

Mauritius Research Council

Flowable Rockdust-Cement Slurry as Backfill

Final Report

February 2002

Mauritius Research Council

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Executive Summary

The purpose of this research project was to investigate the suitability of rockdust, stabilised with cement, in the form a flowable slurry for the backfilling of trenches, either transversal or longitudinal, over which there will normally be an asphaltic pavement. The slurry would have to comply with the specifications laid down by the Ministry of Public Infrastructure (MPI) which are: -

- The 4-day soaked CBR at 95% BS Heavy Compaction should not be less than 10%
- The plasticity index should not be more than 25%
- The liquid limit should not be more than 35%

In order to achieve this objective, investigations were carried out in three stages.

The first stage consisted of investigating and gathering suitable test laboratory data to enable a statistical evaluation of the rockdust-slurry with varying cement contents.
The second stage consisted of evaluating the performance of the selected mixes under actual loading conditions compared with the traditional compacted backfilling method.
The final stage was to evaluate the economics of the slurry compared with the traditional backfilling method.

It was concluded that rockdust could not be used as a mechanically stabilised filler in saturated soils and in regions of high rainfall where the water table would be high. Therefore one of the alternatives was to stabilise it with cement in the form of a slurry.

It was found that although laboratory testing had shown that the various test mixes used could, in fact, satisfy the Ministry of Public Infrastructure criteria, caution would have to be exercised over the method of testing. The samples were tested for CBR, which is a static loading test when in fact the trenches had undergone dynamic loading during the asphalt compaction process and subsequently due to traffic flow. This difference was seen in the results of the deflection tests.
Also, climatic conditions have a significant effect on measured deflections of the pavement. It was shown that rain prior to deflection testing or the trenches being subject to soaking in water could adversely affect the results. It was shown that the 6% cement content rockdust-slurry trench failed the deflection criteria due to the fact that it constantly had water in its rut (used for dust abatement) whereas the 4% cement-rockdust slurry passed the deflection criteria, it being usually dry.

The main conclusion from this study is that the lower limit of cement content was found to be above 2% and it was found that 4,5,6 and 8% cement content slurries satisfied the MPI specifications. However, the 8% cement slurry was the least susceptible to weather effects and would be considered the ideal cement content to be used for optimum performance.

The cost analysis of the slurry being delivered to site by mixer truck was carried out and although this would be done in the case of extensive works only, it was shown that for a 8% cement-rockdust slurry being poured on-site, a saving of the order of 9% could be made compared with the traditional backfilling method. The lower cement content mixes, though less expensive, would be expected to have lower performance

Acknowledgements

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Dr B.K.Baguant	Research Institution Investigator	University Of Mauritius

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Kiran Rumjansing

13 February, 2002

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1.0 Background of the Project

ISO 14001 is an Environmental Management System geared towards protection and preservation of the Environment and is being adopted more and more by companies to prove that their operations are environmentally sound. Solid waste management practices are being encouraged by industry in order that compliance to regulations is observed.

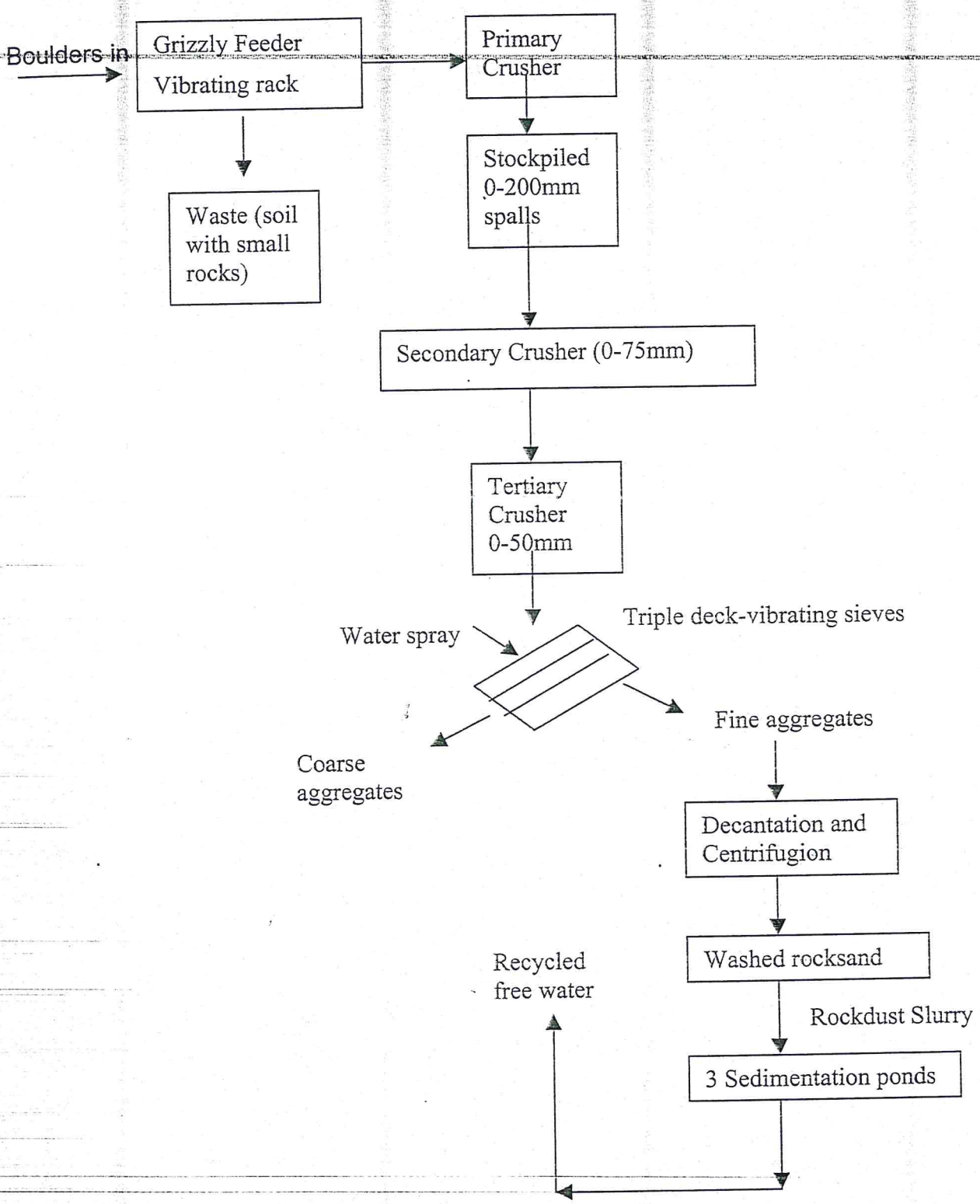
The stone crushing industry is constantly being faced with pressure to comply with environmental regulations One of the main problems with stone crushing activities, apart from vibration and noise levels, is waste material. The waste material comes in the form of particles in the air and rockdust. Particles in the air are controlled by enclosing the crusher/impactor and also water sprinklers being strategically placed to capture the particles being emitted to the atmosphere. The water, once having trapped the particles, then flow to the water ponds where the particles settle and the free water is recycled. This is a minor part of the contents of the pond. The major part comes from the washing of the aggregates. The contaminated water which contains silt, dust and clay also goes, in the form of a slurry, to the pond. This slurry, when dry, becomes a major environmental pollutant. The slurry, once dry, is commonly called rockdust.

With the introduction of the ban on removal of coral sand in our lagoons, pressure to increase the production of washed basalt sand to meet demand has been put on our local stone crushing industries.
The implication of this is that the volume of rockdust associated with this increase in production will also increase proportionally.

The need to find a constructive use for this rockdust is therefore necessary.

2.0 Introduction

The stone crushing process can be diagrammatically summarised as thus: -



As can be seen from the above schematic, rockdust is a by-product obtained from the crushing and processing of basalt boulders to produce coarse final products (5-10mm, 10-14mm, 14-20mm) as well as fine final products (0-5mm). The bulk of the rockdust comes from the fine aggregates (0-5mm) .The latter is washed in order to remove the excess fines (silt, clay and dust), which, if left behind in the crushed sand, would constitute a harmful concrete contaminant. It could: -

a) affect bond development between the cement paste and aggregate in concrete and consequently affect strength (and possibly durability)
b) Increase the amount of water required to achieve the desired workability of the concrete mix due to the large surface area, and thus increase the risk of drying shrinkage cracking of concrete.

Once washed, the rockdust mixed with water flows to three sedimentation ponds arranged in series. The first pond contains the coarsest rockdust particles, the second contains medium sized particles and the last contains the finest rockdust particles. Once transported to the ponds, the rockdust settles at the bottom and the free water is recycled back to the plant. Over a period of time, the ponds become full. The excess water is allowed to drain and then the rockdust, in mud form, is transferred to dumping grounds where the rockdust eventually dries out. It is estimated that the annual rockdust being recuperated from the sedimentation ponds and being disposed of by the local industries is around 120 000 Tons. Being fine in nature, the rockdust once dry, becomes a significant environmental pollutant.

Being available in abundance and at the same time being an environmental nuisance has led researchers to investigate the possibility of using the rockdust in a constructive way. In the past, trials were carried out to ascertain the suitability of rockdust as a backfill material. Mechanical stabilisation at optimum moisture contents of the rockdust by compaction was carried out and CBR values of approximately 18-20% were achieved.

The Ministry of Public Infrastructure (MPI) has laid down the minimum requirements for backfill material for road trenches. It reads as follows: -

1.	4 days soaked CBR at 95% BS heavy compaction	not less than 10%
2.	Plasticity Index	not more than 25%
3.	Liquid Limit	not more than 35%

This type of compaction of rockdust satisfied the MPI specifications However, upon soaking, these values fell to 3-5% which are out of MPI specifications which implies that the rockdust cannot be used for backfill in regions of high rainfall.

A method of stabilising the rockdust so that it achieves the above specifications even in regions of high rainfall is possible using additives such as lime, cements, bitumen and polymer resins. The most commonly available of these on the local market is cement. Hence the justification of this investigation

3.0 Aims and Objectives

The objective of this research project was to find a constructive use for the utilisation of rockdust in the construction industry. The particular area of interest is the backfilling of trenches and other excavations. As explained above, the rockdust will be stabilised with cement. With the addition of water to the cement stabilised rockdust, a slurry shall be produced in order that it can be poured into the trench or excavation and left to develop strength over time. No compaction will be required as the slurry shall be self-compacting and self-leveling.

The amount of cement to be added shall have to be determined bearing in mind that a material for a flexible pavement is required and that it should be low cost. The governing factor shall be the specifications laid down by the Ministry Of Public Infrastructure in a document entitled Specifications for Backfilling of Trenches and Reinstatement of Road surfaces, which states

1.	4 days soaked CBR at 95% BS heavy compaction	not less than 10%
2.	Plasticity Index	not more than 25%
3.	Liquid Limit	not more than 35%

The aim of this project was three-fold: -

1) To gather sufficient laboratory test data to enable a statistical evaluation of variability of the material with different cement contents. Assessment of variability is important for developing a methodology that will enable design of slurries to be carried out with confidence.

2) To test the performance of the selected mixes under real/actual loading

3) To evaluate the economics of using the slurry as backfill compared with current practice of using selected/graded granular fill.

There are various advantages of such a product. Firstly, the rockdust is free and so therefore there is an economic advantage. Secondly, as the protection of the environment is becoming more and more important, new government regulation concerning the extraction of coral sand from our lagoons have been passed. As from the 1ST October 2001, the extraction of coral sand from our lagoons will be banned. This means that the use of washed basalt sand, for concrete and mortar production, will increase considerably and consequently the quantities of rockdust being dumped at various locations will increase. The advantage of such a product is that disposal management of rockdust can now be implemented and also the impact caused by the rockdust on the environment will be considerably reduced.
In addition, the advantage that the rockdust-cement slurry would have over the traditional method of backfilling in layers and mechanically compacting would be: -

- No supervision on site required (provided that the quality control procedures have been complied with at mixing)
- No hiring/use of compacting equipment as the slurry is self-compacting.
- Filling of trenches/excavations will be very simple- the slurry is simply poured in.
- Uniform void filling in trenches/excavations
- Less manpower required
- The possibility of using the slurry in saturated soil conditions
- The facility of removing the backfill material without hiring/use of machinery

4.0 Methodology

1. Initial tests were carried out to verify the physical and chemical properties of the rockdust.
2. A study was carried out on the proposed site for trench digging. This site was an entrance used by boulder lorry trucks for delivering boulders to the primary jaw crusher at Gamma-Civic Stone Crusher Yard in Beau-Bassin. The front and rear axle loads for any given mass was also determined using these lorries. All trucks entering and leaving the yard are weighed on the weighbridge and for which complete records were available.
3. test mixes with varying cement contents were studied at laboratory level for the minimum water required enabling adequate flowability.
4. The test mixes were then tested for variation of CBR with time
5. Once the above data was collected, 5 cross road trenches were excavated of which 4 were filled with the test mixes and the fifth was backfilled in the traditional manner. In situ samples were taken from the trenches for CBR testing.
6. Once the samples had reached the required CBR value, the trenches were cut down to 100mm with respect to the original road level and were then asphalted individually.
7. The trenches were open to traffic and regular monitoring for rutting and deflection tests was carried out to evaluate the performance of the trenches under real dynamic loading conditions.

The rockdust was taken from an area reserved for the disposal of rockdust when it was still in the mud form and uncontaminated. It normally dries out into a fine powder and becomes contaminated with aggregates to some extent as yard-cleaning debris is also disposed of there.

5.0 PRELIMINARY TESTS ON THE ROCKDUST

The following tests were carried out on the rockdust: -

1. Specific gravity
2. Bulk density
3. Particle size distribution
4. Specific surface
5. Plasticity
6. Linear shrinkage
7. Absorption and relative densities
8. Chemical composition

5.1 Specific Gravity

The specific gravity of a material is calculated as the mass of a given volume of the material to the mass of an equal volume of water. The test was carried out in accordance with BS 1377- part 2 – 1975 by the density bottle.

5.1.1 Result

The specific gravity was found to be 3.01

5.2 Bulk density

The bulk density of a material is defined as the mass of material required to fill a container of unit volume. The greater the voids in the material, the lower the bulk density value will be. The test was carried out in accordance with BS 812- Part 2 – 1975. The mass of the sample filling a standard container in a specified manner is measured. Both loose and compacted bulk densities were measured and the void ratio in both cases was calculated.

5.2.1 Results

The loose bulk density of the rockdust was found to be 1527 kg/m^3 and the corresponding voids content was 45.2%.

The compacted bulk density of the rockdust was found to be 1662 kg/m^3 and the corresponding void percentage was 40.3%

5.3 Particle size distribution

Particle size distribution is useful for classification of the rockdust. For a coarse grained material, this is determined by sieve analysis whereas for a fine-grained material, it is determined by a measuring the rate of settlement in water. The sedimentation test was carried out for fine analysis as described in BS 1377-part 2- 1975.

5.3.1 results

The results showed that the rockdust could be classified as a slightly sandy medium to coarse silt. It also showed that the rockdust consisted of more than 75% silt.

5.4 Specific surface

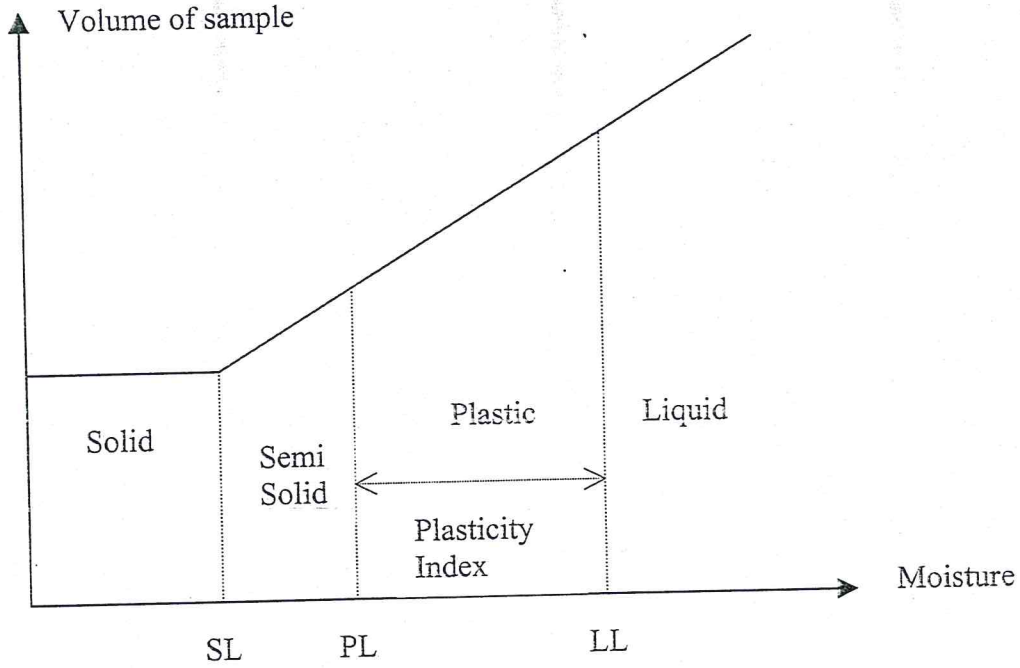
The specific surface of a material determines the fineness of the material. It is calculated by the Blaine permeability method.

