JUNIOR SCIENCE RESEARCH PROJECT

STRENGTH OF CONCRETE WITH DIFFERENT RATIOS OF SAND TO CEMENT

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Background Information

Introduction – Topic Choice – Identified Problem in Society

The importance of concrete in society cannot be overestimated. Concrete plays a vital part in a functioning society. Its benefits to society are immense, being used to build buildings, roads, bridges, tunnels, dams, sewerage systems, pavements, runways and more.

Concrete is the most used man-made material in the world, with nearly three tons used annually for each man, woman and child. Twice as much concrete is used around the world than the total of all other building materials, including wood, steel, plastic and aluminium. None of these other materials can replace concrete in terms of effectiveness, price and performance for most purposes.

Within the construction industry it is important to develop products and systems that can be used to construct more durable, energy-efficient eco-buildings that are economical cost efficient and easily mass produced globally, concrete is such a material. This can be attributed to concretes key properties which are its strength, durability and excellent thermal mass.

Concrete is a composite material which is made up of filler and a binder. The binder (cement paste) "glues" the filler together to form a synthetic conglomerate. The constituents used for the binder are cement and water, while the filler can be fine or coarse aggregate such as sand. The role of these constituents form the basis of this experiment, which aims to identify that the ratios of these constituents need to be right if the concrete is to achieve its key properties of strength, durability and excellent thermal mass.

Concrete Overview

Concrete is a man-manufactured material. It contains various proportions of different materials and is therefore categorised as a composite material. Its primary materials consist of Portland cement, coarse aggregates, sand, water and a limited portion of air.

Portland cement consists of finely pulverized matter produced by burning mixtures of lime, silica, alumina, and iron oxide at about 1,450°C. The rigidity, setting process and strength of concrete is achieved when the various components of the Portland cement react with the added water and the chemical reactions that take place (Lerner, 2008). (Further detail is included in the Portland cement section page 8). While cement is a construction material in its own right, concrete cannot be made without cement. The two terms often are incorrectly used interchangeably, but concrete and cement are distinctly separate products.

Concrete contains many different characteristics and materials that depict its strength such as the type and quantity of arrogate used; and the methods in which the concrete is produced. The water-cement ratio determines the overall characteristics of the concrete. The quantity of cement in comparison to the aggregate is another factor that determines the concretes durability and strength. The overall strength and durability can also be affected by various environmental factors these include humidity and temperature (Encyclopædia Britannica, 2013).

Strengthening the tension of concrete is achieved by placing steel mesh or bars into the concrete mould and pouring concrete around it, this process is referred to as reinforced concrete (Lerner, 2008).

Reinforced concrete enhances the tensile strength of the material and usually consists of imbedded metal that is placed were stress is anticipated. Reinforced concrete can withstand harder conditions such as wind action, earthquakes, vibrations and other tensile affecting forces.

Prestressed concrete renders the ineffective and disadvantageous stretching forces that would commonly break concrete. This is achieved by compressing an area to the extent to where no tension is experienced until the strength of the compressed section is overcome. This is used to create lighter, shallower and elegant structures such as bridges and vast roofs. Due to concretes strength and its fire resistance it has become one of the most frequently used construction materials (Encyclopædia Britannica, 2013).

Concrete is the most vastly used construction material as it is cheap to produce and extremely strong. Concrete is used to build highways and streets, buildings, bridges, dams, aqueducts, airport runways, irrigation structures, piers, sidewalks, and farm buildings and various other structures.

Concrete is also an extremely durable option as it lasts for prolonged periods of time, for example the ancient Egyptians erected many structures created with concrete that still stand today after 3,500 years (Lerner, 2008).

Concrete is produced worldwide and the global market is extremely strong. China is the largest producer of concrete producing one third of the total amount and consuming forty per cent of it annually.

Overview Properties and Characteristics of Concrete

Physical Properties of Concrete

Concrete's properties make it the building material of choice for most purposes. The table below lists the most important features of concrete.

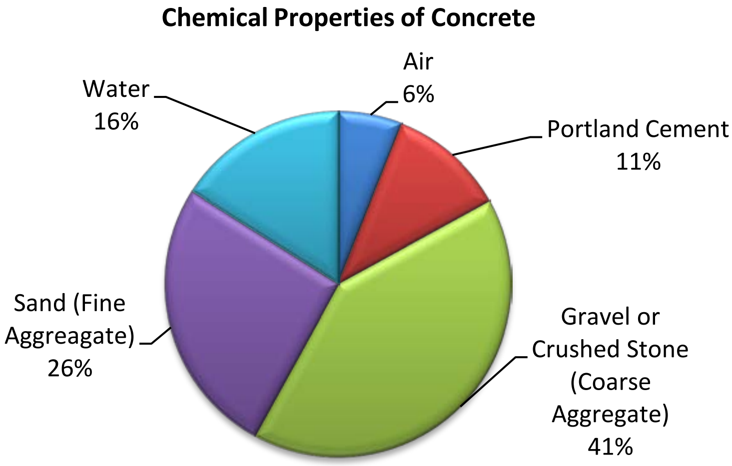
Table 1: The Various Properties of Concrete

Properties of Concrete	Characteristic and Purpose
Strength and Durability	Due to its strength it is used to create the majority of buildings, bridges, tunnels and dams Gains strength over time Not weakened by moisture, mould or pests Concrete structures can withstand natural disasters such as earthquakes and hurricanes Roman buildings over 1,500 years old such as the Coliseum are examples of the strength and durability of concrete
Versatility	Is used to build a variety of structures such as buildings, bridges, dams, tunnels, sewerage systems pavements, runways and even roads
Low maintenance	Concrete, being inert, compact and non-porous, does not attract mould or lose its key properties over time
Affordability	Compared to other building materials, concrete is cost effective especially considering its various other positive properties
Fire-resistance	Concrete provides a medium to stop fire spread as it is highly fire-resistant
Thermal mass	Concrete reduces temperature swings as walls and floors made with concrete slow the passage of heat movement
Albedo effect	Albedo is the reflective qualities of concrete. This means that light is reflected off building walls and pavements meaning that less heat is absorbed thus ruling out the need for cooling devices such as a air-conditioner

Source: http://www.wbcsdcement.org/index.php/key-issues/sustainability-with-concrete/properties-of-concrete

The figure below displays the mixed components found in concrete.

Figure 1: The internal properties of the mixed components in concrete



Source: http://www.cement.org/basics/concretebasics_concretebasics.asp

Concrete States

Plastic state: This state is the original mixing state where the mixture resembles bread dough. In this state concrete can be easily mixed and formed into shaped moulds. The plastic state occurs during the placing and compaction steps of creating concrete. The mixture should not have a water content that allows it to be poured it should be able to be placed in moulds and forms.

Setting state: This state occurs when concrete begins to harder and stiffen. This process of stiffening is known as setting. The setting state occurs after compaction and during finishing.

Hardening state: This state occurs after the concrete begins to set. In this process concrete begins to harden and gain strength (Cement Concrete and Aggregates Australia, 2004).

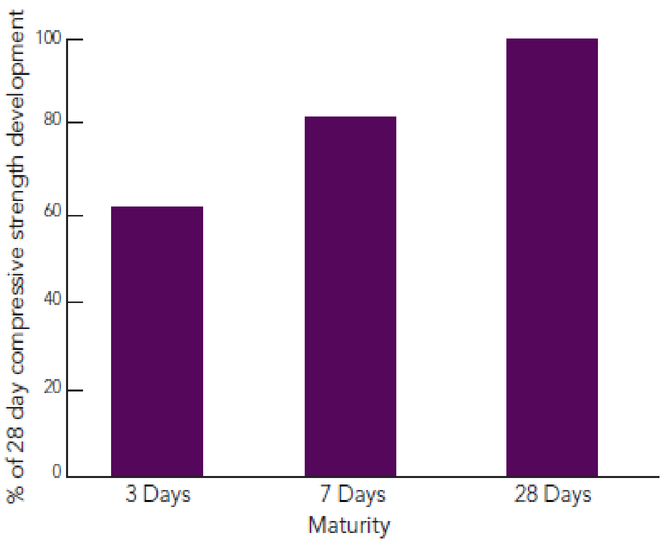
Compressive Strength

Concrete is designed to consist of various durability properties to meet the design requirements and guidelines of a certain structure or product. The compressive strength is the most important structural property considered by developers. The compressive strength is the maximum load or force a structure can sustain until it fractures or breaks.

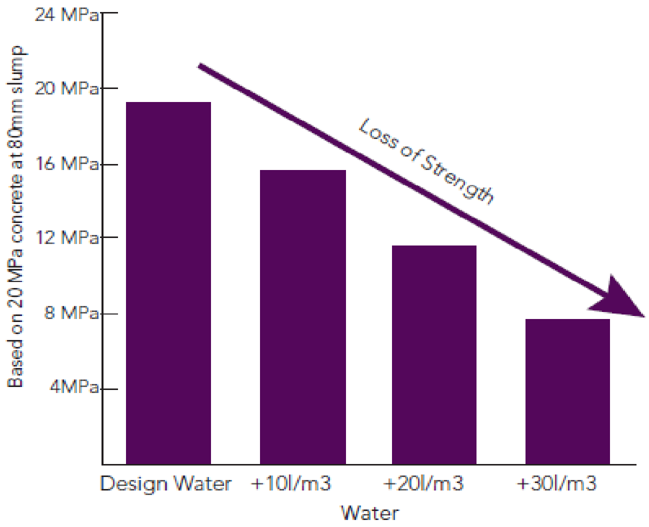
Strength development is affected by a number of factors, these include:

- Environmental conditions;
- Water to cement ratio;
- Physical and chemical properties of the cement; and,
- Curing (Cement Australia, 2012).

Graph 2: Development of the compressive strength concrete over time.



Graph 1: Representation of the effects of excess water on compressive strength



Source: http://www.cementaustralia.com.au/wps/wcm/connect/website/packaged-products/resources/0f30f68046152743947995b796eb3285/PDS-GP-Rev-3-170212.pdf

Portland Cement

Overview

Cement is used in concretes and mortars and is used as a binding agent. The term Portland is generalised term and is primarily used to describe the variety of different cements with their different properties. Portland cements are recognised as hydraulic cements. This means that the cement reacts chemically with water gradually increasing its strength and hardness.

Chemical Properties

Portland cement contains finely pulverized matter produced by burning mixtures of lime, silica, alumina, and iron oxide at approximately 1,450°C.

Portland cement contains a mixture of calcium aluminium silicates also known as clinker. During the manufacturing process of cement, limestone, clay and shale are mixed in a kiln at very high temperature to produce clinker. Clinker primarily contains calcium aluminates and calcium silicates:

- Tricalcium silicate (3CaO × SiO2)
- Dicalcium silicate (2CaO × SiO2)
- Tricalcium aluminate (3CaO × Al2O3)
- Tetra-calcium aluminoferrite (4CaO × Al2O3Fe2O3)
    - The abbreviated notation of these compounds that does not consist of atomic symbols is as follows: C3S, C2S, C3A, and C4AF
        - C stands for calcium oxide (lime)
        - S for silica
        - A for alumina
        - F for iron oxide.
- It may also contain:
    - Un-combined lime magnesia, alkalies and small amounts of other elements (Encyclopædia Britannica, 2013)

The table depicts the percentages of major and minor chemical compounds found in Portland cement.

Table 2: Composition of Portland cement

Cement Compound	Weight Percentage	Chemical Formula
Tricalcium silicate	50 %	Ca_3SiO_5 or $3CaO{\cdot}SiO_2$
Dicalcium silicate	25 %	Ca_2SiO_4 or $2CaO{\cdot}SiO_2$
Tricalcium aluminate	10 %	$Ca_3Al_2O_6$ or $3CaO{\cdot}Al_2O_3$
Tetracalcium aluminoferrite	10 %	$Ca_4Al_2Fe_2O_{10}$ or $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$
Gypsum	5 %	$CaSO_4{\cdot}2H_2O$

Source: http://matse1.matse.illinois.edu/concrete/prin.html

Structural Properties

The overall strength of Portland cement is affected by the composition and the fineness to which it is ground. During the period of the first week of the hardening stage of the C3S is mainly responsible for the strength that is developed. The C2S contributes to the strengthening process that occurs after the C3S stage.

Natural, artificial, and chemical agents are all factors that cause the cement deterioration. Chemical attacks greatly affect the alumina compound as soils contain sulphate slats, the compounds of iron and calcium silicates are more resistant to these types of attacks.

During the process of hydration (further explanation found in the *Cement Hydration* section page 12) calcium silicates release calcium hydroxide that is also vulnerable to attack.

During hydration cement emits heat causing concrete in large masses to increase temperatures which can reach 40 °C above the outside temperature. The cooling that follows this process leads to the concrete cracking (Encyclopædia Britannica, 2013).

Types of Cement

The table below lists the various compositions in Portland cements.

Table 3: Composition of Various Portland cements

Approximate composition of Portland cement set in United States by the American Society for Testing and Materials (ASTM) (ASTM types I–V)						
ASTM type and name	Composition (%)*				Characteristics	Applications
	C_3S	C_2S	C_3A	C_4AF		
I (Ordinary)	42–65	10–30	0–17	6–18	no special requirements	general construction (e.g., sidewalks)
II (Modified)	35–60	15–35	0–8	6–18	moderate sulphate resistance, moderate heat of hydration	drainage systems, sea walls, floor slabs, foundations
III (High-early-strength)	45–70	10–30	0–15	6–18	higher strength soon after pouring	cold-weather construction
IV (Low-heat)	20–30	50–55	3–6	8–15	low heat of hydration	massive structures (e.g., dams)
V (Sulfate-resistant)	40–60	15–40	0–5	10–18	high sulphate resistance	foundations in high-sulphate soils

Source: http://www.school.eb.com.au/all/eb/article-76651

Aggregates

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete. Although aggregate is considered an inert filler, it is a necessary component that defines the concrete's thermal and elastic properties and dimensional stability.

