.0152		
0.65	107.7	107.3	107.9	107.6	10.8	3	0.0306	-0.2	-8
0.7	110.1	109.9	110.5	110.2	11.0	3	0.0306		
0.8	108	107.8	108.1	108.0	10.8	3	0.0153	2.9	122.9
0.95	79.9	79.3	79.2	79.5	7.9	3	0.0379		

Statistical Analysis can be performed on any two sets of results. This appendix only compares results next to each other in the table.

The null hypothesis is

$H_0 : x_1 = x_2$ $\qquad$ $H_1 : x_1 \neq x_2$

$$Z = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}\right)}}$$

The 5% (two tailed) critical values for z are $Z_{95} = \pm 1.96$.

It can be seen that all results are statistically significant since they are larger than 1.96, so H_0 can be rejected. It can be concluded that there is significant evidence of a difference in means between each set of results.

Appendix A4

PUNDIT Test Readings

Appendix A5

Cube Strength versus Pulse Velocity

Cube Strength (MPa) versus Pulse Velocity (km/s)

Type of concrete	Cube Strength MPa		Pulse Velocity km/s	
	Range	Mean	Range	Mean
Sand "X" Cubes	12.01-12.22	12.12	2.77-2.88	2.83
	17.52-17.6	17.07	3.17-3.27	3.22
Sand "Y" Cubes	10.99-11.05	11.02	2.69-2.74	2.72
	14.92-15.04	14.92	3.00-3.09	3.05