5.4.1 Results

The specific surface of rockdust was found to be 1656 cm^2/g. Compared with the specific surface of cement, it is approximately half the value, cement particles being smaller.

5.5 Plasticity

Plasticity is the term describing the ability of a soil to undergo unrecoverable deformation at constant volume without cracking or crumbling. Depending on its water content, a soil may exist in different states i.e. liquid, plastic, semi-solid and solid state. This can be demonstrated below in a diagram.



Most fine-grained soils exist naturally in the plastic state. The upper and lower limits of the range of water content over which a soil exhibits plastic behavior are defined as the liquid limit and the plastic limit, respectively. The water content range is defined as the plasticity index. Hence

Plasticity index = liquid limit – Plastic limit

The transitions between the different states are gradual and the liquid and plastic limits though defined arbitrarily are determined using standard methods.
The tests for the determination of the plastic and liquid limits were carried out in accordance with BS 1377-part2-1975. For the liquid limit, the cone penetrometer was used.

5.5.1 Results

The liquid limit was found to be 27.4%. No plastic limit was obtained for the rockdust, as it could not be threaded to 3mm. It cracked and failed to retain shape and also exhibited very little cohesion. No plastic limit was obtained and consequently the plasticity index could not be determined.

5.6 Linear Shrinkage

This test is done by measuring the change in length of a prismatic sample made up of rockdust. The test was carried out according to BS 1377- 1975

5.6.1 Results

The linear shrinkage of rockdust was found to be 0.9%. The advantage of doing this test is that there exists an empirical relationship between the linear shrinkage and the plasticity index. The relation is as follows: -

Linear Shrinkage =Plasticity Index / 2.13

Therefore, the estimated plasticity index for the rockdust will be 1.9%. The only reasonable interpretation that may be given for such a low plasticity index for rockdust is that it is, in fact, a non-plastic material.

5.7 Absorption and Relative Densities

The absorption value is essential for calculating the total water content in a mix. Also the relative density value is used to calculate the void content. The test was carried out in accordance to BS 812 – part 2- 1975 using the pycnometer method. No decantation was necessary as the rockdust had most of its particles less than 75μm.

5.7.1 Results

Relative Densities	
On oven dried basis	2.79
On SSD basis	2.86
Apparent relative density	3.01
Water absorption	2.65%

5.8 Chemical Composition Of Rockdust

Most of the tests were carried out in accordance with BS 4550-part 2-1970, while sulphate, carbonate, chloride content and pH were determined in accordance with BS1377-1975.

5.8.1 Results

pH	8.3
SiO_2	78.3
$Al_2O_3 + Fe_2O_3 + TiO_2$	7.5
CaO	1.6
MgO	0.5%
SO_3	5.3%
L.O.I.	1.1%
Sulphate	0.003%
Carbonate	0.19%
Chloride	0.99%

6.0 AXLE LOADS

6.1 Mass Per Axle Load

In order that the correct design for pavements is achieved, a study needs to be carried out on the type of loading the trenches will have to undergo. Both the number of passes over the trenches and the mass of the lorries + boulders contribute to loading of the pavement .The first study was the number of passes per day. The area chosen for the trenches to be excavated was an entrance at the back of the Gamma-Civic stone crushing yard, which is used principally for the delivery of boulders to the primary jaw crusher. The lorries pass through the back gate, go to the weighbridge where they are weighed before tipping the boulders into the primary jaw crusher. They then go back onto the weighbridge where they are weighed again before leaving through the back entrance.

So the two masses that are of concern are the gross mass and the tare mass of each lorry. All the lorries transporting boulders are 2 axle lorries.

The way in which the mass is distributed over the two axles was next investigated. This information is very important when calculating number of standard axles.

6.2 Results

From the data collected in the appendix 3.0, it can be seen that 33% of the total mass of the lorry is carried by the front axle (called the front axle load) and that 67% is carried by the rear axle (called the rear axle load).

6.3 Discussion

All the boulder-carrying lorries were weighed over a period of time. This was possible as the number of lorries is more or less constant and they carry out many trips during the day. Had there been any 3-axle lorries, it would have been assumed that the load of 67% would have been equally distributed between the two rear axles. The advantage of a 3-axle loading is that the damage caused to the pavement under load is far less than that caused by a 2 axle lorry, thus prolonging the pavement life and/or enabling a cheaper pavement design to be effected.

Each pass is converted into a standard axle load and it is this value that governs the design of an overlay or a road pavement. Previous traffic data is extremely helpful in carrying out a proper design and in predicting optimum maintenance periods for maximizing the economic life of the pavement. One important aspect to bear in mind regarding actual loading, on pavements is that, in many countries, the lorries carrying goods often load beyond their allowable gross weights for economic reasons. This is a feature that must be taken into account in the design of pavements in such countries.

7.0 LABORATORY TESTS

7.1 Determination of Optimum Water Content

In order that a study of the mixes being proposed can be carried out with a view to optimizing their performance in both the fresh and hardened states, a property of the mixes will have to be kept constant. For example, if concrete were being studied, then the workability would normally have been kept constant.
Standard tests such as slump, Vebe, K-slump tester, cone penetration, ball penetration and the remoulding would work well for concrete but not for the cement-rockdust slurry which is a flowable liquid paste.

The viscosity was chosen as the property which is most relevant to flow of the slurry. Experiments were carried out to investigate how the viscosity of the mix varies with increasing water content. The effects of increasing water content in a fresh mix are known to adversely affect properties in the hardened state, such as drying shrinkage and strength. The logical objective was therefore to minimize the total water content, while ensuring adequate flowability of the slurry.

Different viscometers were tried in order to assess their suitability for determining the water content –viscosity relationship with a view to choosing a target viscosity which will result in adequate flowability of the slurry. A sliding plate viscometer, a capillary viscometer, a standard tar viscometer and a standard penetrometer were tried before finally selecting a torsion viscometer. This type of viscometer is used in the sugar industry for the determination of the viscosity of molasses and is suitable for liquid pastes varying from high to low viscosities.

7.1.1 Torsion Viscometer

When a metal cylinder is rotated in a fluid, a resistance is exerted on the cylinder by this fluid. The higher the resistance the higher viscosity of the fluid. The viscometer makes use of this principle.

The common viscometer has a steel cylinder or a paddle suspended in the liquid by means of a wire. When this wire is twisted, it imparts a torque to the cylinder or paddle, which causes rotation. The speed of this rotation is a function of the viscosity of the liquid. This rotation is observed at regular intervals from a scale until the reading becomes constant.

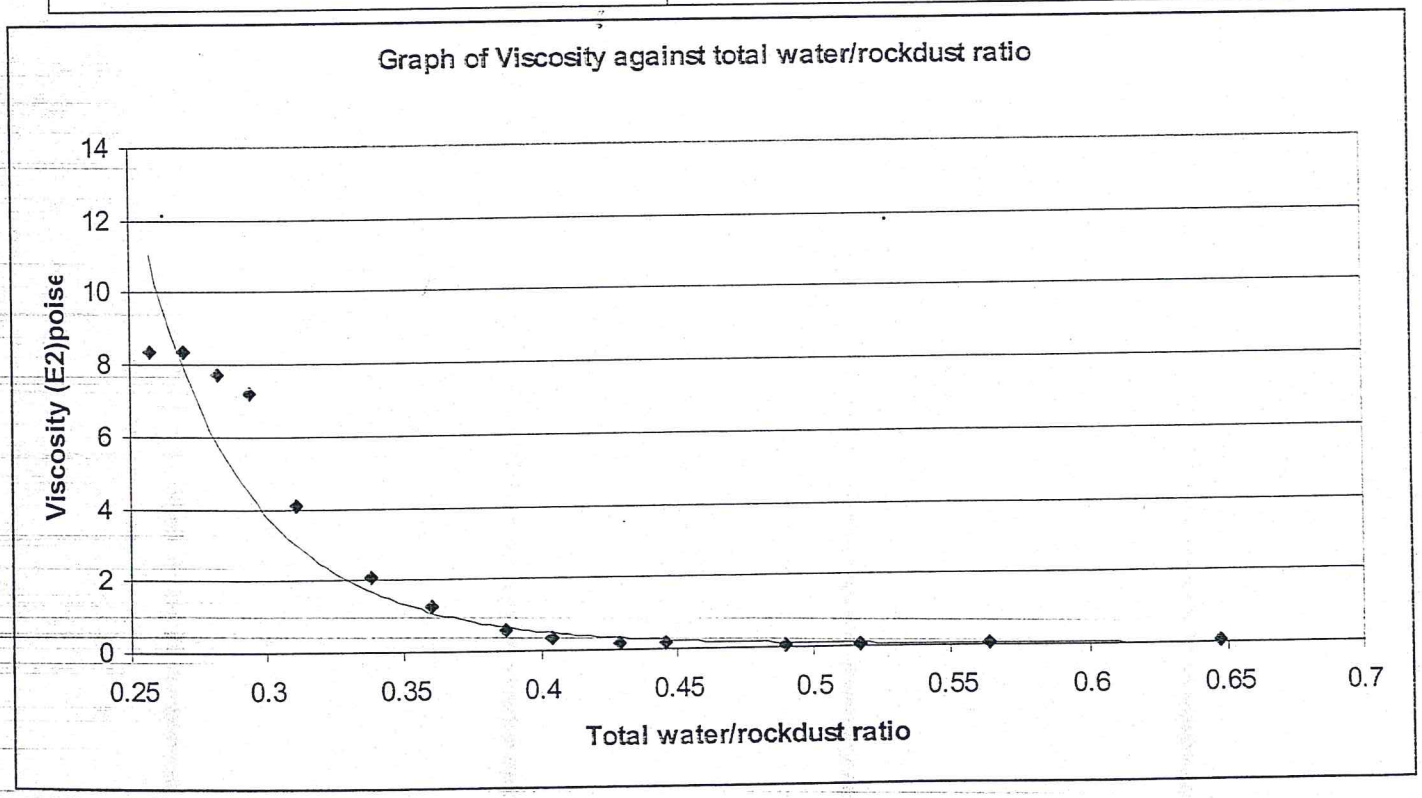
7.1.2 Procedure

500g of oven dried rockdust was placed in a beaker and water was added gradually with continuous mixing until a smooth paste was obtained. The beaker was then centered below the paddle of the viscometer and the latter switched on. As rotation occurred, the paddle was lowered into the paste to a certain depth and the reading was taken. The paddle was then raised at a constant rate at various levels in the paste and the corresponding readings were taken. The average of these readings was then converted into viscosity.

The paddle was then removed completely from the beaker and water was added in increments of 5 ml to the paste and mixed again. Readings were taken for each additional increment of water, averaged and converted to viscosity. This procedure was followed until the addition of water caused no change in the viscosity of the paste.
This enabled the plotting of a graph of Viscosity (in Poise) against water to rockdust ratio.

7.1.3 Results

Total Water/Rockdust Ratio (by weight)	Viscosity E 2 (poise)
0.257	8.33
0.27	8.33
0.282	7.71
0.294	7.20
0.311	4.10
0.338	2.08
0.36	1.25
0.387	0.58
0.404	0.33
0.429	0.19
0.446	0.16
0.490	0.083
0.517	0.058
0.564	0.058
0.647	0.058



From the graph it can be seen that readings for water-rockdust ratio under 0.26 could not be taken due to the fact that there was little or no flowability present. It is the area beyond the 0.26 mark that is of interest to us and where flowability begins. As the water-rockdust ratio increased, the corresponding viscosity decreased up to the ratio of 0.517 where the addition of water caused no further change in viscosity.

This test has several disadvantages in the fact that firstly, it is time consuming and also as the water-rockdust ratio increases, the rockdust settles very quickly at the bottom of the beaker creating a paste with the liquid above. To ensure that meaningful results were recorded, the readings were taken as the paddle entered the paste at the bottom of the beaker.

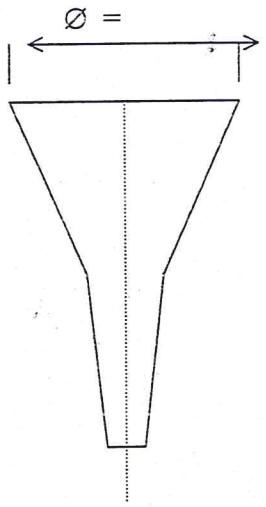
However, due to the impracticalities experienced above, an alternative method was used which was quicker and reliable. The viscosity was measured empirically by measuring the flow time.

7.2 Modified Method

The principle underlying this method is similar to that of the standard tar viscometer. A funnel of known volume is used such that the time taken for a liquid-filled funnel is above 10 seconds (as specified by the standard—10-140 seconds). The minimum time was chosen for practical purposes i.e. mixing time. In order to ensure this, an appropriately sized funnel of known volume was filled with water and the time taken for the water to flow out of the orifice was timed. This proved to be more than ten seconds and thus ensuring that the slurry would take longer due to its greater viscosity.

7.2.1 Apparatus

1. bench stand with attachment to hold funnel
2. funnel of appropriate volume. The funnel used in this experiment is shown below.



Volume = 350

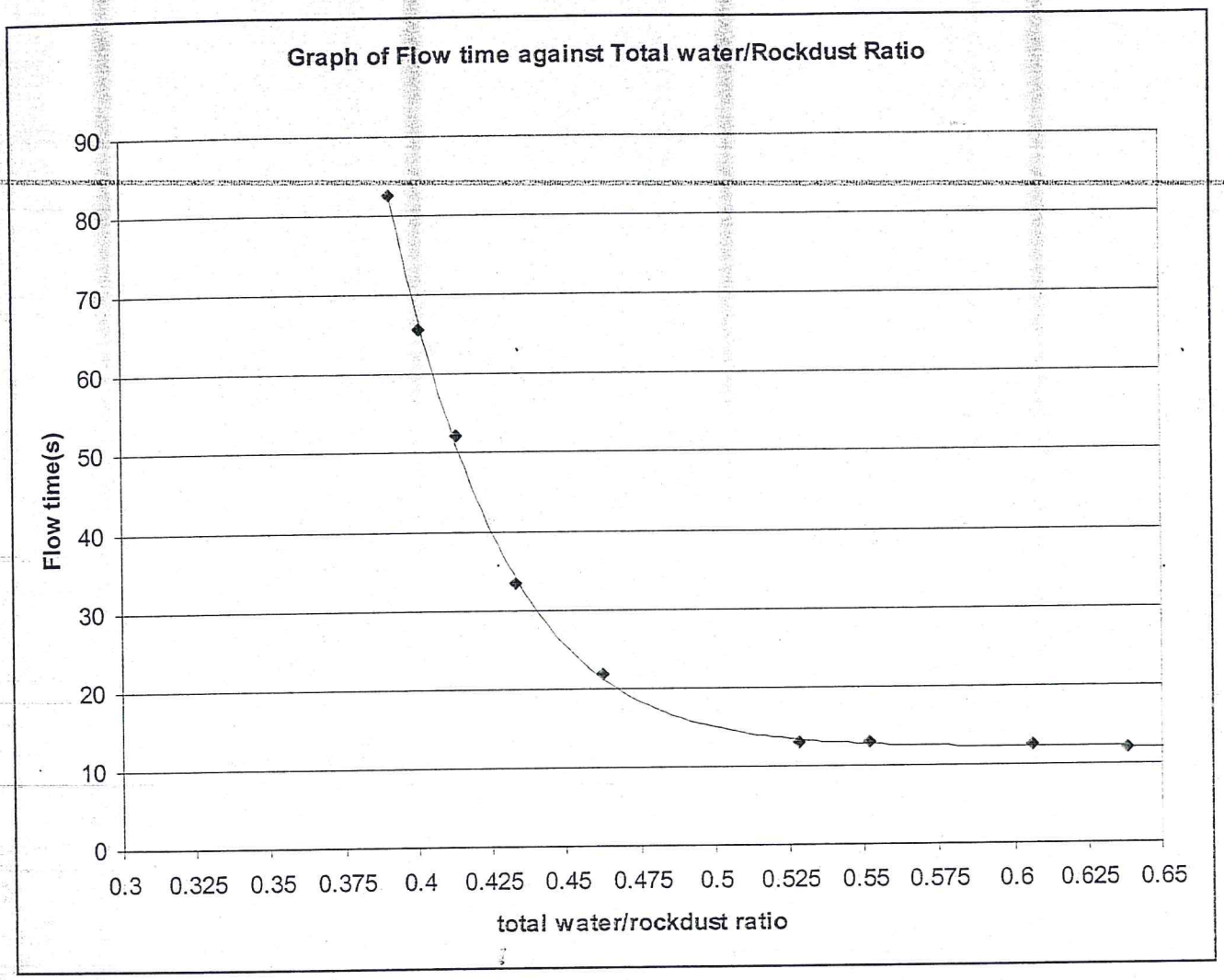
3. spirit level
4. suitable receiver of volume greater than 350 ml
5. straight edge
6. stop watch accurate to 0.1 secs

7.2.2 Procedure

1. the funnel was fixed to the stand and setting both horizontal and vertical was ensured by means of a spirit level.
2. The receiver was placed 100mm directly under the orifice of the funnel.
3. The orifice was shut off with a finger whilst the slurry was poured very slowly into the funnel (to avoid air bubbles). The meniscus was removed by cutting across with a straight edge.
4. The timing was begun simultaneously as the finger was removed from the orifice.
5. Timing stopped as soon as a break in the flow of stream occurred
6. The time recorded for flow was noted to the nearest 0.1 seconds

7.2.3 Results

Total Water/Rockdust Ratio	Flow Time (s)
0.391	82.65
0.401	65.70
0.413	52.20
0.433	33.32
0.462	21.85
0.528	13.02
0.552	12.89
0.606	12.45
0.638	12.01
0.693	11.47
0.751	11.47
Water only	11.3



From the two experiments, it can be seen that there exists a relation between the two methods of testing From the graph above, a flow time within the range of 14.5 to 15 seconds was chosen as a fixed parameter for the three mixes to be studied.