Aggregates make up a high percentage (60 to 75%) of the total volume of concrete and are divided into two distinct categories:

- Fine aggregates: range from 0.025 to 6.5 mm in size (natural sand or crushed stone);
- Coarse aggregates: range from 6.5 to 38 mm or larger - gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder.

The main purpose of aggregates is to fill the void space thus adding extra strength to the concrete. The larger aggregates and sand are used to fill the majority of the void content. The excess void space that requires smaller particles is filled with cement. Distributing the particles evenly to fill the void space will result in a stronger concrete as the mixture will be denser (Portland Cement Association, 2013).

All aggregates must be clean and clear of any excess vegetable matter or soft particles. The reason for this is that organic matter found in concrete can dramatically affect its strength and can lead to the overall deterioration of the concrete due to processes that occur during the plastic, setting and hardening state.

The properties of freshly mixed concrete can be influenced by the size, shape and texture of the aggregate. Rough textured and angular aggregates require more water content so the mixture is workable. Smoother surfaces and rounder shapes require less water to result in a workable state.

Image 1: Different types of aggregates

Water - Cement Hydration

Hydration is the process in which the major compounds in cement form chemical bonds with water molecules and become hydrates or hydration products (Winter, 2012).

Hydration Reactions

The main hydraulic components of cement are various calcium silicates, C2S and C3S. When mixing begins the water molecules react with the calcium silicates this in turn forms calcium silicate hydrate ($3CaO \times 2SiO_2 \times 3H_2O$) and calcium hydroxide ($Ca[OH]_2$). For convenience these compounds are written differently to the conventional atomic symbols and are as follows C–S–H (represented by the average formula $C_3S_2H_3$) and CH. The hydration reaction is clearly depicted below:

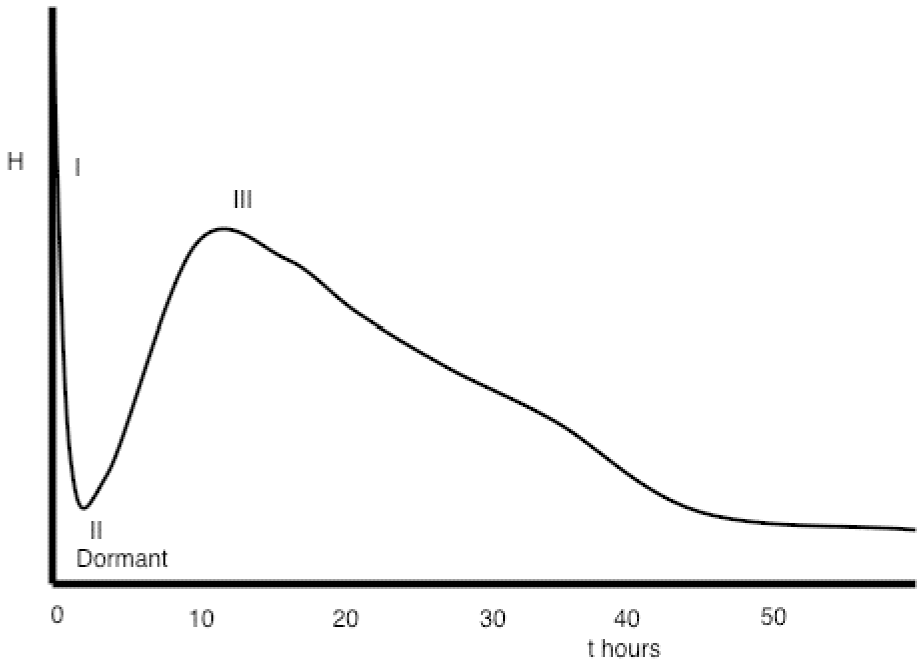
$$2C_3S + 6H = C_3S_2H_3 + 3CH$$

$$2C_2S + 4H = C_3S_2H_3 + CH$$ (Encyclopædia Britannica, 2013)

The reactions that occur when water is added to concrete are exothermic which means they produce heat.

Through a technique called conduction calorimetry, a trend can be noticed, that depicts the rate at which the minerals react. This is achieved through monitoring the rate at which heat is evolved. The following graph is a representation of heat evolution.

Graph 3: Representation of heat evolution



Source: http://www.understanding-cement.com/hydration.html

Three main reactions occur during this process:

- When adding water to concrete there is an instantaneous effect: it consists of some clinker sulphates and gypsum dissolving producing an alkaline, sulphate-rich, solution.
  The alite, belite, aluminate (C3A) phase (which out of the four main clinker materials is the most reactive) begins a short time after mixing. This phase consists of the C3A reacting with water to from an aluminate-rich gel (Stage 1 on the heat revolution curve).
- This gel substance then reacts in a solution to form small rod-like crystals of ettringite.
  The C3A reaction is an exothermic reaction although only lasting for a few minutes. This reaction is soon followed by a stage of fairly low heat evolution that lasts the duration of a few hours. This period is known the dormant or induction period as seen on Stage 2 on the above graph. During the preliminary stage of the induction period correlates to when the concrete is ready to paste. As the induction period continues over time the paste become too stiff to remain workable.
- Alite and belite then begin to react as the end of the dormant period. This reaction forms calcium silicate hydrate and calcium hydroxide. This correlates to Stage 3 as shown in Graph 3, which is the main period of hydration. During Stage 3, the concrete begins to harden and gradually gain strength. The maximum heat evolution period commonly occurs 10-20 hours after mixing the properties of concrete. The heat evolution reaches its peak and then gradually falls away. Ferrite reaction commences rapidly as water is added to the mixture, it then slows down gradually (Winter, 2012).

Curing

Controlling moisture content and the loss of moisture is essential to gain maximum strength out of concrete. Curing is the process in which concrete is kept moist and maintained in a controlled environment so it can gain maximum strength during the process of hydration. During curing the residual water reacts with the concrete gaining strength gradually.

The duration of curing changes mainly due to different properties of the concrete and the purpose in which the concrete will be used.

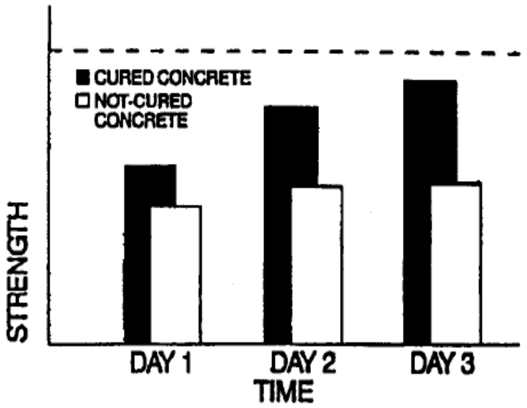
Curing Methods

Curing is adding extra moisture by spraying or applying water to the surface.

There are ways that moisture can be retained rather than having to continually add extra moisture:

- leaving formwork in place;
- covering the concrete with an impermeable membrane after the formwork has been removed;
- by the application of a suitable chemical curing agent (wax etc.); and,
- or by a combination of such methods.

Graph 4: Representation of the effect on strength when concrete is left to cure



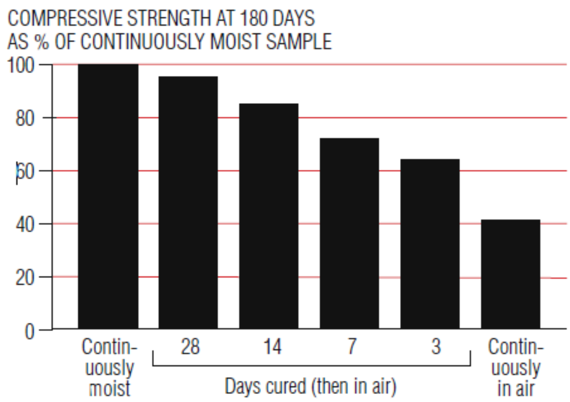
Source: http://www.concrete.net.au/publications/pdf/concretebasics.pdf

Duration of Curing

As time passes concrete gradually gains strength becoming harder and more durable. For household jobs concrete requires at least three days to cure, although for better strength and durability seven days is more appropriate.

Graph 5 is a clear representation of how concrete gains strength when methods of curing are applied. (Cement Concrete& Aggregates Australia, 2006)

Graph 5: Effect of duration of water curing on strength of concrete



Source: **http://www.concrete.net.au/publications/pdf/Curing06.pdf**

Workability

Workability is one of the physical parameters of concrete which affects the strength and durability as well as the cost of labor and appearance of the finished product (About Civil.org, 2011).

Concrete is workable when it is easily placed and compacted homogeneously, without bleeding or segregation. Segregation refers to the separation of the various mixed concrete properties. The overall consequence segregation is the concrete becomes weaker, less durable and will often have a poor surface finish. Concrete that is too stiff will be difficult to mould handle and transport.

The workability is affected by a number of factors, these include:

- Water content in the concrete mix
- Amount of cement and its properties
- Aggregate grading - smooth, round and well-graded and equally sized aggregates will improve the overall workability of the mix
- Nature of aggregate particles for example shape, surface texture, porosity
- Temperature of the concrete mix
- Humidity of the environment
- Mode of compaction
- Method of placement of concrete
- Method of transmission of concrete (Cement Concrete and Aggregates Australia, 2004).

Temperature Effects on Concrete

Temperature can affect the preparation, setting, strength and durability of concrete. The recommended temperature range is within the range 10 to 35°C.

Hot Weather

Most of the problems associated with placing concrete in hot weather conditions relate to the increased rate of cement hydration at higher temperatures and the increased rate of evaporation of moisture from the fresh concrete. Hot weather can affect the following aspects of concrete:

- **Setting time**. As the concrete temperature increases, the setting time and the time to place, compact and finish the concrete is reduced.
- **Workability**. Higher temperatures reduce the workability of the concrete more rapidly with time. By adding more water to improve the workability of the mix will in turn decrease the strength and increases the permeability and affects the durability of the concrete.
- **Compressive strength**. Higher water demand and higher concrete temperature could lead to reduced 28-day strengths. If more water is added to the concrete mix at higher temperatures to maintain or restore workability, the water cement ratio will be increased and this leads to loss of both strength and durability.
- **Poor surface appearance**. With the increased rate of evaporation, the surface of the concrete dries out and stiffens. This can cause the concrete to flake and colour differences on the surface may appear due to the different rates of hydration and cooling effects.
- **Concrete temperature**. Higher temperatures significantly influence the compressive strength gain of hardened concrete. While increased concrete temperatures may result in an increase in the early

rate of strength gain, in the longer term, concrete cured at lower temperatures will achieve higher strength.

- **Plastic shrinkage cracking**. Hot weather conditions accelerate the loss of moisture from the surface. If the rate of evaporation is greater than the rate of bleeding (rate at which water rises to the surface), surface drying will occur, resulting in shrinkage of the concrete.
- **Thermal cracking**. Concrete is at risk of thermal cracking when it is first placed, and the heat of hydration raises the temperature of the interior of the concrete compared to the interior mixture. Depending on the temperature differential between the interior and exterior of the concrete slab can result in the cracking of the concrete.

Cold Weather

Low temperatures can have a number of effects on the behaviour of the concrete; most of these are related to the reduction in the rate of cement hydration.

- **Extended Setting Times**. The lower rate of cement hydration at low temperatures increases the setting times for concrete. This means that concrete finishing operations will be delayed, and this may add cost. In addition if concrete is finished prematurely, problems may be experienced with flaking and weak, dusty surfaces.
- **Cracking**. The extent of cracking is increased at lower temperatures which in turn decreases the strength of concrete due to the drying shrinkage stresses it experiences.
- **Freezing**. Freshly placed concrete is vulnerable to freezing conditions both before and after it has set. If allowed to freeze after setting (i.e. sudden drop in temperature overnight), the expansion of the water as it freezes will cause damage to the pore structure of the cement paste, thus reducing the potential strength of the concrete. The extent of the damage will depend on its age and strength when frozen.

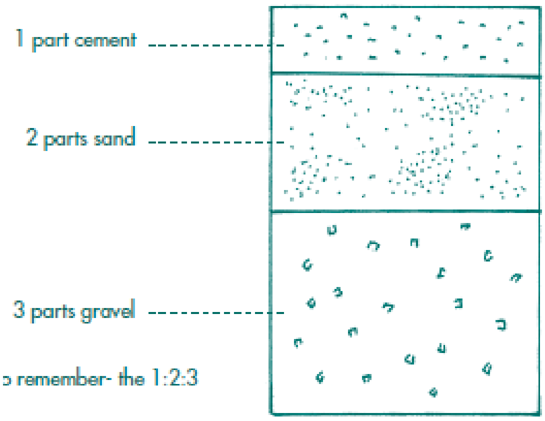
Mixing and Proportioning of Concrete

A concrete mix is designed to be cohesive and workable when in the plastic state and then gradually gain strength to become durable concrete. The environment in which the concrete will be created must also be considered when creating concrete.

Proportioning is adjusting something so that it has a suitable relationship with something else.

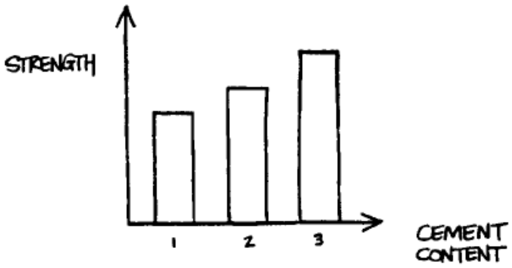
When mixing concrete the following ratio is used: 1:2:3

This means one part cement, two parts sand, three parts aggregate.

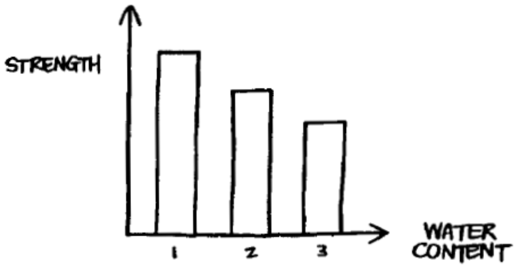


Each material in the mixture of concrete must be proportioned correctly as if they are not the strength of concrete can be dramatically affected. Large mixtures should be measured by weight although smaller projects can be measured in volume.

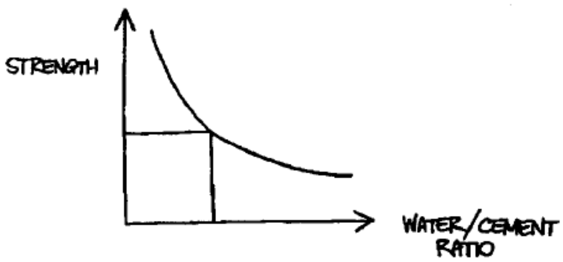
Cement Content: the durability and strength increases as the concrete content increases. This is represented through the graph on the right.



Water content: The more water that is added decreases the strength of the concrete. This is represented through the graph on the right.



Water to cement ratio: The strength decreases as the water to cement ratio increases. This is represented in the graph on the right. (Cement Concrete and Aggregates Australia, 2004)



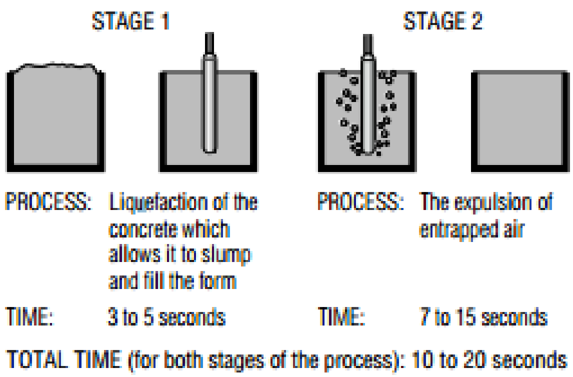
Compaction

Compaction is the process which expels entrapped air from freshly placed concrete and packs the aggregate particles together and in turn increases the density and strength of concrete. Compaction also increases the abrasion resistance and general durability of the concrete, decreases the permeability and helps to minimise its shrinkage and creep characteristics.

Compaction also ensures that the formwork is completely filled, that is there are no pockets of of honeycombed material and the required finish is obtained on vertical surfaces of the formwork.

When concrete is originally placed in the form the mixture will generally consist of between 5% and 20% entrapped air content. The aggregate particles, although coated with mortar, tend to arch against one another and are prevented from slumping or consolidating by internal friction.

Overall there are two main stages of compaction. The first stage consists of the aggregates particles being set in motion and then slump to level the top surface. The second stage consists of trapped air being expelled as depicted in the diagram on the right (Cement Concrete& Aggregates Australia , 2006)



Experiment

Aim

To determine whether different ratios of sand to cementwill affect the strength of concrete.

Hypotheses

That the cement mixture containing a higher ratio of sand to cement will strengthen concrete.

Variables

Independent variables

- The ratio mixture of sand to cement used for each of the brick batches

Dependent variables

- The mass held by the various brick batches that have ratios

Controlled variables

- Sand of the same type
- Cement of the same type
- Keeping the ratio of water a constant
- The bricks created in the same conditions – same form work used , consistent temperature and environmental conditions
- Compaction process consistent for each of the batches
- The bricks maintained in the same conditions and timeframes during the setting, hardening and curing processes
- The bricks created at the same time – batches of bricks made at the same time
- Allowing the bricks to cure for the same duration
- Same testing methodology
- Same testing day
- Same measuring utensils
- Same technique and timeframe on mixing materials with trowel

Materials

Materials used to create bricks

Sand 1 x 20kg bag

Aggregates

Plastic moulds x 18

Measuring cylinder used to measure the volume of concrete

Measuring cylinder for measuring the volume of water

Measuring cup to measure the volume of sand

Portland Cement

Trowel for mixing

	
Labels to label each batch mixture	Board to mix the concrete on


Hose used to spray water to aid in the curing process

Weighing Materials used to place upon Mass Holding Base to test the strength of the brick batches

Masses

3 lots of 2kg masses

2 lots of 5kg masses

Add up to 30kg

10 lots of 1kg masses

4 lots of 0.5kg masses

	
20 Bricks used for extra mass: 3.8 kg each	4 masses used due to their efficient flat size (additional mass objects could beloaded above these flat masses). Each mass weighs 1.6kg
	
Mass Holding Base – this holding base weighed 19.9 kg and also acted as the holding base that was by suspended by rope to support the additional masses that applied to test the strengths of the brick batches.	

Materials used to create the Suspension Apparatus

A suspension apparatus was constructed to support the Mass Holding Base and the additional required masses to test the strength of the brick batches. The materials used to construct the suspension apparatus were:

- Mass Holding Base (refer to section above)
- Rope to suspend the 19.9 kg Mass Holding Base
- Two wooden planks
- Table and brick wall constructed to acts as pillars of support and enable suspension of the Mass Holding Base, refer to diagram of the Suspension Apparatus page XX.
- Permanent marker to mark placement of brick batches

	
Planks used to suspend Mass Holding Base and the additional required masses	Rope used to suspend the Mass Holding Base

Safety equipment

	
Dust mask: to avoid the cement dusk being inhaled	**Safety glasses:** Avoid cement dusk floating into the eyes and other particles that will fly during the cracking of the bricks.
	
Boots: to avoid masses or bricks falling during the resting process	**Gloves:** To avoid the particles of dust that could potentially affect the hand and to avoid the cutting of the hand due to the use of bricks.

Methodology

A. Creating the Bricks

Method: Experiment 1.1 - Making the bricks with varying sand to cement ratios

Steps listed below:

Calculating the ratios of sand to cement to water

1. To calculate the ratios of the various components in concrete the following calculation was used. Using the first ratio of 20% sand, 80% cement. 400 was multiplied by 0.2 to derive the sand ratio and then 400 was multiplied by 0.8 to derive the amount of cement needed.
2. The above calculation applied to the formation of one brick. To derive the volume required for 3 bricks the above formula was multiplied by three so that three bricks could be made in one mixture.
3. To derive the water ratio the original cement ratio was multiplied by 0.5 then multiplied by three to obtain the volume for three bricks.

Making the cement mixtures and ensuring a workable state

4. Three separate mixing cylinders to avoid contamination were used to measure the quantity needed for each mixture.
5. The appropriate ratio of sand and cement were placed on the mixing board. The two components were then mixed thoroughly with a trowel.
6. Water was gradually added and mixed in a slow motion with the cement and sand using a trowel. This was done slowly to avoid any spillage from the board and to mix the components into a workable state. (Explained in *Background Information* section on Workability)
7. The mixture was then placed equally into three plastic moulds labelled 1.1, 1.2 and 1.3 (to signify the mixture type (20% sand, 80% cement) and the brick number of the mixture (brick 1,2 and 3)
8. Three bricks were made per batch to enable the ability to duplicate and validate the test and record a set of results whereupon an average could be determined.

Compaction

9. The bricks were then compacted by hitting the base of the brick on the ground eliminating any air bubbles. (Explained in *Background Information* section on Compacting)

Making the Brick Batches with Different Ratios of Sand to Cement

10. Steps 1-6 were repeated although with different ratios of sand to cement the water ratio remained constant to the volume of cement.

    The following ratios were also made:

    a) 30% sand, 70% cement
    b) 40% sand, 60% cement
    c) 50% sand, 50% cement
    d) 60% sand, 40% cement
    e) A controlled group was created containing only cement and water

The following table lists the proportions (calculated ratios) of sand, cement and water that were used in the experiment.

	Mixing Components (ml)		
	Sand	Cement	Water
Brick Batch 1 - 20% sand, 80% cement	240	960	480
Brick Batch 2 - 30% sand, 70% cement	360	840	420
Brick Batch 3 - 40% sand, 60% cement	480	720	360
Brick Batch 4 - 50% sand, 50% cement	600	600	300
Brick Batch 5 - 60% sand, 40% cement	720	480	240
Brick Batch 6 (Controlled) – Cement and water only	0	1200	600

11. Each of the mixtures were labelled as per below:

- 20% sand, 80% cement – Batch 1 - Brick 1 (1.1), Brick 2 (1.2) Brick 3 (1.3)
- 30% sand, 70% cement – Batch 2 - Brick 1 (2.1), Brick 2 (2.2) Brick 3 (2.3)
- 40% sand, 60% cement – Batch 3 - Brick 1 (3.1), Brick 2 (3.2) Brick 3 (3.3)
- 50% sand, 50% cement – Batch 4 - Brick 1 (4.1), Brick 2 (4.2) Brick 3 (4.3)
- 60% sand, 40% cement – Batch 5 - Brick 1 (5.1), Brick 2 (5.2) Brick 3 (5.3)
- Cement and water mixture - Batch 6 (Controlled) - Brick 1 (6.1), Brick 2 (6.2) Brick 3 (6.3)

12. Step 9 was repeated for each batch of bricks

Curing of Brick Batches

13. All the bricks were then left to cure in their moulds with the plastic mould lids fitted securely for three weeks before testing (Explained in Background Curing section)
14. All the bricks were sprayed with two sprays of water using the mist setting on the garden hose. This was done on days 1, 3 and 5 days post the creation of the bricks.

Photographs that document the making of the cement mixtures, ensuring the cement is in a workable state, the moulds and formwork used and the labeling of batches

The sand and cement mixed together

Measuring cylinder used to measure the quantity of water

	Gradually adding water to the mix to avoid water being lost off the board.
	Mixing the concrete into a workable state.
	Placing mixture into moulds.
	Labelling the various Batches
 	

Method: Experiment 1.2 - Making brick batches with aggregate (blue metal)

As part of this experiment an additional element was examined this was the addition of aggregate (blue metal) to the prescribed ratios identified in Experiment 1.1 above. The aim of this exercise was to determine whether adding blue metal would affect the strength of the brick batches.

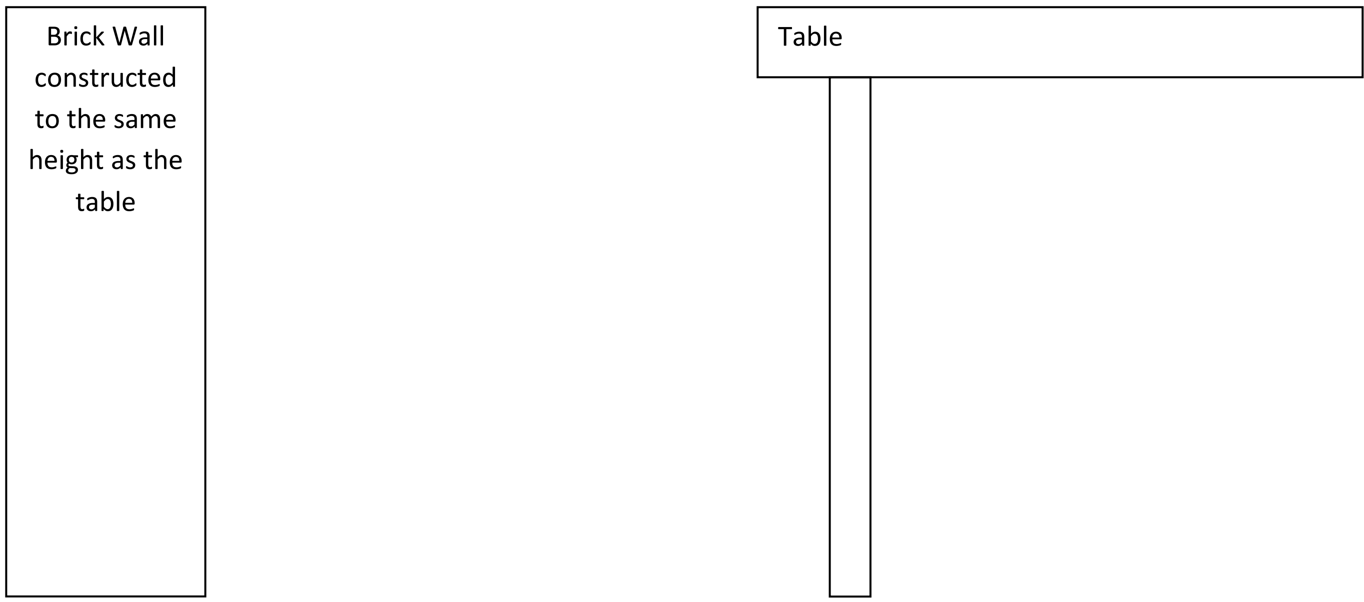
Experiment 1.2 is identical to 1.1 with the exception that each batch mixture included the addition of 200ml of aggregate (blue metal).

The testing of this batch was scheduled to occur, however, based on the results findings of Experiment 1.1 and the test results obtained in the Brick Batch 1 Aggregate Sample (refer to Results section on page 35 and 36), it was concluded that the experiment could not proceed with the available resources. That is, it was evident that there would need to be substantial increase in masses required to test the breaking of the bricks made with blue metal aggregates. The available masses for this experiment were not sufficient to test the strength and capacity of the brick batches with blue metal aggregates.