7.3 Variation Of Water Content For Increasing Cement Content

Having established the target flow time required, an investigation was made to see how the water would vary for an increasing amount of cement content.

7.3.1 Procedure

1250g of rockdust oven dried, was placed in a mechanical mixer and 725 ml of water was added. The amount of water added was obtained from the previous experiment whereby a water/rockdust ratio of 0.55 was obtained for a target flow time of 15 seconds). This value was verified practically and then an addition of 2% cement was added to the slurry as well as a small amount of water until the flow time was within the limits of 14.5 to 15 seconds. The cement was increased each time by 2% and the quantity of water added in order to reach the target flow was recorded. This was continued up to a cement content of 14%.

7.3.2 Results

The percentage of cement, total solids (cement + rockdust), water demand to reach the target flow time and the water/solids ratio are tabulated below.

cement %	Cement mass Kg	total solids kg	qty water required for flow time between 14.5 and 15 s	Water/solids ratio
0	0	40	20.4	0.51
2	0.8	40.8	20.45	0.501
4	1.6	41.6	20.55	0.494
6	2.4	42.4	20.69	0.488
8	3.2	43.2	20.83	0.482
10	4	44	20.97	0.477
12	4.8	44.8	21.43	0.478
14	5.6	45.6	22.24	0.488

A graph can be plotted to see the variation of the total water content against the increasing percentage of cement.

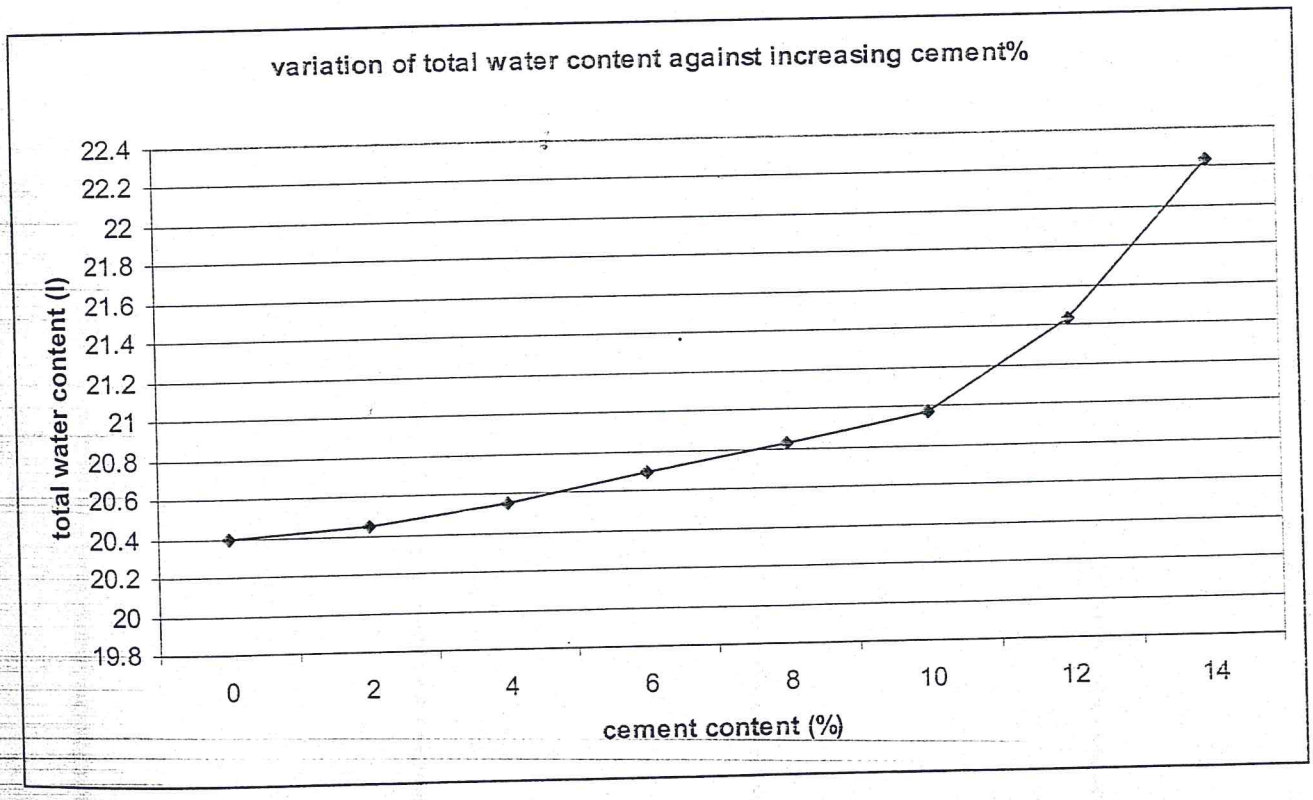


Figure 3

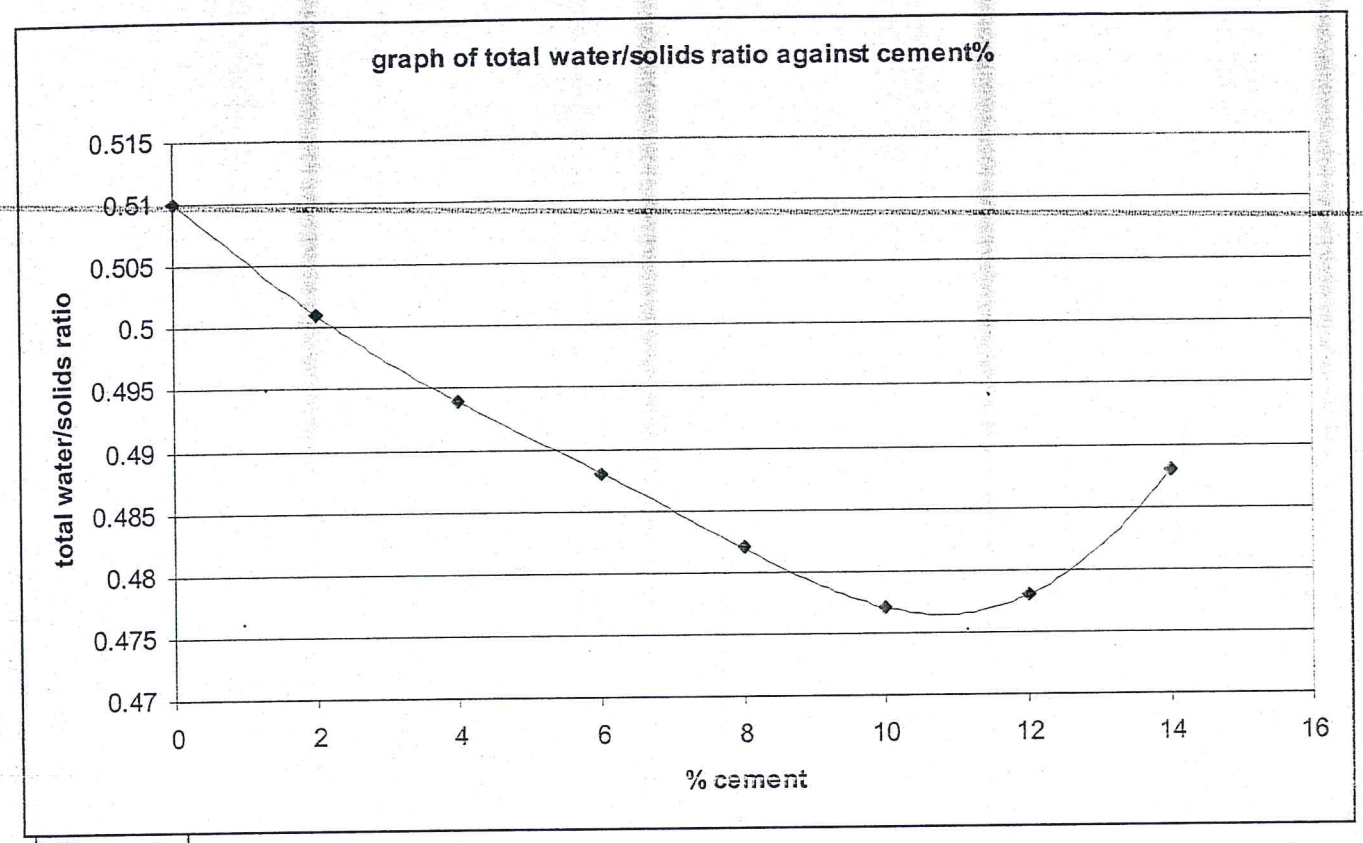


Figure 4

Also, using the above results, a graph can be plotted for water/solids ratio against cement.

7.3.3 Discussion

From the above graph, it can be seen that the increase in total water demand to reach the target flow time was more or less constant for cement contents up to 10%, hence only slight increases in total water. Beyond 10% a change in gradient was noted.

This, can be explained and confirmed by the graph of figure 3, by the fact that the cement particles being much finer than the rockdust particles were in fact filling the voids between the dust particles and thus had very little effect on the water demand required to reach target flow time. For an increase of cement from 0 to 10%, a corresponding increase of only 0.5 lt of water was required to reach target flow time.

Beyond 10%, the voids between the rockdust particles were filled and now the cement was in excess and thus in order to achieve target flow time, additional water was required in the mix to fill in the voids contained in the cement itself.

Another test carried out to confirm this explanation was a measurement of the void ratio. The results yielded were as follows: -

% cement	Void Ratio
0	1.334
2	1.311
4	1.292
6	1.277
8	1.263
10	1.246
12	1.271
14	1.3

This confirms that for an increasing cement content, the void ratio is in fact decreasing as the cement particles fill in the voids between the rockdust particles. Beyond 10%, the cement contributes directly to the target flow time and requires water in order to achieve required flowability hence an increase in the void ratio as the cement itself has voids.

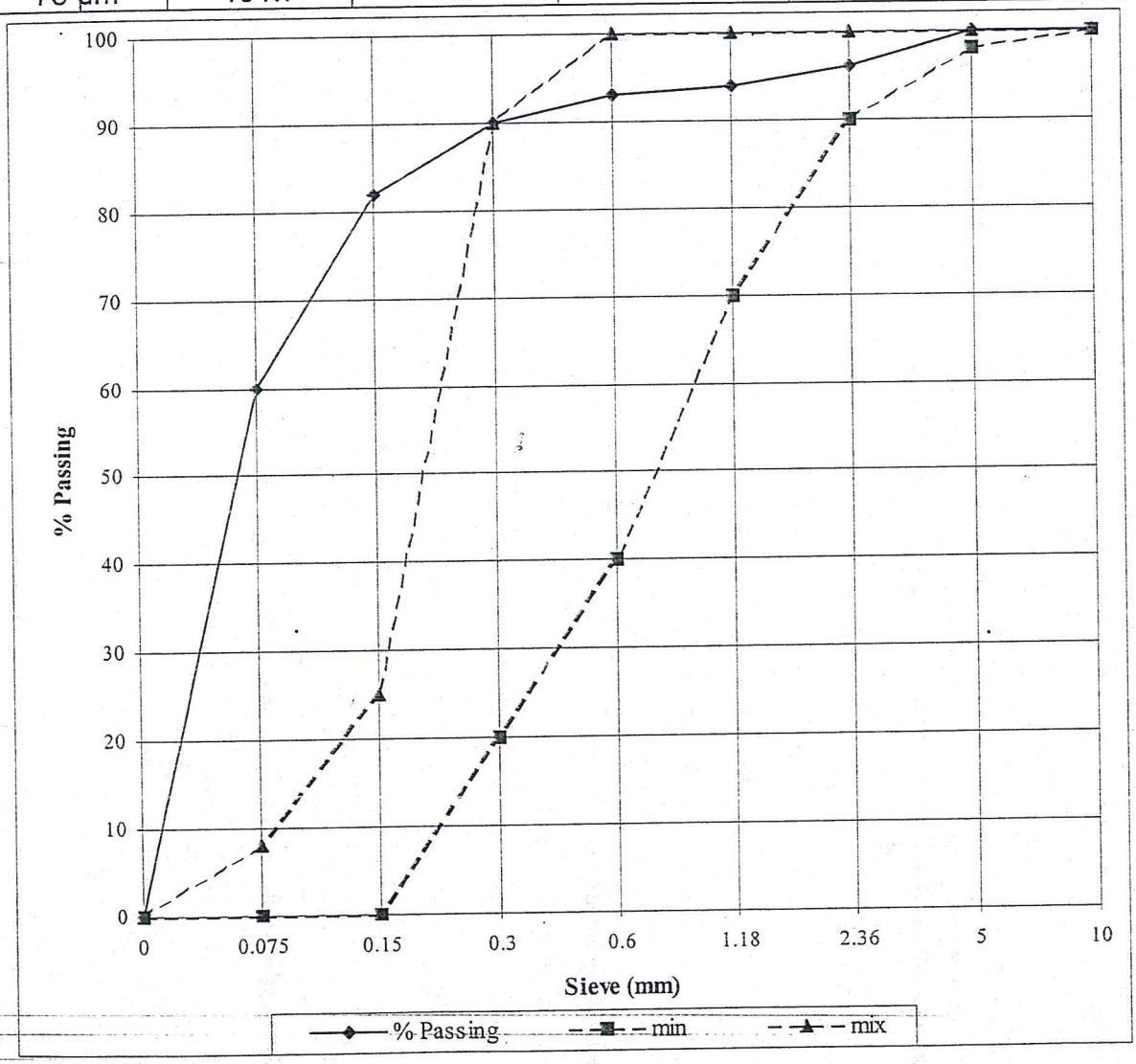
At this stage of the project, it was thought worthwhile investigating the properties of the slurry in the mud form. The slurry is accumulated in the settling ponds and the excess water is recycled back to the plant as previously described. As time goes by, the accumulation is such that the excess water carries over the rockdust in suspension to the plant. Before this occurs, cleaning of the pond is required. The water supply to the pond is cut off and the rockdust, which is in the mud form, is taken from the pond by front-end loaders and transported in lorries to waste land where it eventually dries out. This operation is carried out every two weeks.