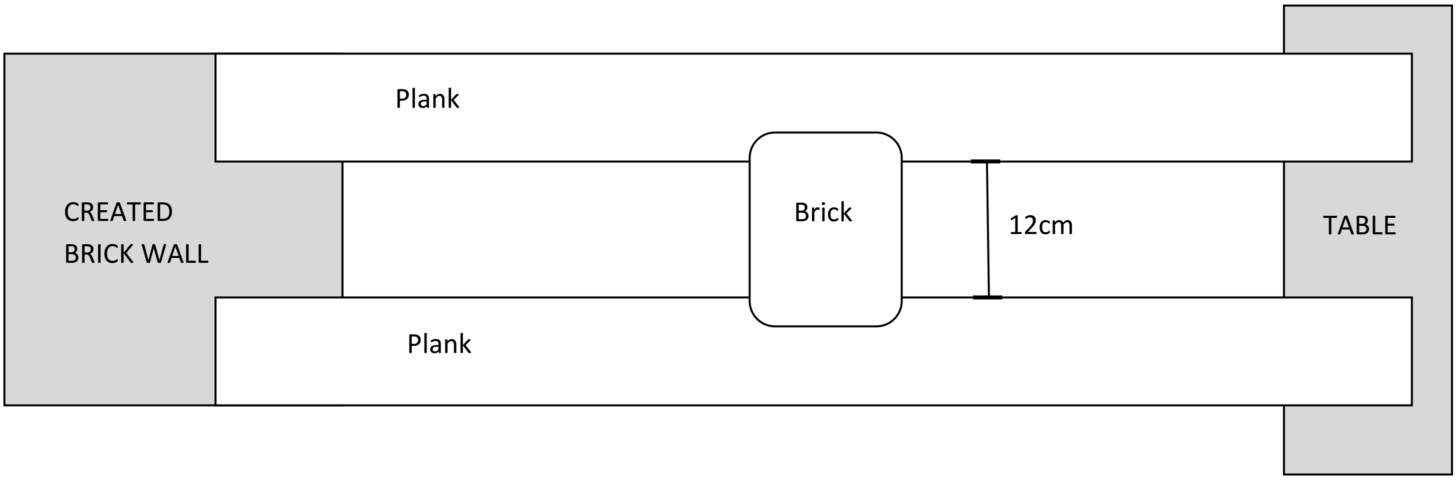
B. Creating the Suspension Apparatus to test the strength of the Brick Batches

To determine the strength of the bricks a Suspension Apparatus was constructed. The aim of the Suspension Apparatus was to suspend the Mass Holding Base and apply additional masses.

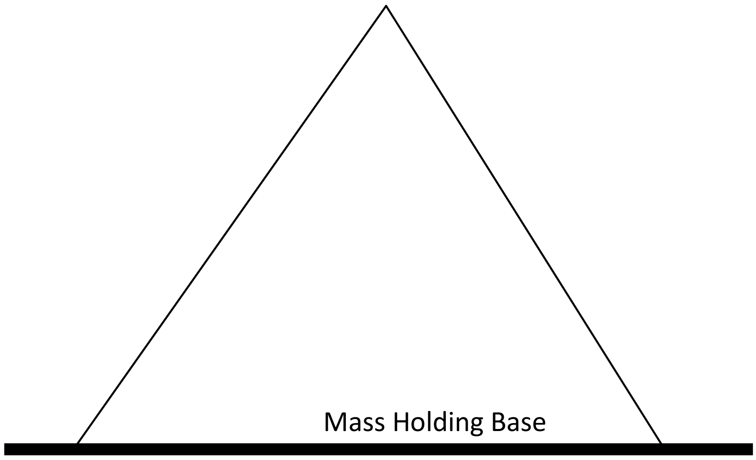
A brick wall was created to make a level platform with the table and to support the suspended Mass Holding Base. The following diagram demonstrates the brick wall construction.



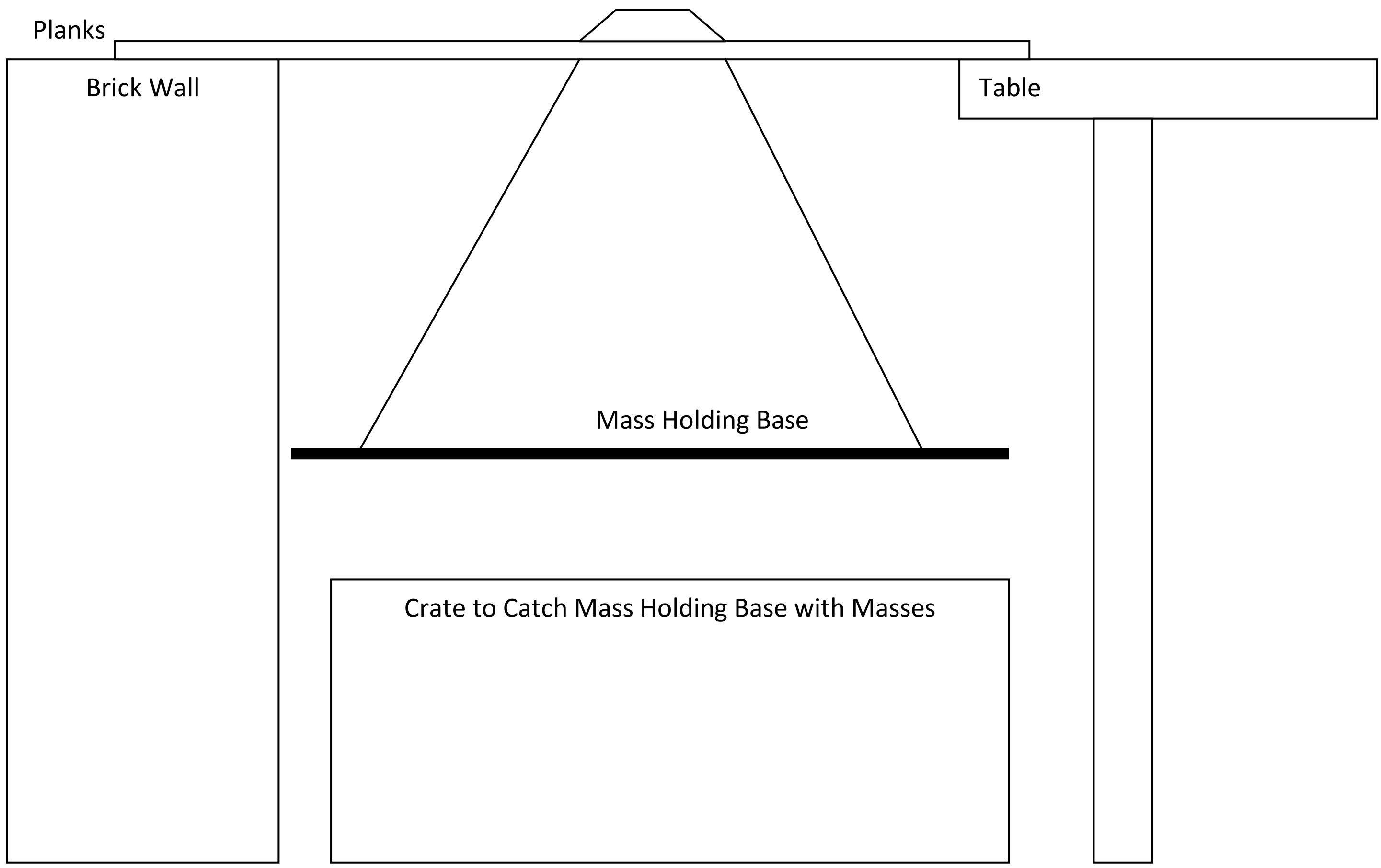
2. Two wooden planks were then positioned between the brick wall and the table. The planks were positioned 12cm apart to allow the bricks to be placed across the two planks. The position of the planks was marked with a permanent marker.



3. A rope was tied to the Mass Holding Base which was the platform used to support the various masses. The rope was suspended an equal distance to ensure the base was exactly horizontal to the ground, as depicted in the following diagram.



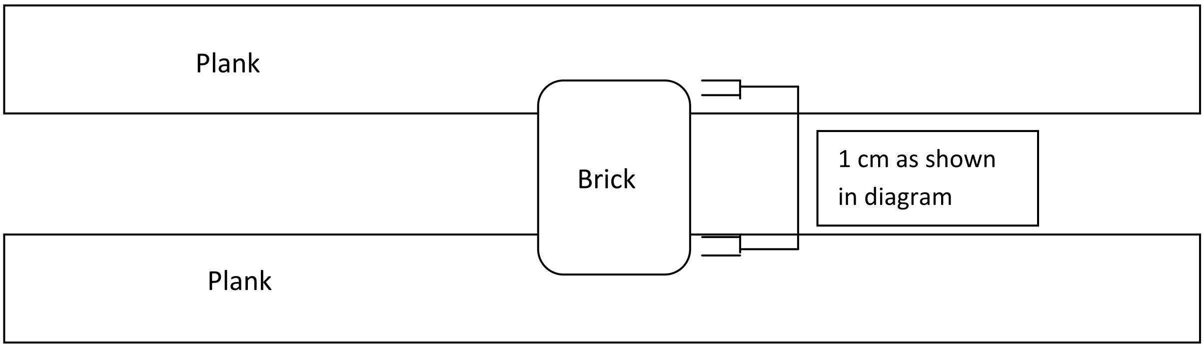
4. The hanging Mass Holding Base was then placed across the brick on the previously created supporting platform, as depicted in the following diagram.



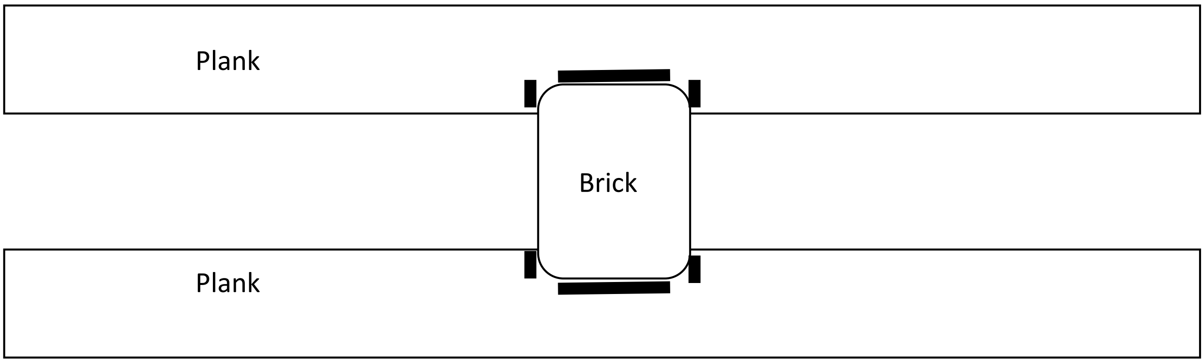
C. Holding Capacity of the Bricks

1. To test the holding capacity of the bricks (the breaking point at which a brick broke due to amount of mass suspended on it) the apparatus described on the previous page was utilised.

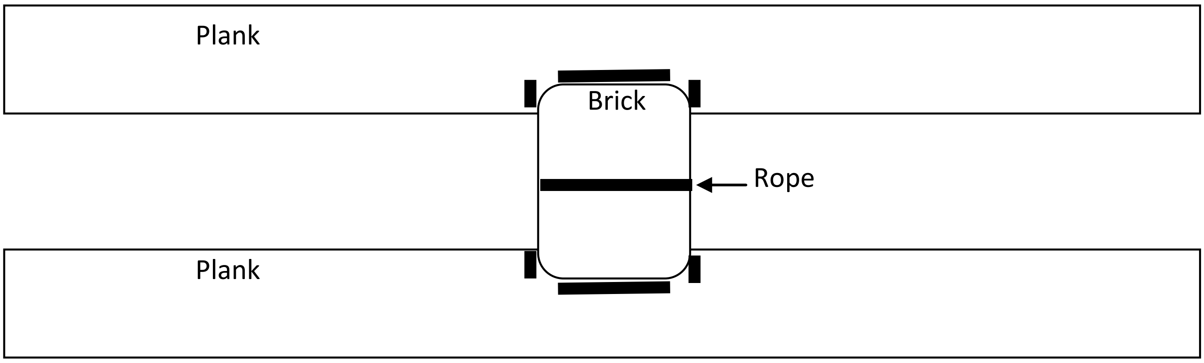
2. The brick was placed perpendicular across the two parallel wooden planks as depicted in the below diagram. The brick was placed upon the parallel planks and positioned at a distance of one cm from either end of the brick. The brick was placed in the centre of the planks to ensure the Mass Holding Base was distributed and balanced evenly.



3. The plank surfaces were marked with a permanent marker so when testing the next brick it would remain in the same position. As depicted in the following diagram.



4. The rope with the Mass Holding Base was suspended off the brick as depicted in the diagram. It was made sure that the apparatus was sitting level. The rope was placed in the centre of the brick to ensure the even distribution of mass across the bricks surface.