7.4 Grading Analysis Of Rockdust

7.4.1 Grading Analysis Of Rockdust In The Mud Form

SAMPLING FROM : Settling Pond No.1

SIEVES NO	CUM. WEIGHTS	% RETAINED	% PASSING	LIMITS
6.3mm	0	0	100	100
5.0mm	0	0	100	98-100
2.36 mm	18.8	4	96	90-100
1.18 mm	27.9	2	94	70-100
600 µm	34.7	1	93	40-100
300 µm	46	2	90	20-90
150 µm	86.3	8	82	0-25
75 µm	191.7	22	60	0-8

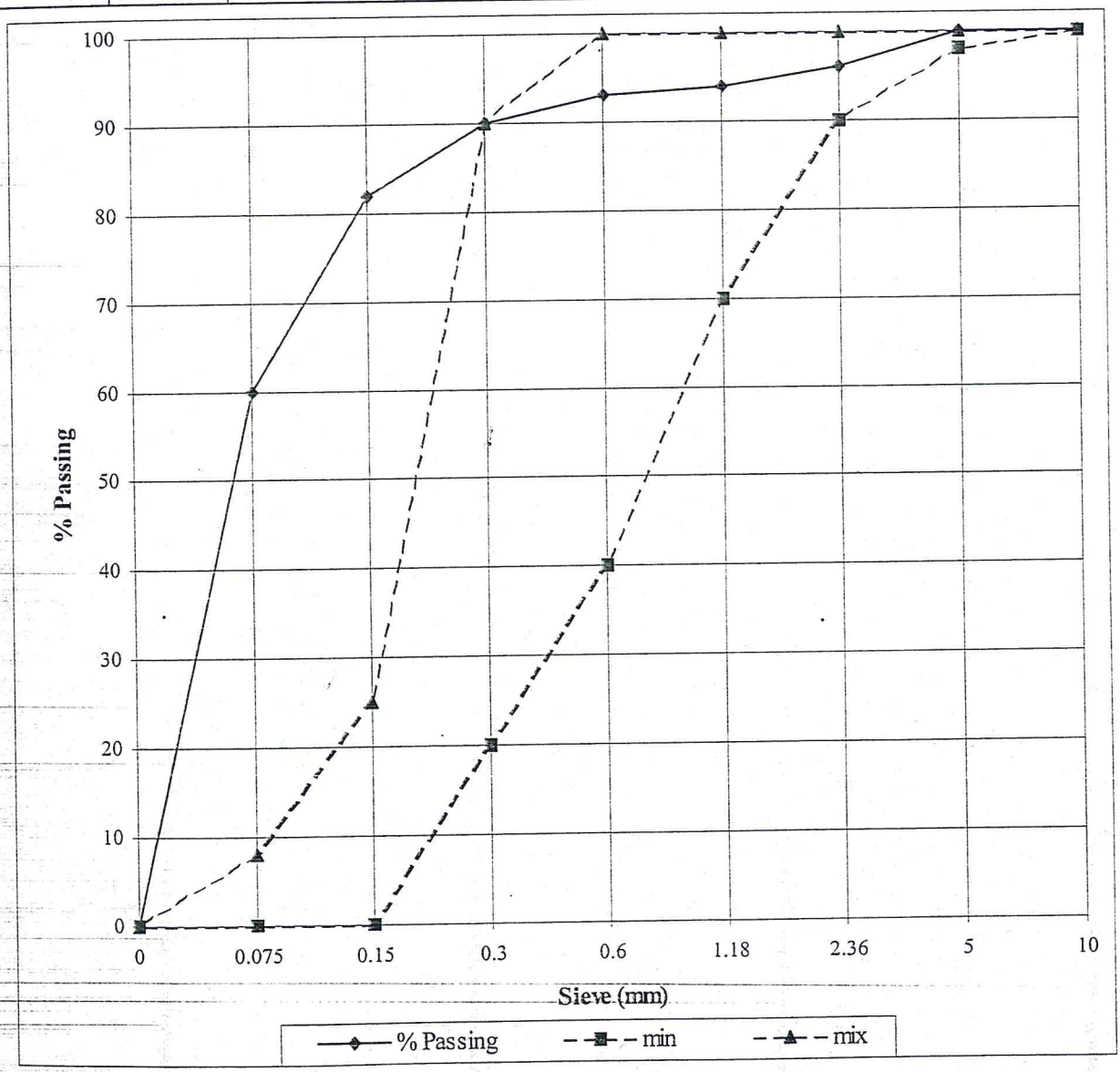


This sample was taken from the first settling pond and graded in the laboratory.

7.4.2 Grading Analysis Of Rockdust In Powder Form

SAMPLING FROM : Stockpile Near Stone Crusher

SIEVES NO	CUM. WEIGHTS	% RETAINED	% PASSING	LIMITS
6.3mm	0	0	100	100
5.0mm	0	0	100	98-100
2.36 mm	19.1	3	97	90-100
1.18 mm	44.1	4	94	70-100
600 µm	60.3	2	91	40-100
300 µm	76.6	2	89	`20-90
150 µm	96.3	3	86	0-25
75 µm	121.8	4	82	0-8



a test was carried out whereby each rockdust in equal amounts were oven dried and added with equal amounts of cement and water and the flow time was measured.

7.4.3 Results

	Dry mass	Cement mass	Water (ml)	Flow
Stocked rockdust	400	24	270	16.58
Mud form	400	24	270	12.96

The test was repeated and the following results were obtained: -

	Dry mass	Cement mass	Water (ml)	Flow
Stocked rockdust	400	24	270	17.69
Mud form	400	24	270	13.23

7.4.4 Discussion

It can be seen from the two sieve analysis that the rockdust in the stocked form is much finer than that of the mud form. The former has 82% passing sieve size 75μm whereas the latter has only 60% passing sieve size 75μm. In order to confirm this conclusion further, the results of the second test can be analysed.

The stocked rockdust is finer than that existing in the mud form since it has a greater surface area and hence would require additional water in order to achieve the same flow time as that of the mud form. The test was performed with various samples of rockdust taken at differing locations and it was found that whilst the mud form definitely required less water to obtain target flow times due to it being coarser in nature, the flow time measurements were not consistent.

Much difficulty was found with regard to the repeatability of the flow test for example, for a given material the same flow test approach was indicating different water requirements to achieve the minimum flowability. This was probably due to the highly flowable nature of the mix wherein the suspended solids had a tendency to settle within the funnel used for the flow measurement This inevitably disrupted the time measured for the slurry to flow out of the funnel. Another main inconsistency was the human error involved in the time recorded for the flow measurement of the same slurry mix to be emptied out of a 350-ml funnel. This varied up to 1 second in some cases.

In addition to the above, laboratory tests had shown that there was a significant difference in particle size distribution for rockdust sampled from the stockpile as compared to rockdust material sampled from the sedimentation pond and consequently, differing flow values were obtained depending on source sampling.

A number of remedial measures were attempted such as oven drying the rockdust prior to measuring the water demand for flowability, addition of dispersing/defloculating agents (e.g. sodium hexametaphosphate) and sieving the mass of rockdust in order to exclude agglomerated dust particles. Although all these measures had some beneficial effects to some extent, none was entirely satisfactory.

At this point, it was decided to change the approach. Instead of using flow to control the mix, a more reliant and controllable way was found to keep the water to total solids ratio constant and expect some variation in the flowability. As long as this flowability is adequate for ensuring easy pouring and self-compaction, these variations have little or no practical significance.

The water to total solids ratio used was determined by adding water in small amounts from the more or less dry condition until adequate flowability was achieved bearing in mind that the aim is to keep the water content to a minimum.

7.5 California Bearing Ratio For Soaked and Unsoaked Conditions.

7.5.1 Introduction

The California Bearing Ratio (CBR) test is a penetration test used for the evaluation of strength of different materials. It is obtained by measuring the force required for the penetration of a cylindrical plunger of cross sectional area 1935 mm^2 to penetrate the soil at a given rate. At any given penetration value, the California Bearing Ratio will be defined as the ratio of the force to a standard force.

The CBR tests were carried out to evaluate the strength of the cement-rockdust slurry. Both the soaked and unsoaked conditions were tested for CBR at various ages i.e. 1,2,3,4,7 and14 days to evaluate the evolution of CBR with time.

Soaked CBR were carried out as it is one of the specified parameters of the Ministry of Public Infrastructure which states a CBR of not less than 10% after a soaking period of 4 days.

As far as the soaked CBR test was concerned, the material were put into water after 24hrs moist curing implying that a 4 days soaked sample would have undergone 1 day moist curing and 3 days soaking.

It should be stated that the results obtained for CBR have the following limitations: -

1. The results give an empirical strength value, which cannot be directly related to more fundamental properties governing the strength of materials.

2. The results only have a direct application to the method of design for which the test was devised.

The California Bearing Ratio test caters for a wide range of materials from clay to fine gravel.

7.5.2 Procedure

Mixing of the cement-rockdust slurry was done in the lab in a mechanical mixer. The CBR moulds were thoroughly cleaned and oiled in order to prevent the hardened material from sticking to the internal surface of the mould and thus facilitating cleaning.
The cement-rockdust slurry was poured slowly into the mould to prevent the formation of air bubbles, which, if present, would seriously affect the results. The mould was filled up to the rim and the excess material cut off with a straight edge and wiped clean. The sample was then moist cured by means of damp cloths placed over the top surface for the first 24 hours after which the samples which were meant to be unsoaked were left in the air until the age of test had been reached. For the samples which were meant to be soaked, after the moist curing, the solid baseplate was removed and replaced with a porous one. The sample was then immersed into a bath of water such that the water level was just below the top collar. When testing age had been reached, the sample was removed 15 minutes before testing and allowed to drain.

7.5.3 Results

The results shall be recorded, according to BS 1377-1975, to the nearest 1% for CBR values up to 30, to the nearest 5% for CBR values between 30 and 100 and to the nearest 10% for CBR values over 100 and results within 10% of the mean bearing ratio shall be averaged.

For comparison purposes, tests were carried out on top face and bottom face of the moulds used for testing CBR. Also soaked and unsoaked samples were tested and results compared. Soaked samples form part of the specifications laid out by the Ministry of Public Infrastructure.

Age at Test	6%		8%		10%	
	Top Face	Bottom Face	Top Face	Bottom Face	Top Face	Bottom Face
2	7	10	10	11	19	22
3	9	13	12	13	27	30
4	12	18	16	18	34	58
7	23	27	32	38	57	65
14	40	51	54	64	83	90
28	66	80	85	106	106	120

Age at Test	Test Condition	6%	8%	10%
2	Soaked	7	11	18
	Unsoaked	8	13	20
3	Soaked	10	12	26
	Unsoaked	16	21	28
4	Soaked	12	16	33
	Unsoaked	13	17	38
7	Soaked	21	31	55
	Unsoaked	22	32	70
14	Soaked	42	51	82
	Unsoaked	43	52	112
28	Soaked	65	83	102
	unsoaked	80	96	130

Additional tests to include 2 and 4% cement-rockdust slurries for CBR were done at 4 days soaked. A summary of the overall data collected is as follows: -

	1d	2d	3d	4d	7d	14d	28d
2%	1	1	1	4	8	14	23
4%	5	6	8	10	20	35	60
6%	5	7	9	12	23	40	66
8%	8	10	12	16	32	54	85
10%	15	19	27	34	57	83	106

7.5.4 Discussion

An observation made concerning the tests made after soaking. It was observed that the bottom surface of the sample was smooth and hard compared to the top surface which was easily indented with a finger when pressed hard enough thus implying a harder bottom surface compared to the top.

As previously stated, the Ministry of works specifies a 4 day soaked CBR to be not less than 10%. From the results obtained, it can be seen that at even 3 days soaking (and I day moist soaking), the target CBR value had been reached in all three mixes. It was decided that the original mix designs of 6,8 and 10% be changed to 2,4,6 and 8 % and also a control trench which shall be backfilled in the traditional manner.

7.5.5 Conclusion

From the results, it can be seen that the air cured 10% cement-rockdust slurry had the greatest strength followed by the 10% soaked slurry. The trend was proportional to the cement content with 2% being the lowest in strength.

It was noted that the water cured samples had a lower CBR value compared to the air cured ones and also that the CBR values were greater at the bottom surface compared to the top.

This can be explained by the fact that for water cured samples, bleed water migrating to the top surface was acting as a hindrance to the strength development of the cement-slurry. The bottom face had better hydration of cement compared to the top face and hence a greater CBR value. Also, the particles of the slurry, when poured will segregate during settling with the large particles settling to the bottom and the fine particles accumulating near the top. The excess water on top will keep the finer particles loosely packed as compared to the bottom part which will be more compact due to gravity and with less free water. Also the 24 hr moist curing period was advantageous to the bottom surface as its hydration was better compared to the top surface and enabled it to develop greater strength.

The fact that the bleed water could not evaporate fast enough and hindered bond development, reflects in the CBR results for top and bottom faces where the initial values are similar with the difference increasing in magnitude with time.

7.6 Plastic Density

The plastic density is an important factor when designing mixes. It enables the mass of materials per unit volume to be calculated in a mix. The plastic density would be the mass of a material occupying known volume. It is expressed as Kg/m^3. The plastic density also enables the degree of compaction to be assessed.

7.6.1 Test method

Plastic density was measured according to BS 1881-Part 107- 1983 with the exception that no compaction was done. The slurry was mixed and poured into a pre-weighed standard mould up to the rim. The mass of the container + slurry was noted. The plastic density was obtained by dividing the uncompacted mass of the slurry by the volume of the container.

7.6.2 Results

Cement % in mix	Plastic Density Kg/m^3
2%	1704
4%	1720
6%	1725
8%	1719

8.0 Test Mixes

The ingredients and their relative proportions are known as the design mix. The design mix relies on data accumulated by previous trials and shall be expressed in Kg/m^3.

8.1 Mixes

Test Mix Ref.	Mass of dry rockdust Kg/m3	Cement Content Kg/m3	Total Water Lt/m3
MC	N/A	N/A	N/A
M1	1100	22	572
M2	1100	44	583
M3	1100	66	595
M4	1100	88	606

MC is the control mix, which was excavated the traditional way according to the specifications of the Ministry of Public Infrastructure.

M1 shall be 2% cement content slurry
M2 shall be 4% cement content slurry
M3 shall be 6% cement content slurry
M4 shall be 8% cement content slurry

The 2 %cement content slurry (M1) was included in the tests even though it did not meet the minimum 10% CBR at 4 day soaked condition .as specified by the Ministry of Public Infrastructure.
This trench was filled first in order that the maximum obtainable CBR value was reached for the given cement content. Samples were taken in situ and tested as of 7 days. Past results had shown that the 2% slurry was not expected to achieve the minimum 10% CBR value as laid down by the specifications of the Ministry of Public Infrastructure.
The CBR results, once stabilised (from past results, approximately 4%), was followed by the asphalting of the five trenches. The 2 % cement content slurry trench was expected to fail in terms of the settlement and deflection measurements and would provide useful data as regards to the limits of the cement content for the slurries as well as the mode/mechanism of failure.

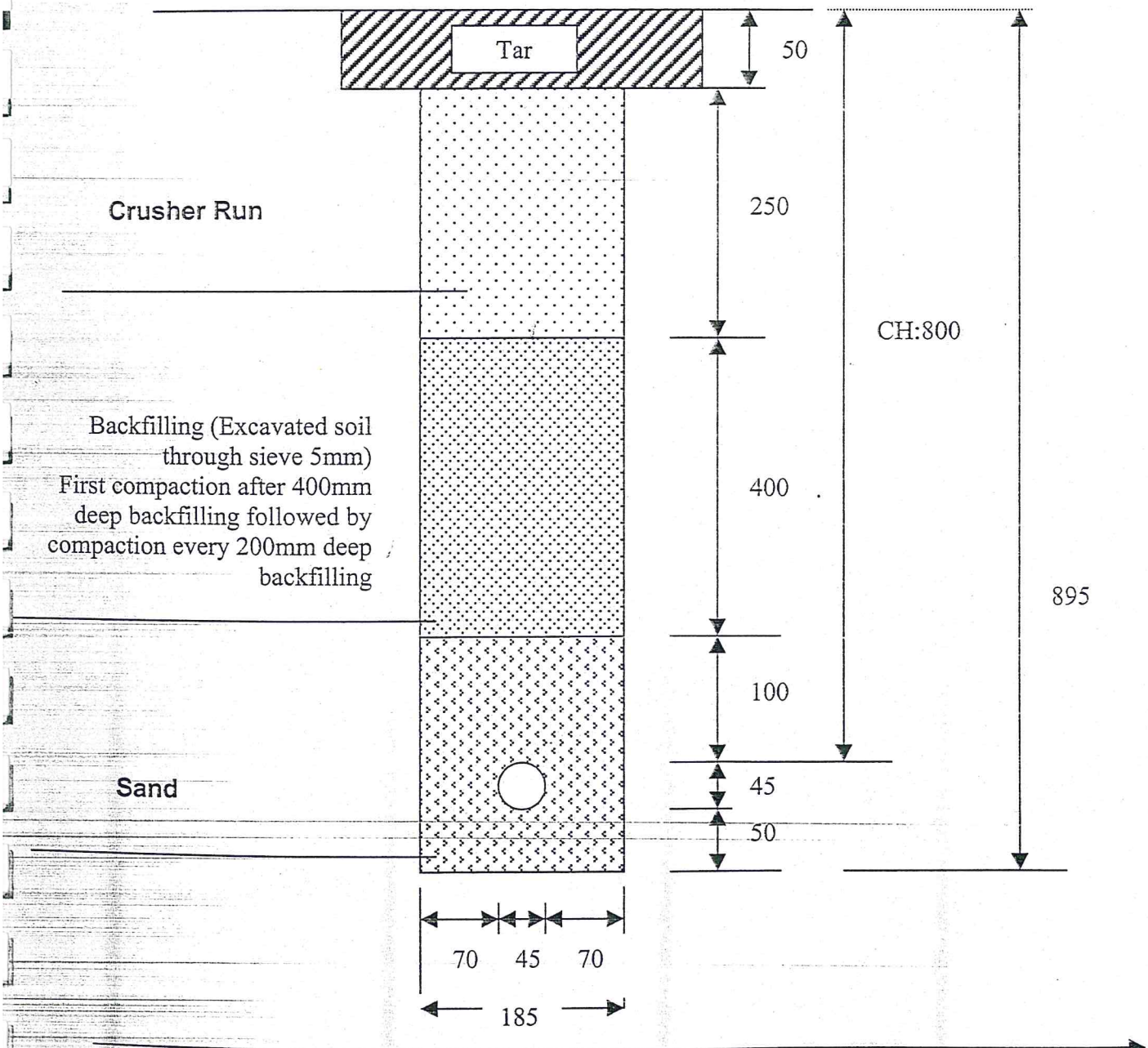
9.0 Specifications for Road Trenches by Local Authorities

The project was geared toward the backfilling of trenches and excavations. Trenching is regularly carried out by the local authorities such as Mauritius Telecom, Central Electricity Board and the Central Water Authority, to name a few. Different local authorities have differing specifications for their trench designs and these were looked into before choosing an appropriate one.

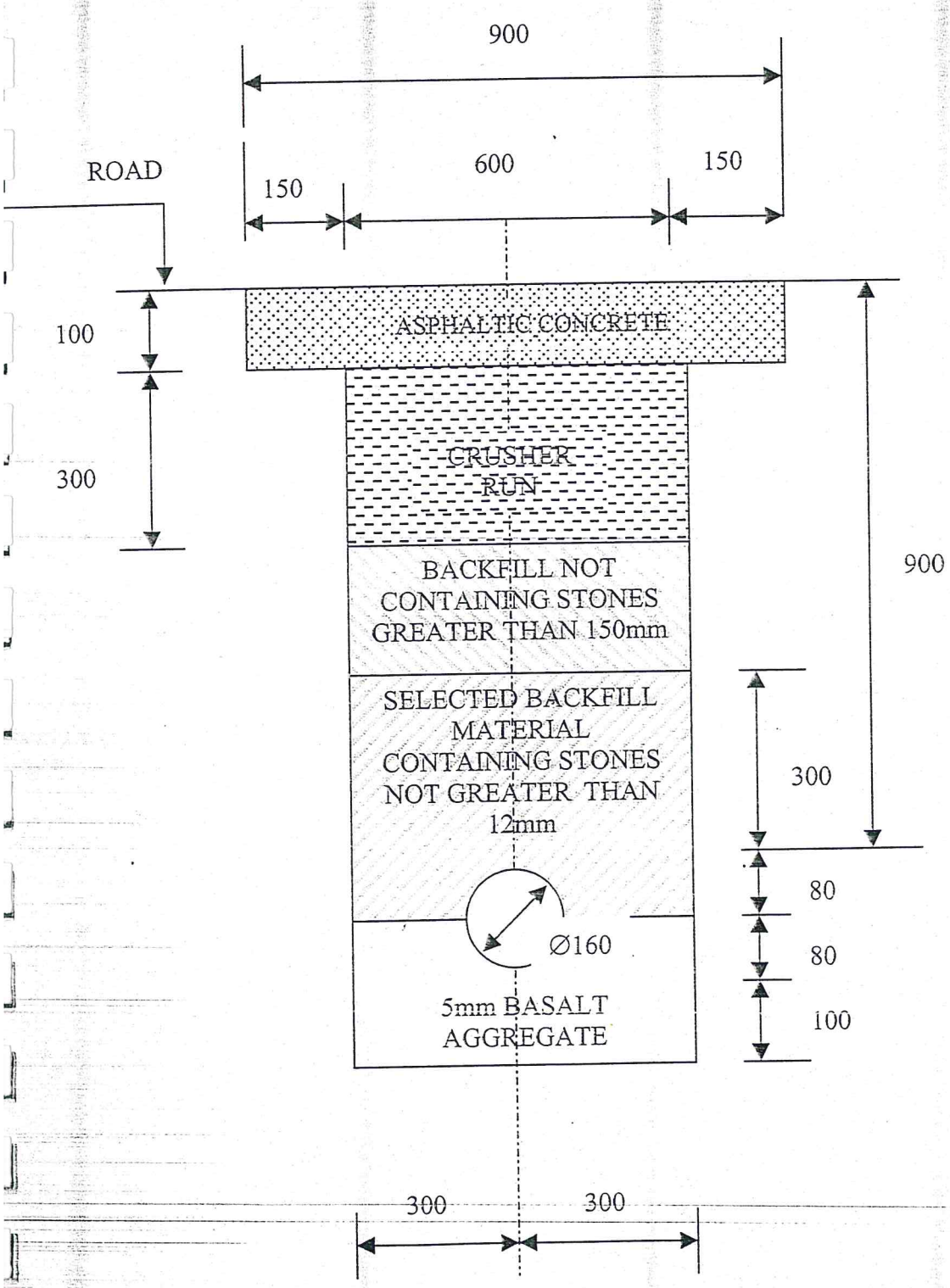
9.1 Mauritius Telecom

TYPICAL TRENCH

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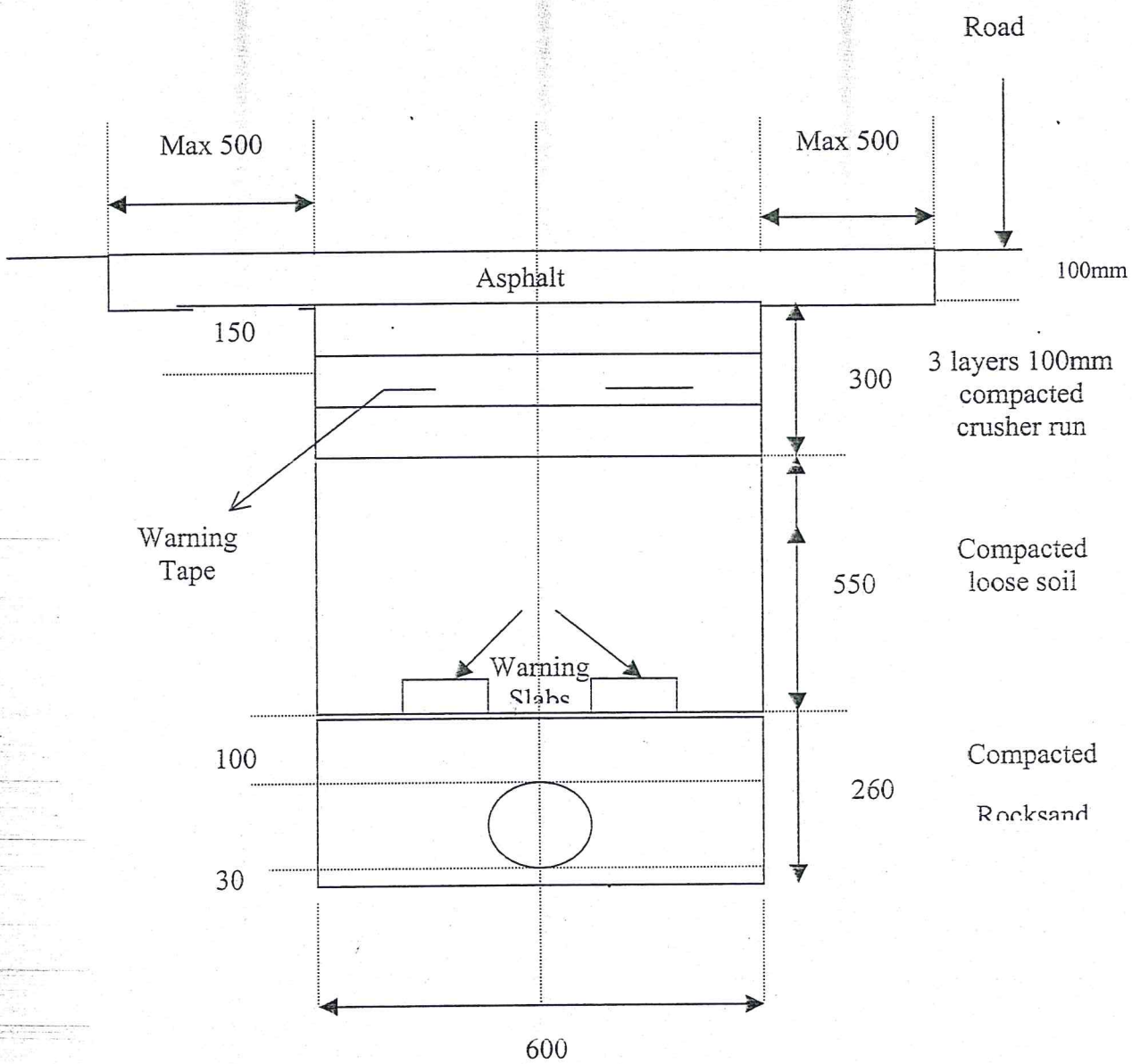
9.2 Central Water Authority



9.3 Central Electricity Board

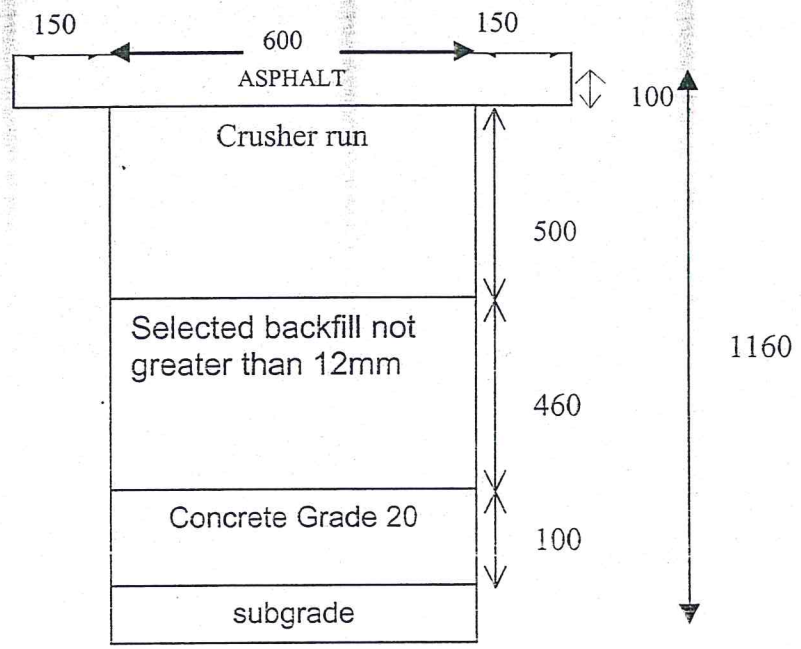
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Typical Cable Trench



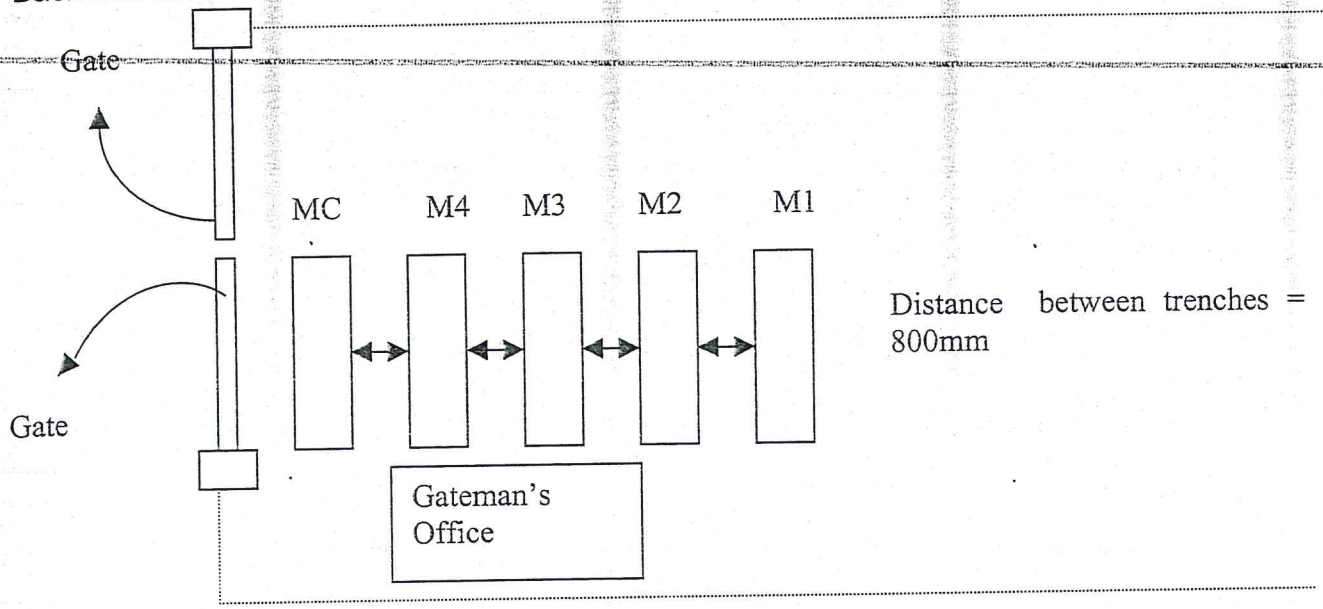
9.4 Trench Specification Adopted

The control trench details were as follows: -
The rockdust-cement slurry trenches were of same dimensions but the slurry was poured into the whole excavation.



10 Trench Works And Performance Measurements

Back Entrance –site for trench excavation



10.1 Excavation and Back filling of Trenches

The trenches were excavated at the back entrance of the Gamma Civic yard. The main traffic coming and going through these gates are lorries which transport boulders to the primary crusher. The lorries enter through the back gates which are normally left open. They stop at the gateman's office for paperwork and then proceed to the weighbridge where their tare+mass of boulders is recorded via a software package called Weighbridge. They then proceed to tip their boulders into the primary crusher after which they return onto the weighbridge where their tare only is taken, the difference between the two masses being the mass of boulders delivered. They leave through the back gates.

The back gate entrance was chosen because there is a record via the Weighbridge software package of the number of lorries entering and leaving the yard and thus the masses of lorries + boulders and lorry tares are known as well as the number of trips each lorry makes during the day.

The trenches were excavated such that the width of the trench was equal to the width of one gate which is 3m. During excavation, the gate no.1 was closed to traffic whilst gate 2 was open.
For the rockdust-cement slurry trenches, all four subgrades were compacted in accordance with specifications and overlaying by 100mm C20 grade concrete. This ensured that the contribution of the subgrade to the performance of the system (if any) was identical in all cases.

The trenches were filled to road level and shall be cut down to –100mm with respect to the road level once the target CBR had been been reached. This had several advantages e.g. facilitating the pouring process as there are no levels to respect and also removal of the weakest part of the trench before asphalting as the results for CBR had shown that the weakest part of the cast moulds were the top.

The 2% cement-slurry took 14 days to reach the minimum 4-day soaked CBR value of 10% as specified by the Ministry of Public Infrastructure (MPI). During this waiting period, the trenches were not loaded with traffic. This was achieved by closing the half of the gate which is in direct line with the trenches. Once the CBR value of 10% had been reached, the slurry-filled trenches were cut down to -100mm with respect to the road level by means of a hoe and a pick. It took one person less than half an hour per trench, to cut the slurry down to –100mm. The control trench (compacted in layers of sieved soil and crusher run) was cut down to –25mm as per the MPI specs for Reinstatement of Road Crossings and Pits. In addition to being cut down, the trenches were also cut wider by 150mm as per the MPI specs. The trenches were then brushed clean of all debris.
The advantage of proceeding with the works in the manner described is two – fold. Firstly the pouring procedure is straight forward as there are no levels to respect and secondly, cutting off the top 100mm of the slurry actually removes the weakest part of the system. This fact was proved during the laboratory trials, which showed that, during the CBR test, the top part of the mould systematically yielded lower results than the bottom part.

Troxler tests were carried out on the cut down surfaces of each trench to ascertain the density (%) as compared to the values of the maximum dry density obtained in the laboratory. The results are as follows: -

Trench No.	% Cement	Density (%)
1	2%	100
2	4%	100
3	6%	100
4	8%	100
5	Control trench	98.5

The above results demonstrate that the slurry filled trenches are fully saturated and are therefore null of voids as compared to the control trench. Being null of voids reflects a very good density as compared to the control trench which has compacted crusher run at optimum moisture content. The above results are an average of 5 tests and they show that the density of the slurry is uniform for the trench due to it being fully saturated. The control trench however, reflects the difficulties faced when having to compact uniformly and at the same time ensuring that the optimum moisture content value of the crusher run is being respected.
This demonstrates the advantage of the slurry, which is self-leveling and also self-compacting when poured into the trench.