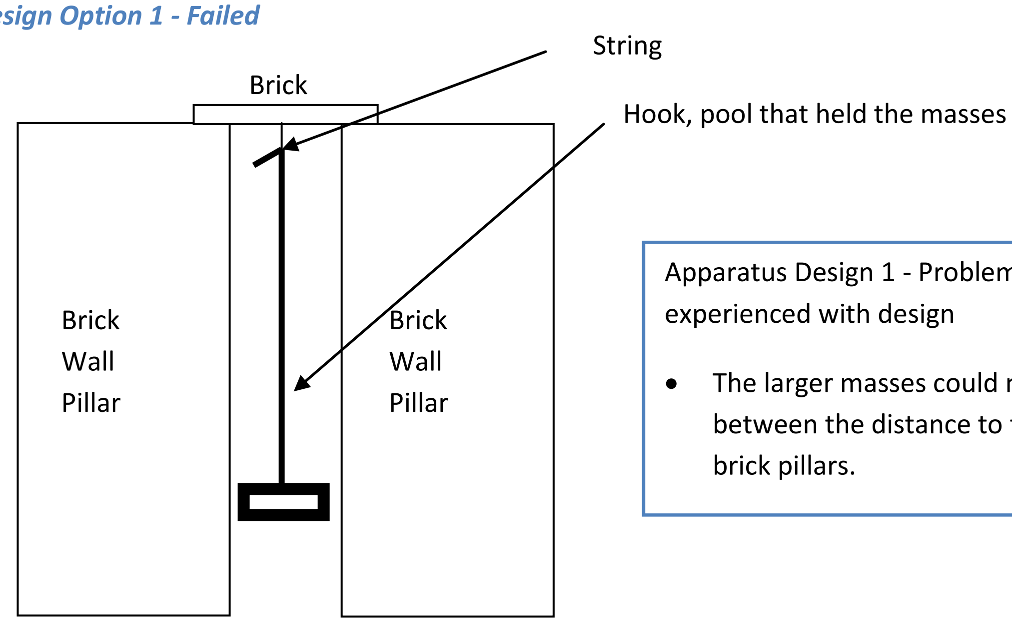


6. Additional mass was gradually placed on the Mass Holding Base whilst making sure it remained level, up until the brick finally cracked.
7. The mass that the brick cracked at was recorded.
8. Steps 1-4 were repeated but with the other created bricks in the batches.

D. Development of the Appropriate Suspension Apparatus-Alternative Options Considered

It needs to be noted that various attempts were made to create an appropriate Suspension Apparatus. These attempts are described below and a summary of why the Suspension Apparatus failed.

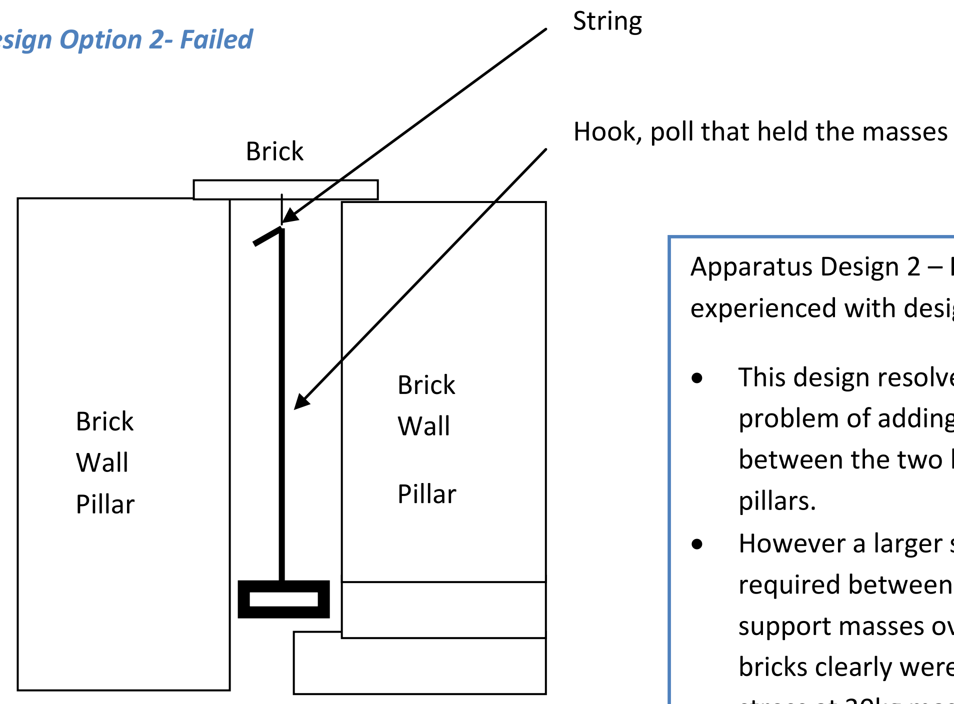
Apparatus Design Option 1 - Failed



Apparatus Design 1 - Problems experienced with design

- The larger masses could not fit between the distance to the two brick pillars.

Apparatus Design Option 2- Failed



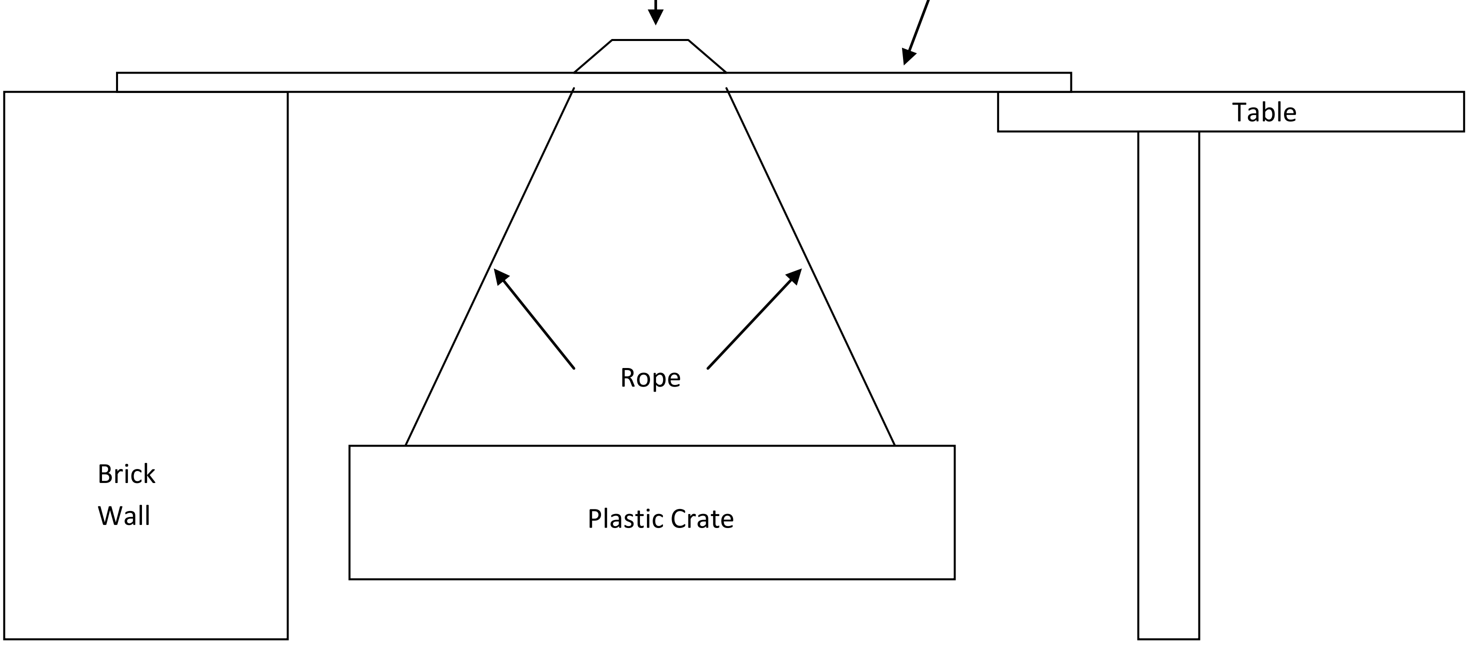
Apparatus Design 2 – Problems experienced with design

- This design resolved the pervious problem of adding masses between the two brick wall pillars.
- However a larger space was required between the pillars to support masses over 30 kg. The bricks clearly were under no stress at 30kg masses.

Apparatus Design Option 2 - Photographic Evidence

	
	
Brick with the hook mass holder hanging off	Diagram of brick supporting 30 kg

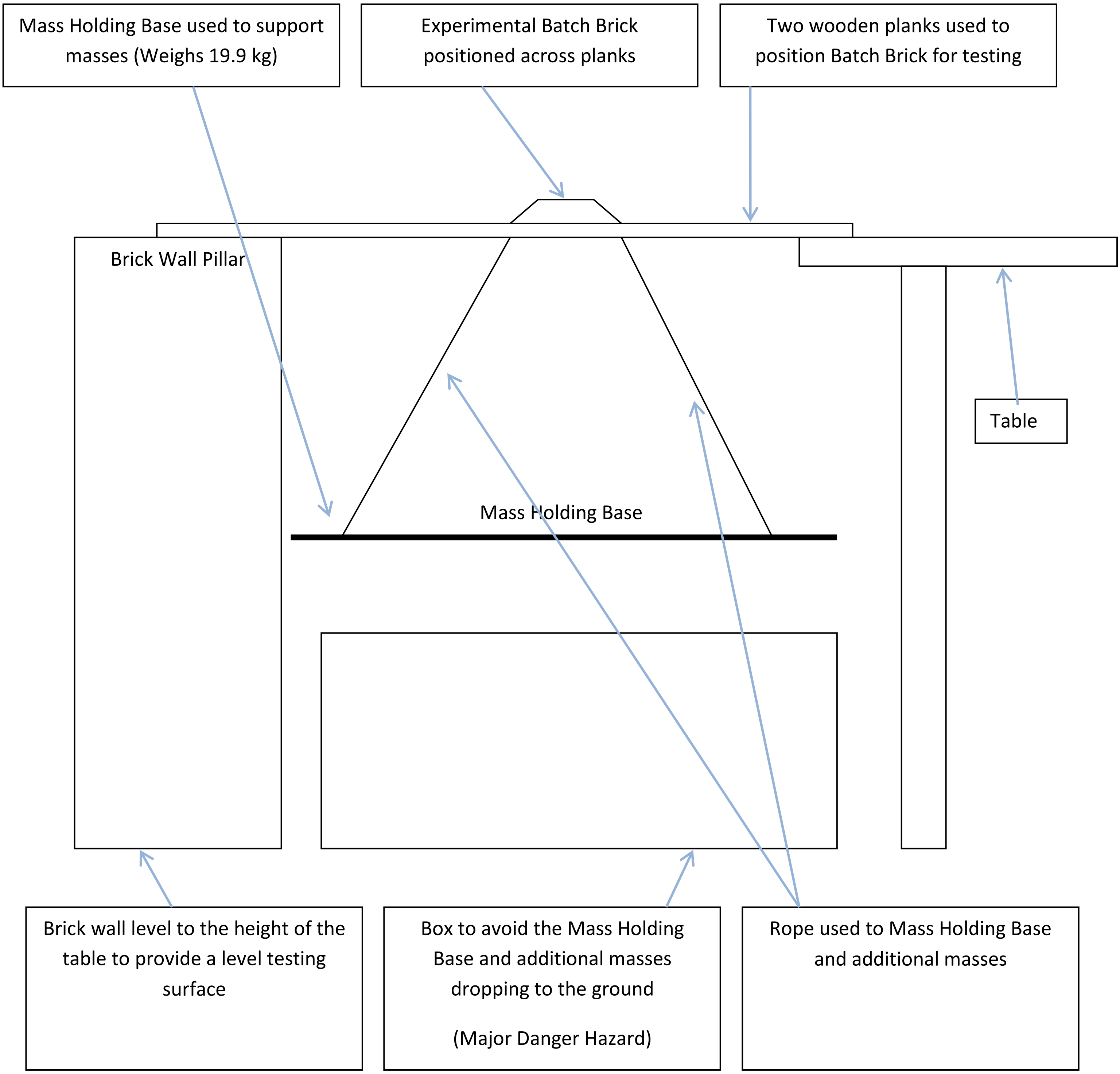
Apparatus Design Option 3-Failed



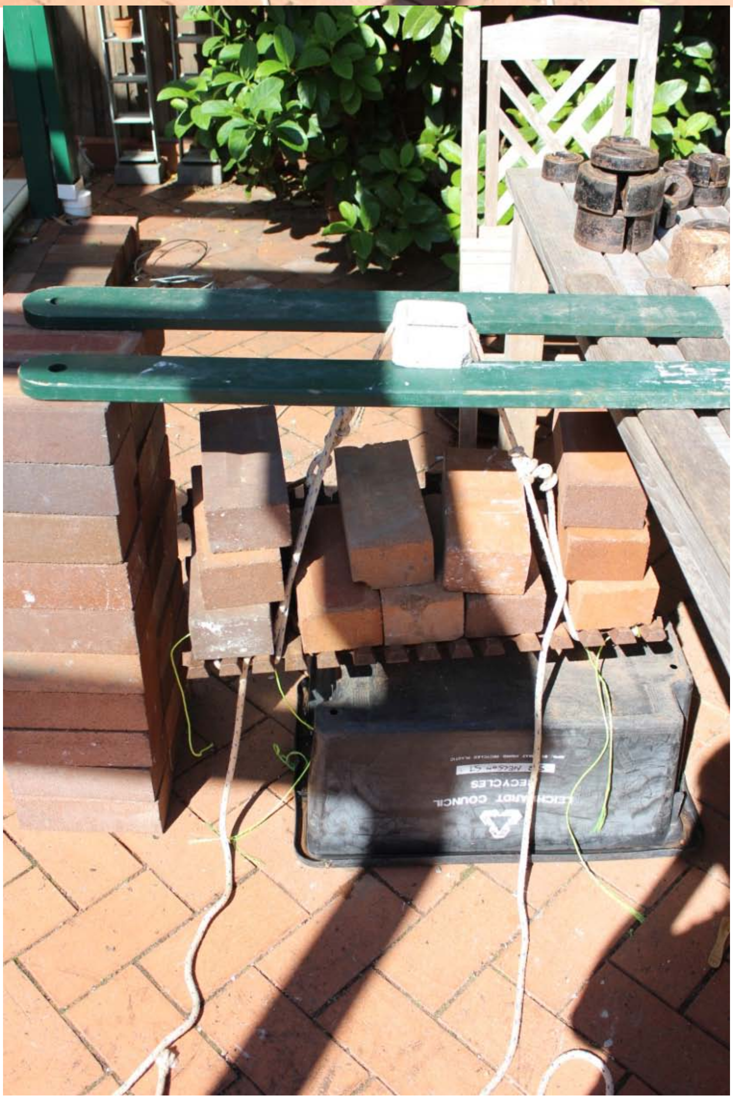
Apparatus Design 3 - Problems experienced with design

- This design overcame the restricted mass of 30 kg, however, the key failing in this design was that the plastic crate began to bend after 60 kg was applied within the crate.
- If more mass was added the plastic crate would have eventually broken. This design therefore limited the amount of masses that could be applied to the brick and it was clear that additional masses would be required.