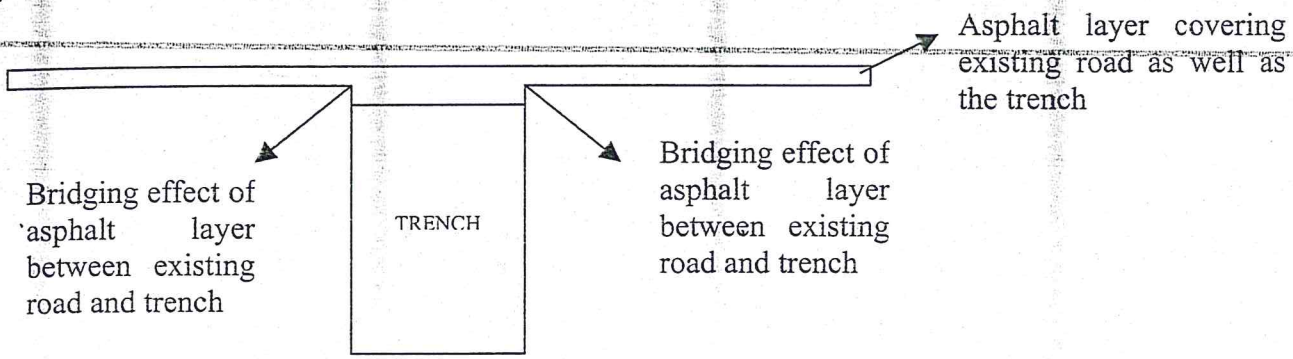
It should also be noted that the rockdust being used for the tests were taken directly from the stockpile and contain contaminants such as aggregates, pieces of broken blocks etc. This will favour the CBR value as the tests carried out in the lab were done with sieved rockdust in order that flow measurements could be taken.

10.2 Asphalting of trenches

Asphalting took place once the 2% slurry trench had a stabilised CBR value (expected at approximately 4). Only the individual trenches were asphalted as opposed to the whole area concerned in order that

a) any bridging effects that may occur be minimised i.e.

b) simulate current practice



10.3 Specifications For Asphaltic Concrete Mix

The mix design for the asphalt used was as per the MPI specifications (see appendix 4.0)which gives the limits of the grading curve for wearing course aggregates as follows: -

Wearing Course

Nominal Size of Sieve (mm)	% Passing by Weight
16.0	100
12.5	90-100
10.0	80-90
5.0	51-63
2.0	32-42
0.6	16-43
0.08	7-9

The trenches were first blown clean by means of a compressor, and then sprayed with prime coat MC 30 cutback bitumen at the rate of 1 l/sq.m. This was left until the surface appeared matt. The asphalt, which was at 147 deg. Celsius, was laid in the prepared area and rolled using a 10-Ton self-propelled roller. The roller made the first two passes without vibrating and then continued making passes with vibration. An average of five passes per trench was observed.

It was immediately noticed that for the 2% slurry-filled trench, the first two passes of the roller had no adverse effect and the asphalt was compacted normally. However, upon vibrating the roller, the asphalt surface began to crack and fluidised slurry was being forced up out of the cracks. This was more apparent at the edges of the trench. The asphalted surface of the trench was very spongy and could not be compacted further and hence asphalting was terminated.

An explanation for this is that the slurry which is saturated with water was able to withstand the static loading of the roller, but once the roller began vibrating, the dynamic loading caused the pore water pressure of the system to damage the skeleton structure of the slurry. The low cement content was insufficient to withstand this pressure build-up and began to break down

thus fluidising the slurry which was forced upward due to the downward force exerted on the system.

At this point, it was decided that the 2% slurry would be replaced by a 5% slurry. The 2% trench was hand excavated. It took two people two hours to excavate the trench (including removal of the asphalt layer) again, by means of a hoe and a pick. The volume of the trench is 3.6m^3 which means that the excavation rate is 0.9m^3 per man-hour. Another advantage of the slurry is that excavation can be done by hand as opposed to using excavation equipment thus reducing overheads.

The 5% slurry obtained 20% CBR at 4day soaked and had reached the minimum 10% at 2 days soaked. The trench was asphalted in a similar way as described above.

10.4 The Deflection Test

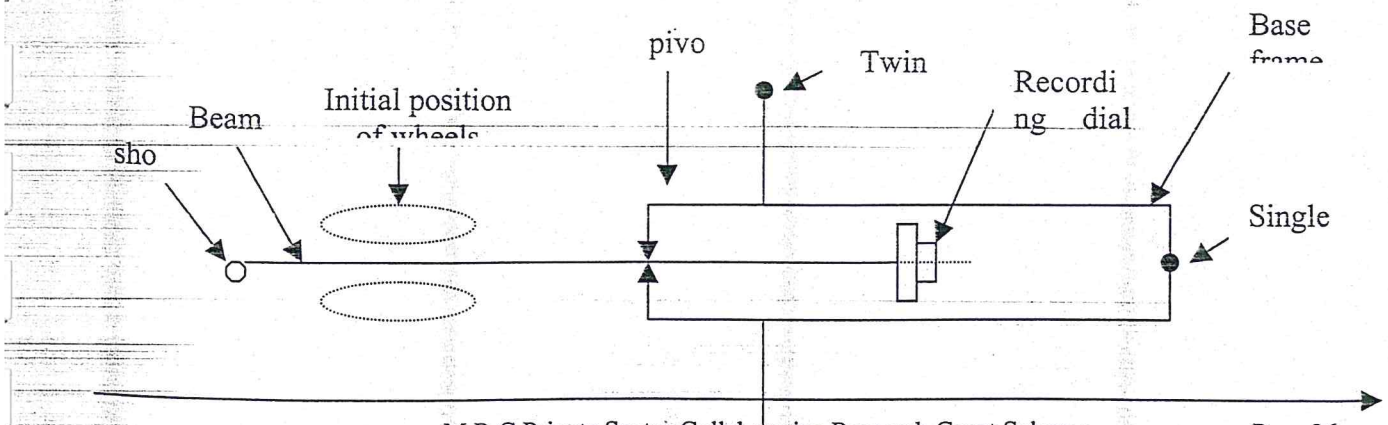
As a wheel passes over a flexible pavement, a downward force occurs which is approximately equal to the wheel load. Its magnitude also depends on the type and thickness of the pavement and on the nature of the subgrade, subbase and base. In a well-designed pavement, the deflection is almost entirely elastic in the sense that the pavement returns to its original level and thickness after the wheel load has passed. The heavier wheel loads will however cause a very small amount of permanent deformation, the cumulative effect of which results in the rutting and cracking in the wheel paths which are the principal indications of deterioration in flexible pavements. Measurements of the elastic deflection of a pavement under a given wheel load are known as deflection tests.

The deflection tests are made principally for the following reasons: -

1. To help in estimating the ability of existing roads to carry future traffic loads and to predict the optimum time for strengthening them
2. To assist with the design of the thickness of strengthening overlays for road pavements.

It is usually more cost effective to strengthen a road than to reconstruct it and in this way, deflection surveys enable strengthening overlays to be designed to match the existing pavement or to indicate whether reconstruction is required.

The most straightforward and direct procedure for studying the deflection of flexible pavements is that developed by A.C. Benkelman in the United States. It uses a long pivoted beam to measure the deflection point midway between the rear wheel assembly as it passes over the pavement. A long beam is essential to ensure that the points of support are remote from the influence of the loaded wheel at the time of measurement. The design of the beam is as below: -



The aluminium alloy beam is sufficiently slender to pass between the dual wheels of a loaded truck. It is 3.66m in length and is pivoted at a point 2.44m from the tip, giving a 1:2 ratio. The pivot is carried on a frame made of aluminium angle supported by adjustable feet. The frame also carries a dial guage arranged to measure movement at the free end of the beam. The details of vehicles suitable for deflection testing are :-

Characteristic	Specification
Rear axle load	6350 kg
Dual wheel load	3175 kg
front axle load	2300-3300kg
Wheel base	3.85m approx.
Tyre size	7.50 x 20 –preferred 8.25 x 20—preferred 9.00 x 20—accepted
Tyre pressure	85 psi
Gap between walls of dual rear tyres	25-40mm >30mm is recommended
Gap between contact area of dual rear wheels	100-150mm

There are two types of deflection tests that exist, namely the transient deflection test and the rebound deflection test.

10.4.1 The Transient Deflection Test

The procedure is to mark the test point in the verge side wheelpath and to position the lorry parallel to the road edge with its rear axle 1.3m behind the test point. The lorry is aligned such that when it moves forward the test point bisects the distance between the tyres of the verge side dual wheels. With the lorry in the initial stationary position a deflection beam is positioned centrally between the dual rear wheelswith its measuring toe resting on the test point, 1.3m in front of the rear axle. By using the adjustable legs and the built in spirit level the frame of the beam is leveled transversely and having checked the alignment of the beam and adjusted it if necessary, the locking device on the beam is released.

The vibrator is switched on and the dial gauge scale is rotated until a reading of zero is indicated. The lorry is driven forward at creep speed to a point such that the rear axle is not less than 5m beyond the test point. The time taken for the lorry to move a distance of 5m from the starting point should be between 9 and 11 seconds.

Records are kept of the initial, maximum and final dial gauge readings. The difference between the initial and maximum readings is proportional to the transient loading deflection and the difference between the maximum and final readings is proportional to the transient recovery deflection. Because the lengths of the arms of the pivoted beam are in the ratio of 1:2 the difference between the dial gauge readings must be doubled to obtain the actual deflection and recovery of the road surface. The transient deflection is the mean of the loading and recovery deflections in the transient test.

10.4.2 The rebound deflection test

The rebound deflection test differs from the previous test in that the wheels are positioned immediately above the test point and the toe of the beam is placed on the test point between the dual wheels. The beam is adjusted in the same way as for the transient test and when the initial reading has been noted, the lorry is driven forward at creep speed until the wheels are far enough to have no influence upon the deflection beam. The final

dial gauge reading is recorded and the rebound deflection is twice the difference between the initial and final dial gauge readings.

The most commonly used test in Mauritius is the rebound deflection test. However, a common mistake is the rear axle load used for the test. The common tyre sizes of the lorries here is 7.50 x 20 which should have a corresponding rear axle load of 6350kg. The common practice is to use rear axle loads of 8165kg which implies an added safety factor when carrying out the test.

Although the rebound test is a quicker method for testing deflection, it should be noted that when the wheels are over the test point, greater plastic flow will be induced in susceptible materials because of the time during which the wheels remain stationary in that position. When the lorry is driven forward the road surface rebounds but an indeterminate amount of recovery of the displaced surfacing material can occur.

The factors affecting the deflection measurements on the whole are
1. Influence of loading wheels upon the deflection beam
2. Effect of changes in solar radiation on the deflection beam
3. The condition of the road surface
4. The effect of temperature
5. The effect of plastic flow upon the deflection test method
6. Effect of hardening of the bitumen in a road pavement
7. Effect of seasonal rainfall.

10.5 Results for Deflection Tests

See appendix 1.0

10.6 Results of Rutting Measurements

see appendix 2.0

10.7 Conclusion

It should be noted that the results dated 13/04/01 are far worse than the rest. This can be explained by the fact that there were heavy rainfalls prior to the test being carried out.

The norms for the deflection tests vary depending on the type of road in use. For this type of cross road, the deflection limit is 1.1mm.It can be observed that the higher cement content slurry and the control trench are performing satisfactorily. However, the 4,5, and 6% cement-slurry filled trenches have at some time or another failed to meet this criteria even though lab tests had previously indicated good compliant CBR values at 4 days soaked This demonstrates the importance of laboratory testing and actual loading conditions.

The MPI states a minimum of 10% CBR at 4 day soaked condition. This type of loading is static loading and it was demonstrated that all the cement-stabilised slurries met the MPI specifications. However, under dynamic loading, the lower cement content stabilised slurry filled trenches were unable to withstand this type of loading indicating values above the deflection limit of 1.1mm.

10.8 Traffic Loading Over the Trenches

From the time when the trenches were asphalted to the time that the 2% slurry was replaced by the 5% slurry which was consequently asphalted upon reaching target CBR value, the gate number 1 was closed all throughout and barriers were erected to prevent traffic passing over the trenches. Once the asphalting was complete and the pilot deflection tests carried out, the trenches were open to traffic.

10.9 Results

(see appendix 3.0)

10.10 Conclusion

It can be said that damage is proportional to the fourth power ratio of mass to standard axle load. Hence a light vehicle will cause negligible damage when passing over the trenches. For this reason, motorcars and similar light vehicles were not taken into consideration.

It should also be noted that the lorries coming in and leaving were subjecting the trenches to four different loading types. First there was the loading when the lorry was entering the yard. 33% of the gross mass was the front axle load and 67% the rear axle load. When the lorry was leaving, 33% it's tare was the front axle load and 67% the rear axle load. I lorry pass constituted 4 types of loading. The different types of loading are called the FAL (front axle load) and RAL (rear axle load). There are therefore two values for each axle per pass.

The lorries that did the most damage were the heaviest, namely the average gross mass of 40-ton lorries. The rear axle load on entering was equivalent to 116 passes of a standard axle load of 8165kg.

The above data represents 546597 standard axle load passes over the trenches for a period of 6 months. The designer usually would envisage standard axle loads in the order of millions depending on the traffic flow. .

11. Economics of the use of cement-rockdust slurry compared to the traditional method of backfilling.

The cement-rockdust slurry has, up to now, been assessed technically but in order that the assessment is complete, a financial appraisal must be carried out.

The following information was used for calculation purposes:-

Description	Rs	Rate
Ordinary Portland Cement	1700	ton
Rockdust	25	ton
Basalt sand	251	ton
Crusher run 0-20	200	ton

The control trench will be used as an example. As an example, we shall assume that 80 m of trenchworks shall be backfilled.

We shall also assume that the following are constants and shall not be included in the costing:-
Excavation of trenches
Warning tape
Asphalting of trenches

11.1 Traditionally Filled Trench

Description	Rs	rate	qty reqd	price/m3
Bobcat	3000	8hr day	1	53.88
Tiptruck 10T	1800	8hr day	1	32.33
General labourer (sieving)	169.53	8 hr day	6	18.27
General labourer (b/filling)	169.53	8 hr day	8	24.36
Compactor wacker (inc operator)	800	8 hr day	1	12.72

Unwashed basalt sand

Compact density	2142 kg/m3
Volume required	0.1*0.6*80=4.8 m3
Price/ ton (Rs)	251
Qty required (tons)	10.28
Total cost (Rs)	2580.7
Price per m3	537.64
Compactor wacker(price per m3)	29.52
Total cost per m3	567.16

Crusher run 0- 20

Compact density	1874 kg/m3	
Volume required	0.5*0.6*80=24 m3	
Price/ ton (Rs)	200	
Qty required (tons)	45	
Total cost (Rs)	9000	
Price per m3	375	
Compactor wacker(price per m3)	29.52	
Total cost per m3		404.52
Carting away matl retained on sieve		120
Foreman/supervisor		107.75

TOTAL COST PER M3 =Rs 1341

11.2 Cement Rockdust Slurry filled Trench

Volume of trench	55.68	m3		
Mix design (per m3)	R/dust	Cem	water	
	1054	84	581	
Qty reqd	58687	4677	32350	
Tons	58.687	4.677	32.350	
Rs/ton	25	1700	53.33	
Total	1467	7951	1725	Rs 11143
Price per m3				Rs 200
Mixer and transportation costs (mixer truck)				900/m3
Cost of carting away excavated material				120/m3
TOTAL COST PER M3				**1220**

Overall, it can be seen that the slurry is economically advantageous. At worst case situation, a saving of 9% can be achieved as well as a massive time saving. Also the advantage is that the slurry will leave no voids in the trench thus ensuring high-density values throughout.

Cement Content	Trench Backfilling Cost / m3	Conventional	Savings %
4	1149	1341	14.3
5	1167	1341	13.0
6	1184	1341	11.7
8	1220	1341	9.0

Overall, it can be seen that the slurry is economically advantageous. At highest cement content, a saving of 9% can be achieved. Also the advantage is that the slurry will leave no voids in the trench thus ensuring high density values throughout.

12 . CONCLUSIONS

From this study the following conclusions were observed

1. the rockdust-cement slurry was found to be a viable alternative to the traditional way of backfilling trenches.
2. Using an 8% cement-rockdust slurry, savings of over 9% in costs can be achieved in the trench backfilling works.
3. The performance of the slurry filled trenches is influenced by weather conditions to which the wearing course is subjected. It was shown that the trenches which were constantly subjected to water failed to meet the deflection performance criteria.
4. The deflection test results were influenced by the weather prior to the test. Heavy rain prior to the test being carried out was shown to have a detrimental effect on the results. For this reason, as a measure of additional safety, tests should be done when the pavement is at its worst, that is, wettest condition.
5. From the results obtained, it was seen that the 4% and 8% rockdust-cement slurry filled trenches as well as the control trench complied with the deflection performance criteria laid down. The trenches underwent a total of 546597 standard axle loads without failure.
6. Although the mixes tested satisfied the MPI specifications, namely :-
   - The 4-day soaked CBR at 95% BS Heavy Compaction should not be less than 10%
   - The plasticity index should not be more than 25%
   - The liquid limit should not be more than 35%

   a word of caution has to be mentioned with respect to the test method (CBR test) which is a static load-penetration test. The trenches were, in fact, during the asphalting process subjected to a dynamic loading which proved to have a deleterious effect .

13.0 Recommendations for Further Work

1. To investigate the effect of using a retarding admixture in the slurry. Retarders are commonly used in the pre-mixed concrete batching industry where the transportation times to site vary widely. A study of the volume of retarder required per hour required to retard could be defined.

2. To investigate the use of a water reducing admixture to the slurry. This will enable maintaining the same flowability of the slurry whilst using less water. The advantage of this would be to have a lower water cement ratio for the slurry which in turn will improve the strength. This implies that the cement content can reduced in order to gain the same strength and hence a cost benefit. Secondly, it will require less time for the slurry to achieve the MPI specifications thus a saving in time.

3. The CBR test performed is a static testing method and it was observed that, even though the mixes tested passed the MPI specs, upon dynamic loading, one of these mixes failed. Therefore a dynamic testing method could be devised and a correlation between the static and dynamic loading could be established.

4. to investigate how the CBR or an alternative dynamic loading test varies with varying water to total solids ratio. This will enable the determination of the extent of water control needed when mixing (especially on-site mixing)

5. a longer term study of the performance of the trenches (typically 2 million standard axle loads) would give a better picture on the performance of the trenches. Based on the data collected, this would take approximately two years monitoring.

References

1. S.M.A. Paharry Flowable Rockdust Slurry as Backfill Material- Project For B-Tech in Civil Engineering-1996

2. Ministry Of Public Infrastructure - Specifications for Backfilling of Trenches and Reinstatement of Road Surfaces- Appendix C

3. Methods of Sampling and Testing - AASHTO T 256-77 Standard Recommended Practice for Pavement Deflection Measurements

4. H.R Smith and C.R. Jones -TRRL Laboratory Report 935 Measurement of Pavement Deflections in tropical and sub-tropical climates-1980

5. BS 1377: 1975 – Methods of test for Soils for Civil Engineering purposes

Appendices

1.0 Results for Deflection Tests

	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
4%			0.08	0.46	.034	0.22	0.26	0.64	0.40	0.86	0.24	0.66	0.90	1.08	0.84	0.90	0.66	0.94	0.92	1.06
5%	02	0.7	0.12	0.18	0.76	1.2	0.66	1.64	1.2	0.44	0.7	0.7	0.30	0.70	0.38	0.68	0.46	0.80	0.54	0.86
6%	0.52	1.1	0.4	1.00	0.20	0.60	0.36	0.30	1.00	1.90	0.40	1.50	0.48	1.20	0.62	0.94	0.50	1.0	0.3	1.8
8%	0.12	0.44	0.24	0.90	0.18	0.64	0.42	0.92	0.90	0.90	0.60	1.00	0.40	0.94	0.78	0.68	0.52	0.74	0.70	1.0
C/R	0.26	0.64	0.40	0.48	0.18	0.22	0.38	0.52	0.58	0.64	0.64	0.84	0.52	0.58	0.38	0.84	0.70	0.76	0.84	0.92

2.0 Results of Rutting Measurements

	26/01/01		15/03/01		21/03/01		29/03/01		13/04/01		28/04/01		15/05/01		02/06/01		23/06/01		19/07/01	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
5%	0	0	0	0	0	3	0	3	0	5	2	6	2	6	3	8	3	8	5	18
4%	0	0	10	30	10	30	12	35	13	46	15	46	18	48	18	48	20	50	20	50
6%	0	0	5	11	8	17	13	22	15	27	22	39	28	45	32	48	36	51	38	52
8%	0	0	0	0	4	2	4	6	6	8	6	11	8	14	8	14	10	16	10	17
C/R	0	0	0	0	2	2	3	5	03	06	05	08	07	10	08	12	09	13	09	15

3.0 Results for Axle Loads

Mass range	FAL In	Av. Mass	Equiv. Factor	Equiv. SAL	FAL Out	Av. Mass	Equiv. Factor	Equiv. SAL	RAL In	Av. Mass	Equiv. Factor	Equiv. SAL	RAL Out	Av. Mass	Equiv. Factor	Equiv. SAL
3.0-6.9	*	*	*	*	5835	3.79	0.05	272	*	*	*	*	*	*	*	*
7.0-10.9	3655	10.33	2.56	6689	*	*	*	*	*	*	*	*	5835	8.85	1.38	8054
11.0-14.9	2180	11.48	1.41	2189	*	*	*	*	*	*	*	*	*	*	*	*
15.0-18.9	*	*	*	*	*	*	*	*	4	18.20	24.69	99	*	*	*	*
19.0-22.9	*	*	*	*	*	*	*	*	535	22.30	55.64	29768	*	*	*	*
23.0-16.9	*	*	*	*	*	*	*	*	4504	24.99	87.75	395220	*	*	*	*
27.0-30.9	*	*	*	*	*	*	*	*	792	27.66	131.70	104306	*	*	*	*

FAL Front Axle Load
Equiv. Factor The equivalence coefficient of a standard axle of 8.165 Tons
SAL Standard Axle Load
RAL Rear Axle Load

4.0 Load Axle Distribution

The following is a list of lorries that transport boulders to the primary jaw crusher. The calculated front and rear axle loads apply to the trenches when the lorry is leaving the yard.

lorry number	tare mass (kg)	front axle load (kg)	rear axle load (kg)
1518	12.7	3.8	8.9
5835	10.2	3.3	6.9
8858	11.9	4.9	7.0
8868	12.1	5.1	7.0
1215ZH91	12	2.3	9.7
1317ZC88	10.9	4.4	6.5
1523ZB87	10	4.4	5.6
2201ZB84	12.4	4.7	7.7
959ZC86	13.7	4.3	9.4
BR380	9.8	2.3	7.5
CA1162	11.2	2.3	8.9
CB1154	10.6	2.3	8.3
CC1270	10.4	3.5	6.9
N862	11.6	4.8	6.8
Total	159.5	52.3	107.2
Relative %		33	67

The lorry when entering the yard with boulders shall subject the trench to the following front and rear axle loads:-

lorry number	tare mass (kg)	mass boulders	total incoming mass	front axle load	rear axle load
1518	12.7	21.03	33.73	13.04	20.69
5835	10.2	21.41	31.61	6.83	24.77
8858	11.9	28.48	40.38	16.22	24.17
8868	12.1	24.40	36.50	9.42	27.08
1215ZH91	12	22.25	34.25	16.88	17.37
1317ZC88	10.9	25.51	36.41	11.76	24.65
1523ZB87	10	24.86	34.86	14.81	20.05
2201ZB84	12.4	29.33	41.73	12.99	28.74
959ZC86	13.7	29.99	43.69	8.13	35.56
BR380	9.8	27.11	36.91	9.18	27.73
CA1162	11.2	20.91	32.11	15.56	16.55
CB1154	10.6	27.02	37.62	6.96	30.66
CC1270	10.4	27.86	38.26	10.42	27.84
N862	11.6	26.66	38.26	18.33	19.93
Total			**516.32**	**170.53**	**345.79**
Relative %				33.0	67.0

- all masses are in tons

5.0 Specifications For Maintenance, Repairs and Upgrading of Roads (wearing course)

MINISTRY OF PUBLIC INFRASTRUCTURE
LAND TRANSPORT AND SHIPPING
ROADS SECTION - ENGINEERING DIVISION

Phoenix - Mauritius

In reply please quote MPIP/R/1288/2000-2001 Date : 23 February 2001

To:
The Manager
Gamma Civic Co. Ltd
Royal Road
Chapman Hill
Beau Bassin

Dear Sir,

Maintenance. Repairs and Upgrading of Roads

This is to inform you that the limits of the grading curve for wearing course aggregates given on page 108 of the Document have been modified as follows:

WEARING COURSE

Nominal Size of Sieve (mm)	% Passing by weight
16	100
12.5	90 – 100
10.0	80 – 90
5.0	51 – 63
2.0	32 – 42
0.6	16 - 23
0.08	7 - 9

The above limits will apply for works ordered as from the date of this letter.

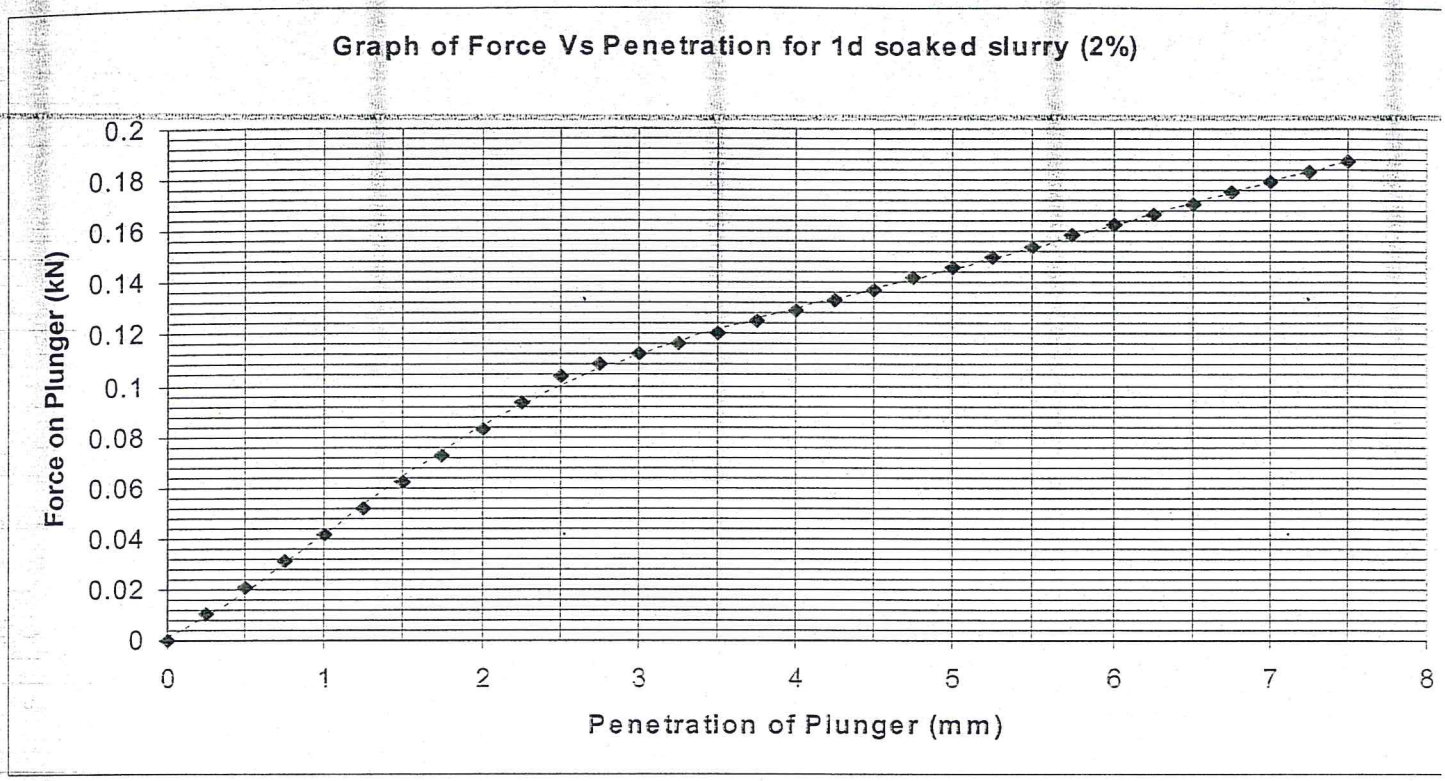
The Supervising Engineer will ask you to proceed with a trial section as per Clause 3.15 of the Specification.