Apparatus Design Option 4 – Successful Suspension Apparatus Design Model



E. Photographic Evidence of Suspension Apparatus Design Option 4 which was used to test the strength and holding capacity of the Batch Bricks



Results

Individual Mass of the Batch Bricks and Controlled Group

Before the Brick Batches where tested on the Suspension Apparatus (Design 4) to determine the strength of the various sand and cement ratios each brick was weighed.

The reason for weighing each of the bricks was to identify any variances that may have occurred when mixing and producing the bricks. The table below lists the actual mass of the bricks per batch in grams.

The results demonstrate low variability and therefore it could be concluded that the bricks could potentially yield similar results when tested for strength by suspending masses on the Suspension Apparatus.

	TABLE 1: Brick Batch 1: Ratio - 20% sand; 80% cement			
	BRICK 1.1	BRICK 1.2	BRICK 1.3	Average
Mass (g)	570	560	570	566.7

	TABLE 2: Brick Batch 2: Ratio - 30% sand; 70% cement			
	BRICK 2.1	BRICK 2.2	BRICK 2.3	Average
Mass (g)	570	570	580	573.3

	TABLE 3: Brick Batch 3: Ratio - 40% sand; 60% cement			
	BRICK 3.1	BRICK 3.2	BRICK 3.3	Average
Mass (g)	590	600	600	596.7

	TABLE 4: Brick Batch 4: Ratio - 50% sand; 50% cement			
	BRICK 4.1	BRICK 4.2	BRICK 4.3	Average
Mass (g)	610	620	630	620

	TABLE 5: Brick Batch 5: Ratio - 60% sand; 40% cement			
	BRICK 5.1	BRICK 5.2	BRICK 5.3	Average
Mass (g)	600	640	590	610

	TABLE 6: CONTROLLED GROUP: This Batch contains only cement, NO sand/aggregate			
	BRICK C.1	BRICK C.2	BRICK C.3	Average
Mass (g)	580	590	590	586.7

Mass Supported on the Various Batch Brick Ratios of Sand and Cement and Controlled Group

The following tables record the mass supported by each of the Brick Batches when tested on the Suspension Apparatus (Design 4)

	Table 7: Brick Batch 1: Ratio - 20% sand; 80% cement			
	BRICK 1.1	BRICK 1.2	BRICK 1.3	**Average**
Mass supported (kg)	53.2	73.3	69.3	**65.3**

	Table 8: Brick Batch 2: Ratio - 30% sand; 70% cement			
	BRICK 2.1	BRICK 2.2	BRICK 2.3	**Average**
Mass supported (kg)	76.3	78.1	80.3	**78.2**

	Table 9: Brick Batch 3: Ratio - 40% sand; 60% cement			
	BRICK 3.1	BRICK 3.2	BRICK 3.3	**Average**
Mass supported (kg)	80.3	87.1	100.6	**89.3**

	Table 10: Brick Batch 4: Ratio - 50% sand; 50% cement			
	BRICK 4.1	BRICK 4.2	BRICK 4.3	**Average**
Mass supported (kg)	97.0	100.6	87.1	**94.9**

	Table 11: Brick Batch 5: Ratio - 60% sand; 40% cement			
	BRICK 5.1	BRICK 5.2	BRICK 5.3	**Average**
Mass supported (kg)	95.3	118.4	106.1	**106.6**

Controlled group no sand/aggregates

	Table 12: CONTROLLED GROUP: This Batch contains only cement, NO sand/aggregate			
	BRICK C.1	BRICK C.2	BRICK C.3	**Average**
Mass supported (kg)	48.5	58.9	37.7	**48.4**

Controlled group with Blue Metal Aggregates (200ml) and a ratio of 20% sand; 80% cement

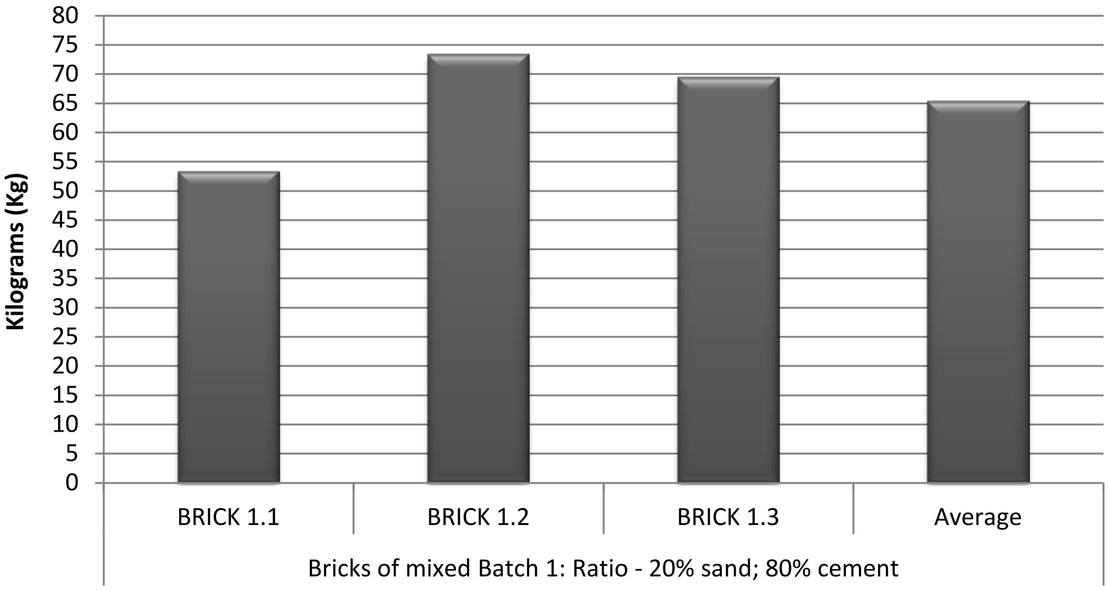
	Table 13: CONTROLLED GROUP: This Batch contains only cement and aggregate			
	BRICK CA.1	BRICK CA.2	BRICK CA.3	**Average**
Mass supported (kg)	75.5	80.3	69.3	**75.3**

Table 14: Average mass supported in each Brick Batch Brick Batches 1, 2, 3, 4, 5 and Controlled Batch (no sand/aggregate)

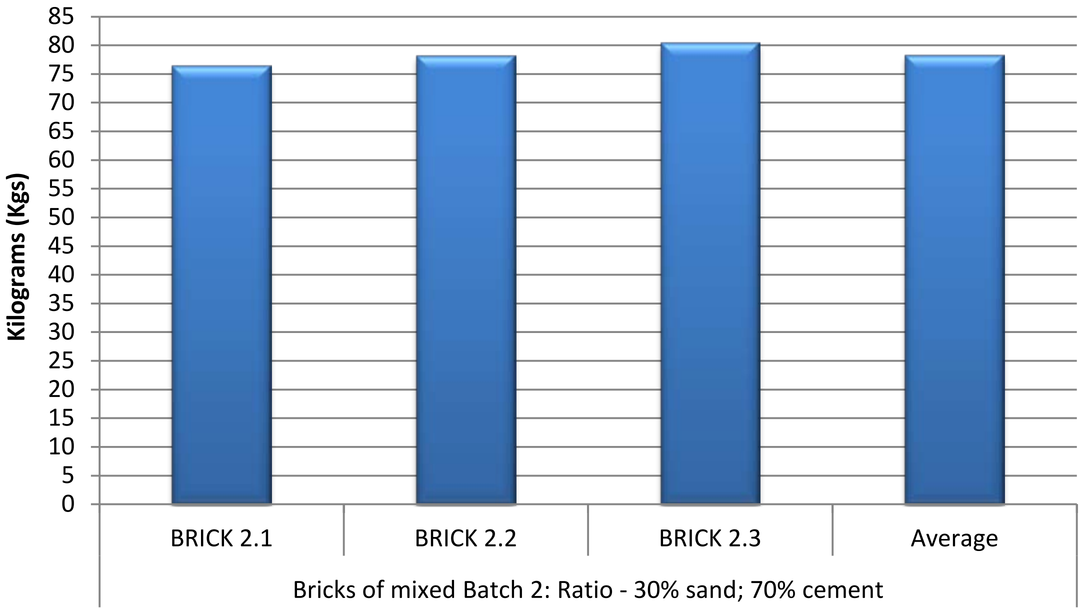
	Brick Batch 1: 20% sand; 80% cement	Brick Batch 2: 30% sand; 70% cement	Brick Batch 3: 40% sand; 60% cement	Brick Batch 4 50% sand; 50% cement	Brick Batch 5: 60% sand; 40% cement	Controlled Brick Batch No sand / aggregate
Mass supported (kg)	65.3	78.2	89.3	94.9	106.6	48.4

Graphs 1 to 7 below plot the results listed in the previous tables for each of the Brick Batches.

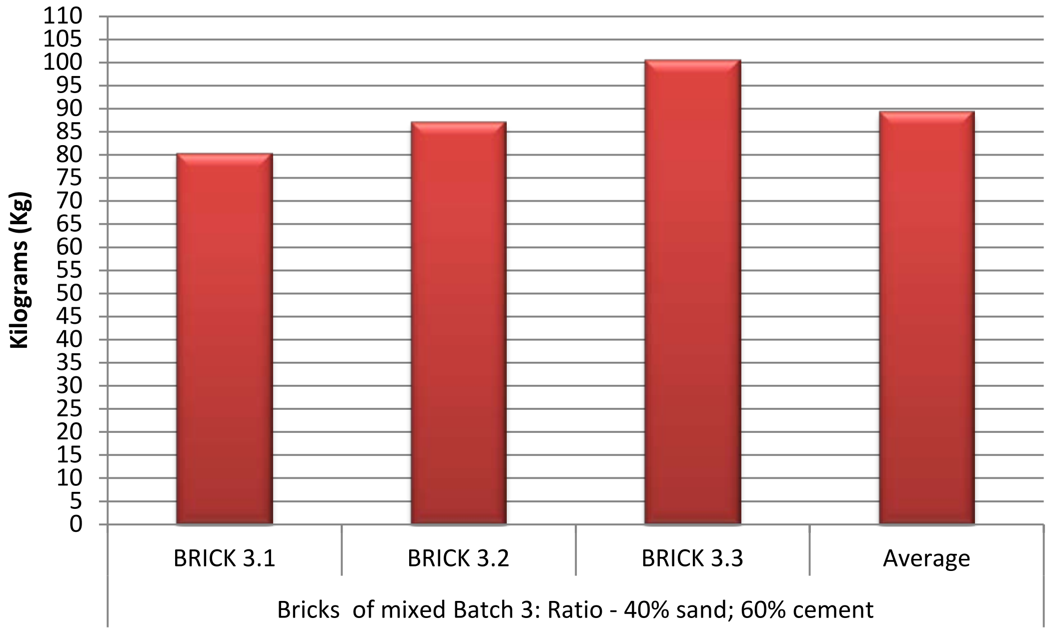
Graph 1: Brick Batch 1 Mass Supported (Kg)



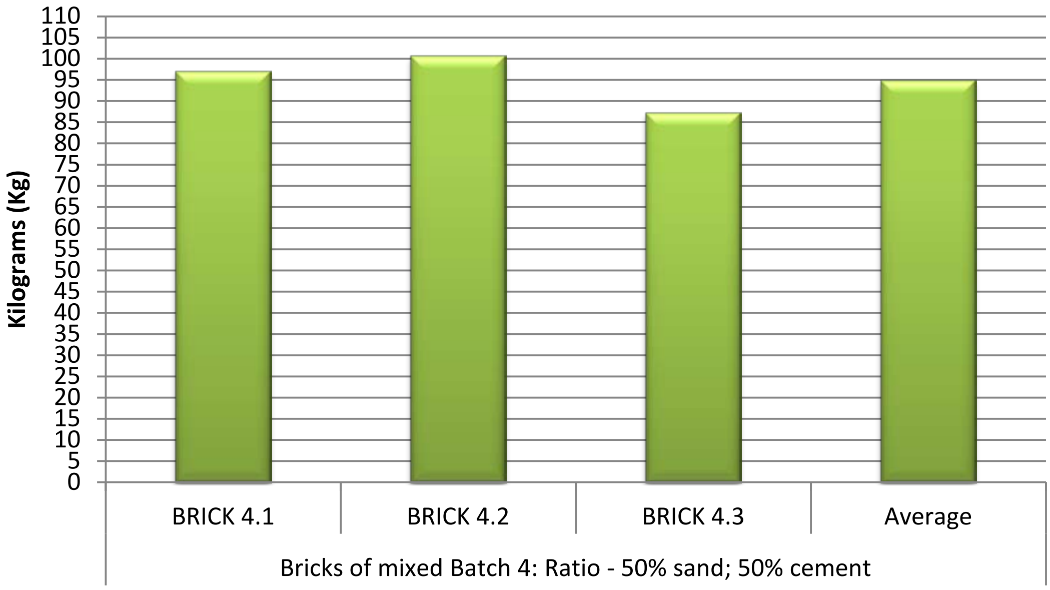
Graph 2: Brick Batch 2 Mass Supported (Kg)



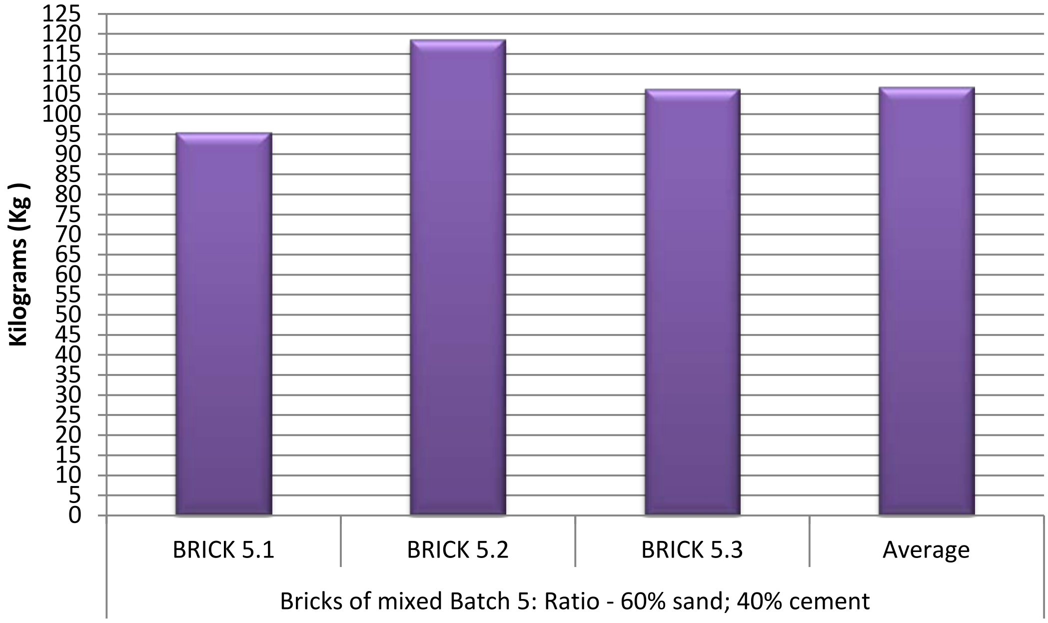
Graph 3: Brick Batch 3 Mass Supported (Kg)



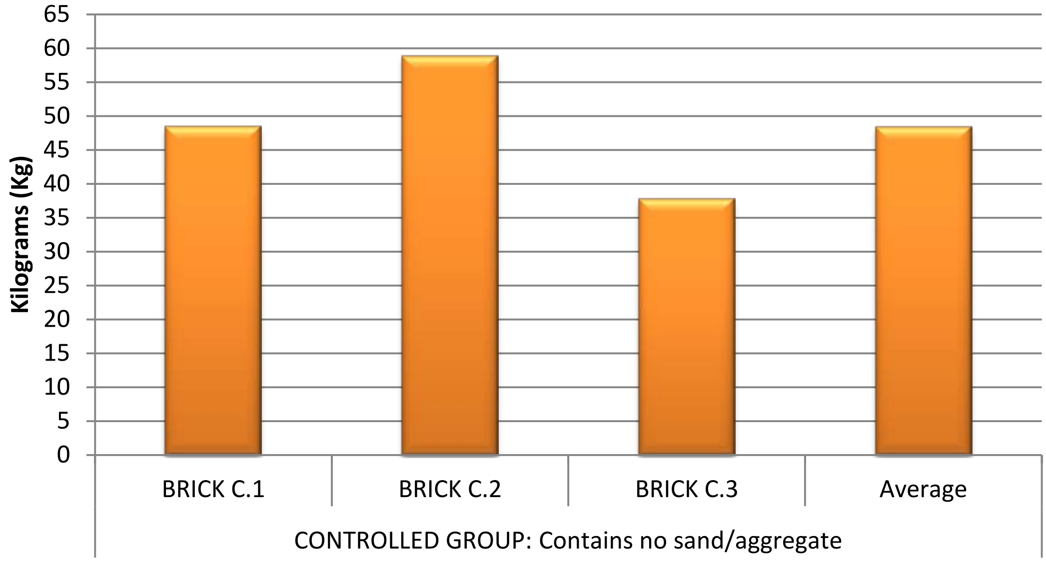
Graph 4: Brick Batch 4 Mass Supported (kg)

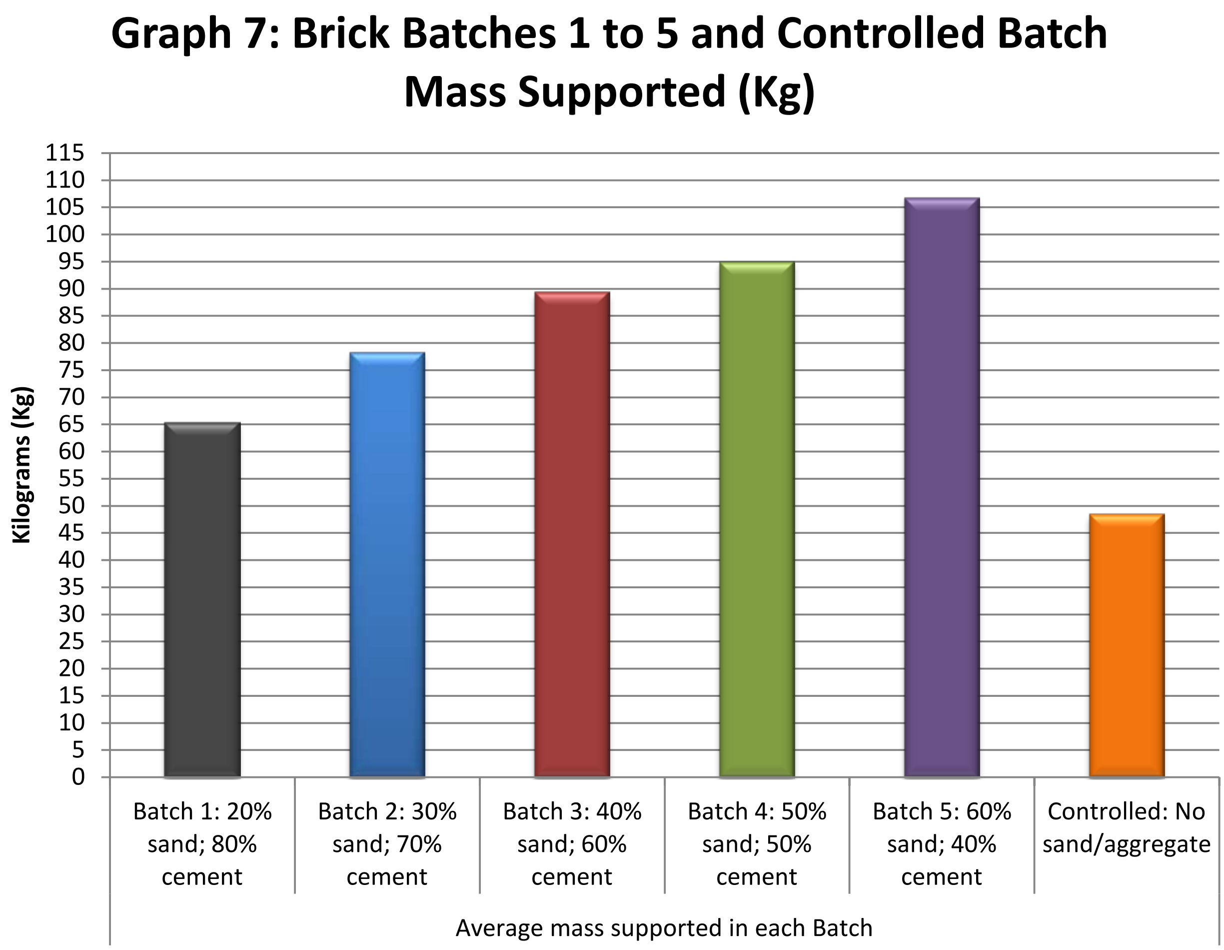


Graph 5: Brick Batch 5 Mass Supported (Kg)



Graph 6: Controlled Brick Batch (no sand/aggregate) Mass Supported (Kg)



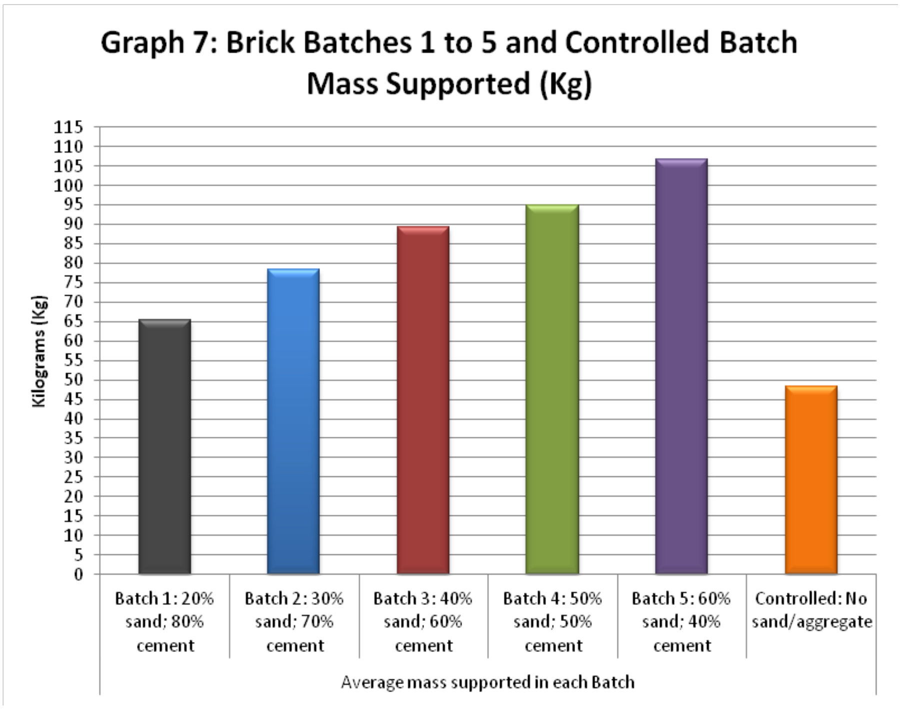

Graph 7: Brick Batches 1 to 5 and Controlled Batch Mass Supported (Kg)
Kilograms (Kg)
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Batch 1: 20% sand; 80% cement
Batch 2: 30% sand; 70% cement
Batch 3: 40% sand; 60% cement
Batch 4: 50% sand; 50% cement
Batch 5: 60% sand; 40% cement
Controlled: No sand/aggregate
Average mass supported in each Batch

Discussion

Results

The results obtained by this experiment prove to be consistent with the proposed hypothesis, that is, the results proved that the higher ratio of sand to cement was the strongest mix and the ratios with an equal or lower sand to cement ratio were substantially weaker.

This was clearly demonstrated in Brick Batch 5 which contained the highest ratio of sand to cement (60% sand, 40% cement). In the results obtained for this batch the average mass held was at a minimum 11kg more and at a maximum 41.3 kg than the other brick batches that contained a lower sand to cement ratio. This is clearly depicted in Graph 7 below which demonstrates that as the sand to cement ratio increased so did the mass supported by the brick.



The result findings are relevant to the independent variable - that is - as the ratio of sand to cement rose so did the strength of concrete. This is clearly depicted in the graph above where the bars increase incrementally based on the ratio of sand to cement. Note that the Controlled batch that contained no sand (aggregate) recorded the lowest mass supported.

The result findings are also relevant to the dependent variable - that is - the experiment clearly demonstrated that there was a clear trend of increased mass being supported by the bricks as the ratios of sand to cement changed so did the strength of the concrete. The graph shows the average mass supported (kg) by the each of the Brick Batches, the higher the mass supported the higher the sand to cement ratio.

Single Batch Explanations and Description

Brick Batch 1

Brick Batch 1 supported the lowest average mass due to the low ratio of sand to cement which was 20% sand to 80% cement. The results ranged from 53.2 kg to 73.3 kg with an average of 65.3 kg.

The individual results within this batch showed a wide range in the mass (53.2 kg to 73.3 kg) that could be suspended from the Suspension Apparatus.

	Table 7: Brick Batch 1: Ratio - 20% sand; 80% cement			
	BRICK 1.1	BRICK 1.2	BRICK 1.3	**Average**
Mass supported (kg)	53.2	73.3	69.3	**65.3**

This variance of 20.1 kg could potentially be attributed to the controlled variables. For example it is highly probable that the sand may not have been evenly distributed when mixing the concrete, water and sand paste. In addition other controlled variables may have contributed to the reliability, accuracy of the results, specifically these controlled variables are: (refer also to *Background Information* relevant section):

- **Moisture content:** some of the mixtures may not have lost moisture at the same rate as the other bricks.
- **Curing:** during the curing stage one of the bricks may have not been spread equally and evenly with water thus contributing to a variance in controlling the moisture content
- **Compaction:** some bricks may have not been compacted as well as the other bricks causing air bubbles to weaken the brick.
- **Hydration:** the rates of hydration may have altered in each brick mixture due to mixture content disparities.

It is important to note that there is a level of confidence that controlled variable - temperature - did not influence the preparation and setting process of the bricks. All the bricks were made during the day with an average temperature setting of 23 degrees Celsius and a night fall average temperature setting of 16 degrees Celsius.

Brick Batch 2

The results obtained from this batch proved that by increasing the sand to cement ratio (30%:70%) – the independent variable – that this in turn increased the mass (dependent variable) that could be suspended from the brick and thus the overall strength of the brick. The average mass (dependent variable) held by this batch was 78.2 kg, which is an increase of 12.9 kg from the average result in Brick Batch 1 (65.3kg), refer to Table 8 page 37.

It is also important to note that the individual results obtained in this batch were more consistent than that of Brick Batch 1 ranging from 76.3 to 80.3 kg (variance of 4 kg) suggesting that the paste was well mixed into a workable state before setting into the mould and compacting (refer to sections on Workability, Compaction and Mixing and Proportioning of Cement). It appears that the controlled variables were all met and consistent thus providing accurate and reliable results.

Brick Batch 3

Brick Batch 3 which contained a 40:60 sand to cement ratio, continued to reiterate and support the hypothesis that the cement mixture containing a higher ratio of sand to cement (independent variable) will strengthen concrete.

In this batch, the average mass supported was 89.3 kg; this represents an increase of 24.0 kg from that recorded in Brick Batch 1 and 11.1 kg from that reported in Brick Batch 2, refer to Table 9 page 37. The dependent variable (mass held by the brick) was thus influenced by the independent variable (ratio of sand to cement).

Brick Batch 3 overall individual results, however, were not as consistent as that of Brick Batch 2 with a variance in range of 20.3 kg (80.3 kg to 100.6 kg). This could be attributed to potential variances in the controlled variables, which in turn influenced the reliability and accuracy of the results. It is highly likely that the controlled variables outlined in Brick Batch 2 (moisture content; curing; compaction; and, hydration) may have contributed to the variance of mass held by the bricks within this batch.

Brick Batch 4

In Brick Batch 4 the sand to cement mixture increased to 50:50 ratio. The results from this mixture concluded that the average mass the bricks could support was 94.9 kg, refer to Table 10 page 37. This represents an increase of 29.6 kg from that recorded in Brick Batch 1, 16.7 kg from that reported in Brick Batch 2 and 5.6kg from that reported in Brick Batch 3.

The ratio used in this batch supported the fact that by increasing the sand to cement ratio (independent variable) this had a direct impact on the strength of concrete as demonstrated by the bricks withholding a higher increase of mass (dependent variable)

The individual results within this batch showed a more consistent range in the mass (87.1 kg to 100.6 kg) that could be suspended from the Suspension Apparatus with a maximum difference of only 13.5 kg when compared to Brick Batches 1 and 3. It is highly likely that the controlled variables were all maintained whilst making the bricks, that is, the moisture content; curing; compaction; hydration; and, offcourse the mixture of fillers and binders were appropriately met.

Batch 5

In Brick Batch 4 the sand to cement mixture increased to 60:40 ratio

This mixture held the overall highest average mass that could be suspended from the Suspension Apparatus with an average result of 106.6 kg, refer to Table 11 page 37. This represents an increase of 41.3 kg from that recorded in Brick Batch 1, 28.4 kg from that reported in Brick Batch 2, 17.3 kg form that reported in Brick Batch 3 and 11.7 kg from that recorded in Brick Batch 4.

This batch clearly supports the fact that the higher sand to cement ratio (independent variable) the stronger the concrete will be as it can support a higher level of mass (dependent variable).

As outlined in the *Background Information* section on Aggregates, aggregates such as sand along with water are an essential ingredient in providing strength to concrete. Although aggregate is considered an inert filler its main purpose is to fill the void space thus adding extra strength to the concrete. Aggregates also define the concretes thermal and elastic properties and dimensional stability (Portland Cement Association, 2013).

With regards to the individual results within this batch, the mass that could be suspended from the Suspension Apparatus ranged from 95.3 kg to 118.4 kg, a variance of 23.1 kg. Again this variance could be attributed to the controlled variables in particular the preparation and setting process of the bricks. Again the effects of moisture content; curing; compaction; hydration and workability processes could have affected the accuracy and reliability of the individual results.

Controlled Batch

The controlled mixture that contained no sand was, as expected, recorded as having the lowest recorded masses that could be suspended from the Suspension Apparatus. The results ranged from 37.7 kg to 58.9 kg with an average of 48.4 kg that could be suspended from this batch, refer to Table 12 page 37.

The variance in mass held between the three bricks was 21.2 kg, this could be attributed once again to the controlled variable factors that have been identified in the other batches: moisture content; curing; compaction; hydration and workability processes.

The controlled batch clearly demonstrated that without any aggregate, such as sand, being applied to the mixture the strength of the concrete would be compromised. It confirms that aggregates are an essential ingredient (along with water) in defining the strength and other proprieties of concrete.

The results for this batch confirmed that the independent variable - ratio mixture of sand to cement - greatly influences the strength of concrete as demonstrated when applying the suspended mass to the brick.

Relationship to Hypothesis and Aim

The results obtained in the experiment support the hypothesis that a cement mixture containing a higher ratio of sand to cement will strengthen concrete. This has clearly been demonstrated and outlined above in the Results and Discussion sections.

The Aim of the experiment was also addressed. Through the application of suspending various mass ranges on the Suspension Apparatus, the strength of the Brick Batches were tested to determine whether their composite of sand to cement ratios influenced the strength of the concrete. It was concluded that the ratio of 60% sand to 40% cement was far superior in providing strength to concrete compared to the other tested ratios.

Accuracy

The measuring instrument (mass holder and rope) and method (developing a batch of differing brick sand/cement ratio) were important and correlated factors in testing the accuracy of the results.

By developing a consistent group batch of bricks this provided the opportunity to test the same brick sand/cement ratio 3 times, thus providing the ability to test the accuracy of that batch using the measuring instrument. This can be demonstrated in Graphs 1-6 which shows that all the bricks in each batch where cracked around the same weight with minimal outlier results, meaning that the method of creating the 3 bricks per batch and then cracking them with the dame measuring instrument provided accurate results.

The accuracy of the results also supported and actually really did measure and address the concept tested, which was that different ratios of sand to cement did in fact affect the strength of concrete. This is particularly exemplified in Graph 7, in this graph each of the batches have been plotted onto the graph and as the ratio of sand rises the strength of the brick increases thus showing consistent movement upwards in the mass supported. Interestingly, each movement upwards consists of a similar sized interval, thus supporting the accuracy of the method and the measuring instrument.

Accuracy - Variances that were controlled that added to the accuracy included:

- Bricks were created in the same condition
- The bricks were left to set and cure through the same conditions
- The bricks were tested in the same conditions in the same way
- The mixing method, using the trowel to mix the components until workable was an accurate process
- The testing method overall: was an effective way to obtain accurate results of the mass the brick could hold

Inaccuracies - Variances that were difficult to control included:

- **Variances in the Mass of the Batch Bricks.** As recorded in the Results section there were some variances in the final mass of each individual brick that was made. The mass of the individual bricks could have ultimately affected the overall strength of the brick.
- **Incorrect placement of the Mass Holding Base and Rope**. By not placing the suspension apparatus in the middle of the brick this could potentially have influenced the actual mass the brick could support as the mass would not have be spread evenly across the brick.
- **Stretching and pulling of the rope**. Care was taken to select an industrial strength rope to suspend the Mass Holding Base and the extra masses. However, it is likely that the rope may have lost it’s strength due to the inordinate amount of weight that was applied to the Brick Batches over time.
- **Variances in the Mass Weights**. The weight of the Mass Weights used could have been not accurately recorded, this in turn could have slightly influenced the total mass recorded.
- **The equal distribution of the sand/cement/water in the bricks.** When mixing the materials together it is likely that some bricks may potentially have had an unequal distribution of the overall mixture which in turn would have influenced the strength of the brick. This can be confirmed by the variances in the mass of the brick batches that were recorded (refer to first bullet point).

Reliability

To ensure there was reliability in the results obtained it was decided that there would a sample size of three bricks made per batch.

This sample size enabled the test to be repeated and the ability to obtain an average from the three recorded results.

The results recorded do show some variability in both the mass of the individual bricks that were made and the suspended mass that each of the bricks could hold. However, the variances are not disproportionate and when an average is calculated, recorded and plotted on the graph the overall result still support the hypothesis.

As such, it can be concluded that the methodology used in the experiment and the results obtained are reliable.

Validity

The results recorded do accurately address, measure and satisfy the concept tested. The results actually really did measure and address the concept tested which was that different ratios of sand to cement did in fact affect the strength of concrete, with higher ratios in sand proving to be higher in strength.

The validity of the results was also demonstrated when taking into account the other variables that had the possibility of influencing the results these included:

- Variances in the Mass of the Batch Bricks
- Incorrect placement of the Mass Holding Base and Rope
- Stretching and pulling of the rope
- Variances in the Mass Weights
- The equal distribution of the sand/cement/water in the bricks. (Refer to inaccuracies section for further details)

Despite these influences the results obtained were within a consistent range of similar and accurate results.

Anticipated and Unexpected Errors

Throughout the experiment there were potential and known errors that may have influenced the overall results; these have been listed under the section above - *Inaccuracies - Variances that were difficult to control*.

Improvements to experiment

Although this experimental design did achieve the overall role if this experiment was to be redesigned the following improvements could be considered.

- **Size of the bricks:** If this experiment was to be repeated a smaller brick size would be recommended if the experiment was to be conducted outside of a laboratory. The smaller the brick size the less mass weights required to test the strength of the brick. In this experiment due to the size of the brick a maximum of 110 kg was required. This in turn affected the Suspension Apparatus Design, ruled out the testing of the Brick Batch contain blue metal aggregate and offcourse presented safety concerns. It is recommended that if the experiment were repeated the dimensions to follow would be of 9cm long, 4cm wide and 1cm tall. Using these dimensions it is likely that Apparatus Design Option 2 could be utilised.
- **The use of wire or chain in replacement of rope:** It is recommended that the use of a chain or thick wire be used if this experiment were to be repeated, this would ensure there is no risk of stretching of a rope and thus affecting the overall validity of the results.
- **The use of different mass increments (having different mass quantities)**: Ideally it would be advantageous to have at one's disposal the use of different incrementally increasing mass tools rather than relying on homemade substitutes as was used in this experiment. The advantage of this would be the results of the experiment would be recorded accurately and the process would be shorter in duration as fewer weights would be needed.

Explanation of Methodology

Steps 1-3: Calculating the ratios of sand to cement to water

The calculation used in steps 1-4 were kept constant throughout the experiment. This ensured that the variables remained equal.

The form and its dimensions and volume for the brick remained constant. The reason the mixture was not filled to the top of the mould (only 2cm instead of 4cm) was provide a slimmer brick that could be used for the experiment rather than a bulkier brick that would require more mass being suspended.

The water ratio remained constant throughout the experiment. The 50% water to cement ratio is the recommended manufacture's volume.

The calculation applied to derive the ratios of sand to cement to water was tested and used to make the volume for one brick and then multiplied by three to create three bricks.

Steps 4 to 7: Making the cement mixtures and ensuring a workable state

Using separate cylinders to avoid contamination was crucial; this ensured the three components (sand, water, and cement) were not contaminated. The results could have been drastically affected this is because if the sand (fine aggregate) is contaminated the plastic state, setting state and hardening state will also be affected consequently leading to the deterioration of the concrete.

This process was crucial in ensuring that the components of the used components of concrete were mixed together into a workable state. If the concrete did not meet this workable state the bricks would have experienced changes in strength as the fixture would not have developed correctly through the plastic, setting and hardening state.

The process of gradually adding water was necessary because the run off from the board could have potentially affected the overall mix and therefore the strength of the concrete.

The labelling of the various mixes on the lid of the boxes ensured that the each mix was not confused with one other. If the bricks had been tested with bricks from different mixtures the results would have been completely inaccurate.

Step 8: Compaction

This process of compacting was crucial in eliminating any air bubbles or imperfections in or on the surface of the brick. The risk of not doing this step would have impacted the strength of the brick.

Steps 9 to 10: Making the Brick Batches with Different Ratios of Sand to Cement

The ratios used in this experiment were chosen to depict a trend and clearly represent that an increasing ratio of sand to cement affect the strength of a brick

Through the use of increasing sand ratios and decreasing cement ratios the experiment indicates how lower higher ratios of cement to sand will be weaker and that the highest ratio of sand to cement (60% sand and 40%) would be the strongest mix. The results obtained clearly represented these trends.

Steps 12 and 13: Curing of Brick Batches

Steps 12 and 13 were used to aid the setting state, hardening state and curing. Allowing the concrete to pass through these various states the concrete states and durability was increased overall. Through a maintained environment and the addition of extra moisture the concrete was able to gain maximum strength during the process of hydration.

The method of curing used in the experiment was the addition of moisture by spraying with the hose and by applying a membrane (the lid of the plastic mould).

Creating the apparatus to crack the brick and Cracking the bricks

The apparatus designed was used to have maximum efficiency and accuracy when testing the brick. Although the brick did have its problems the apparatus that was used for testing overall provided results in an accurate manner.

Conclusion

In this experiment a series of tests were conduct to determine which ratio of sand to cement mixture was the strongest by determining its holding capacity when mass was applied.

The data obtained in the experiment supported the proposed hypothesis which is that as the sand to cement ratio content became higher so did the strength of the concrete.

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