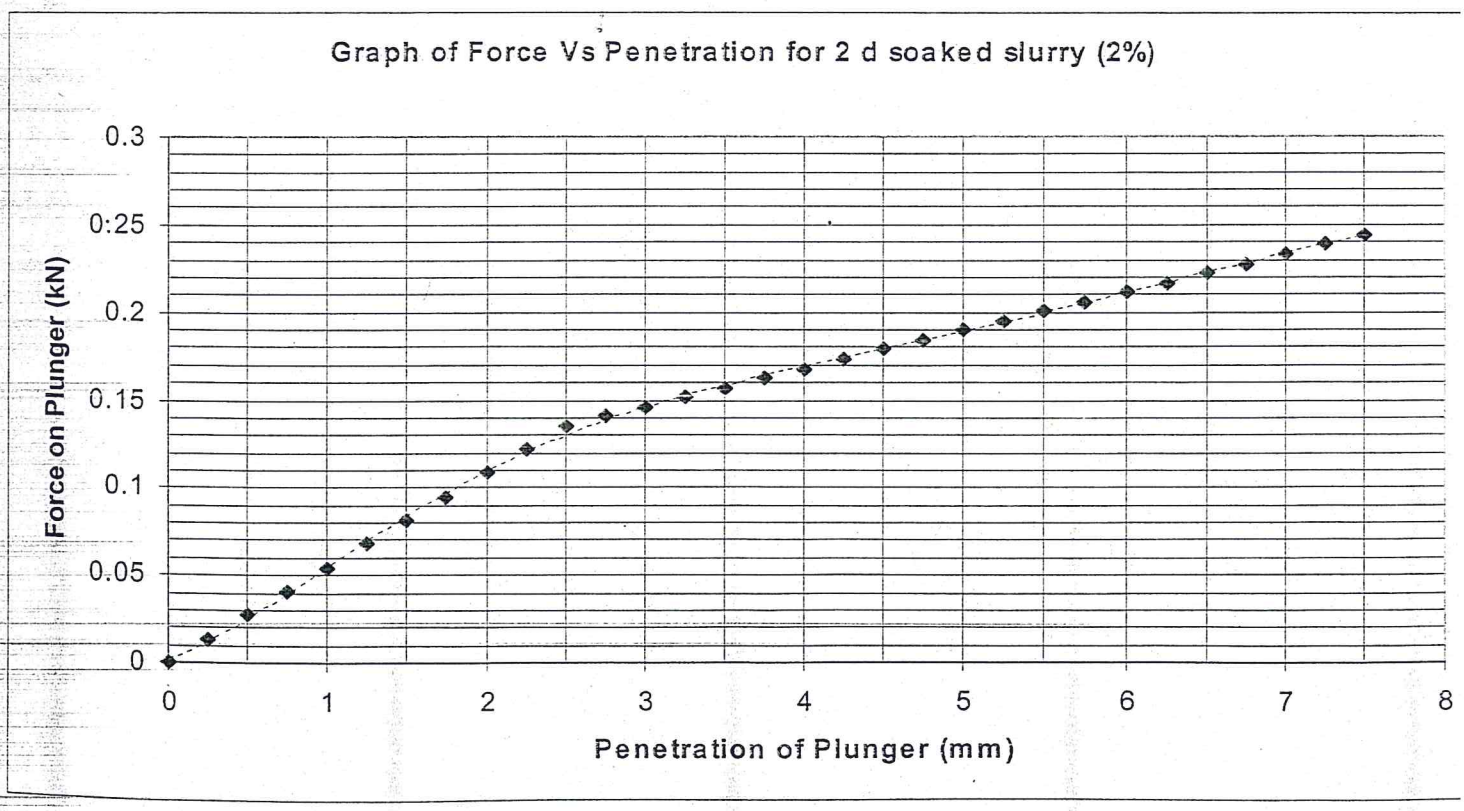
Yours faithfully,

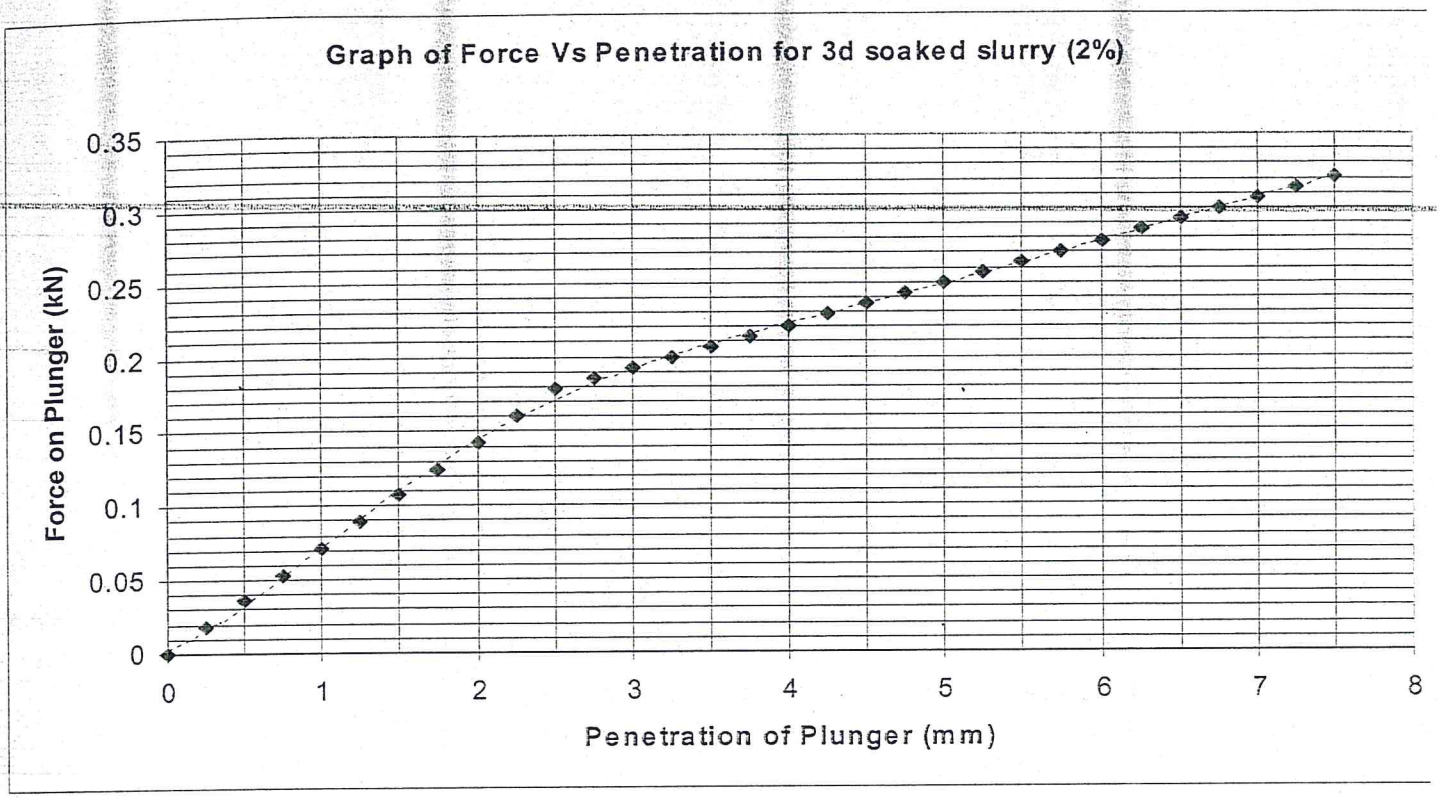
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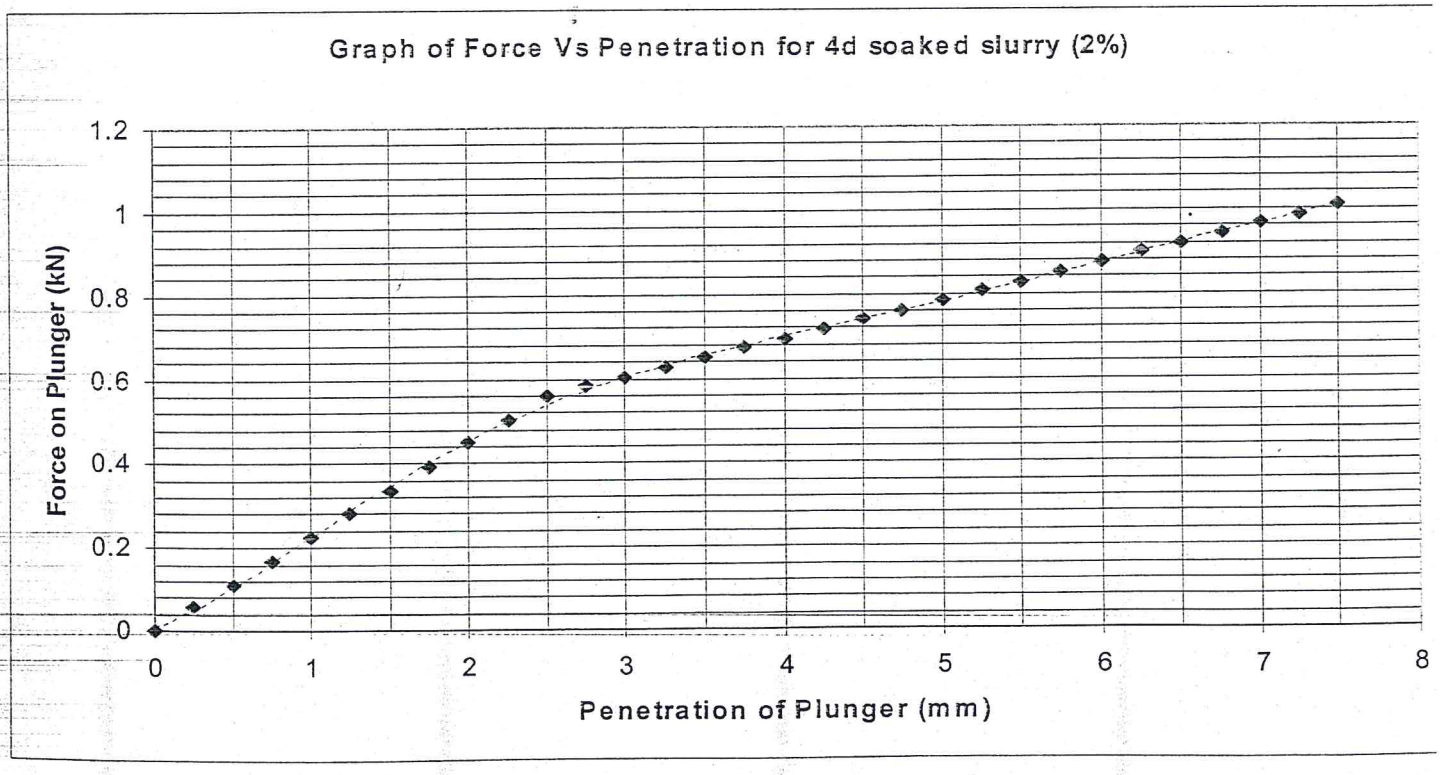
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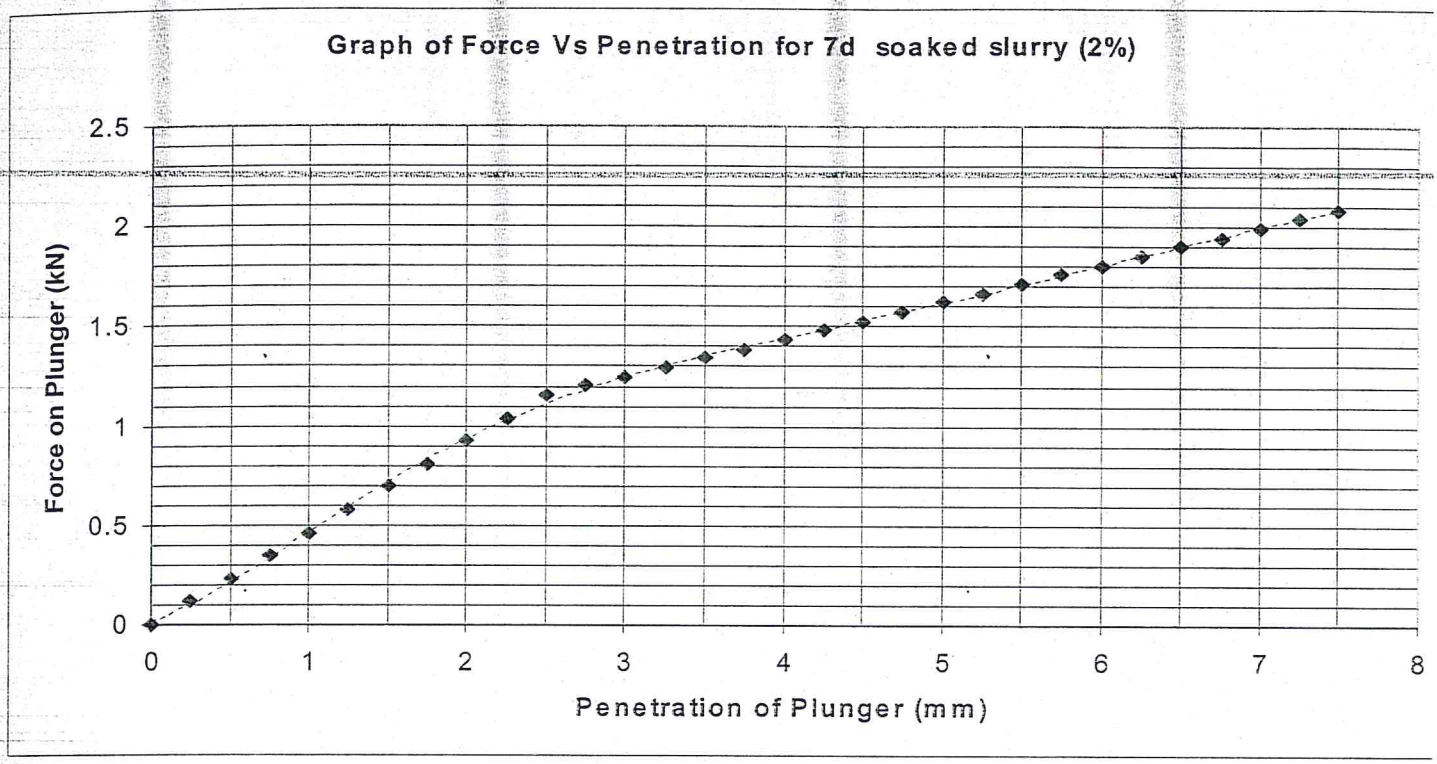
6.0 CBR graphs

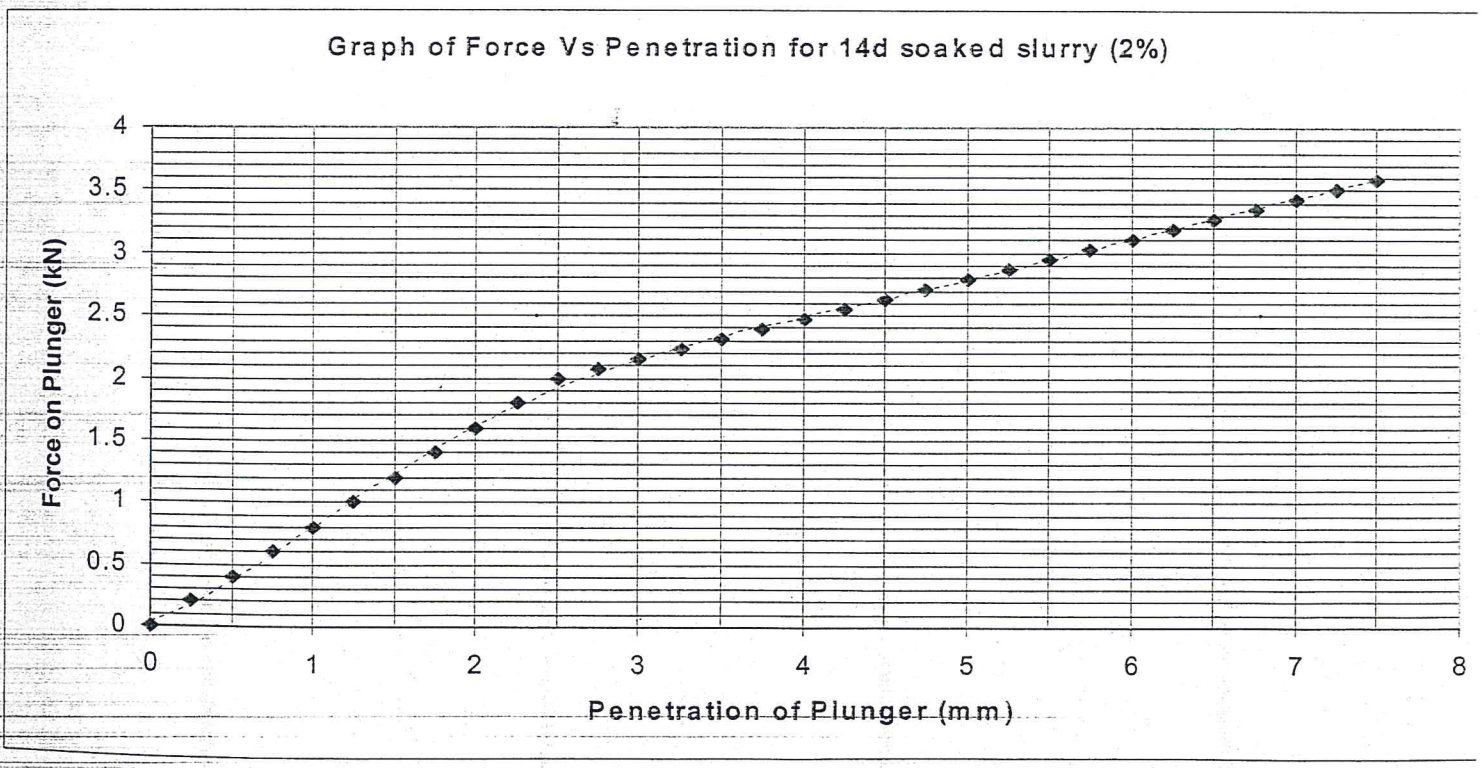


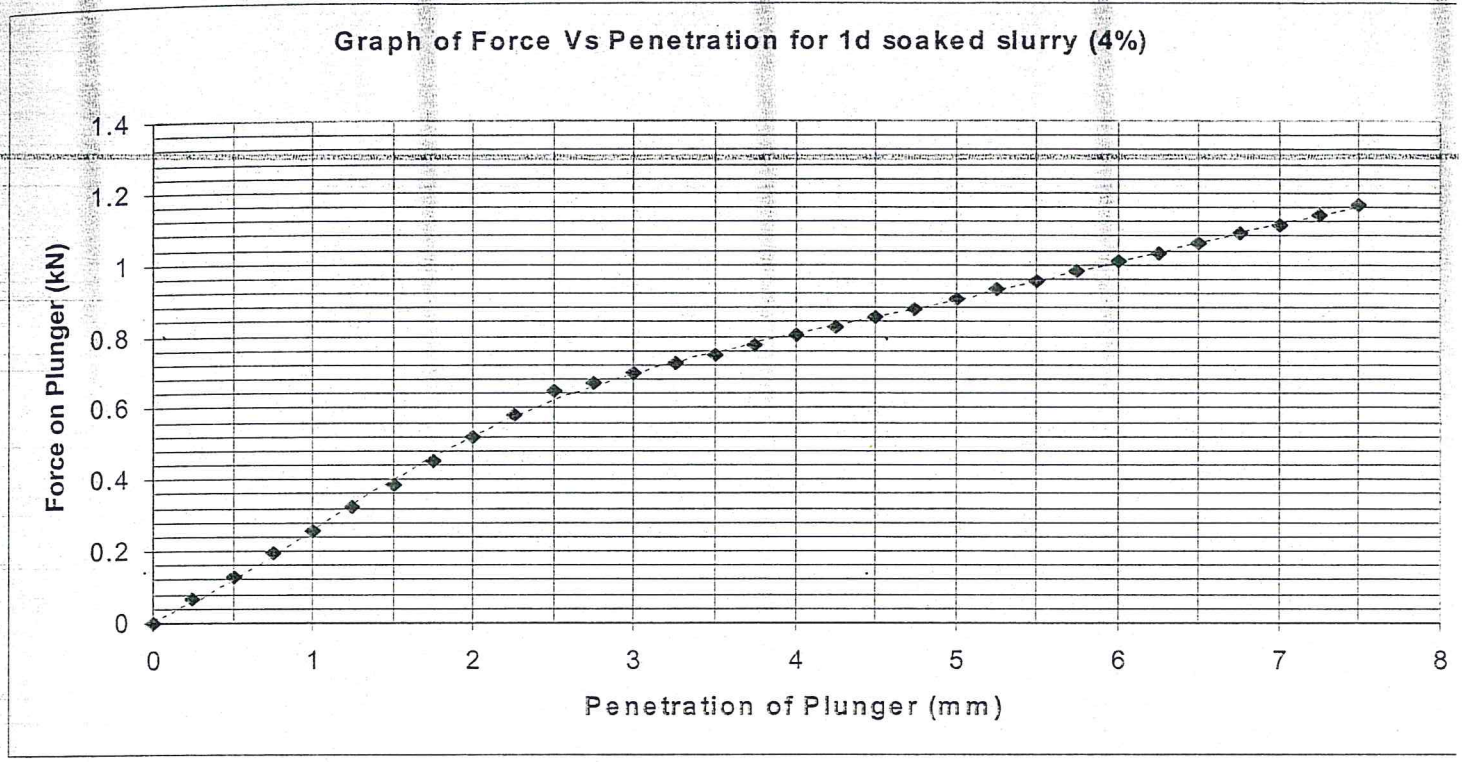


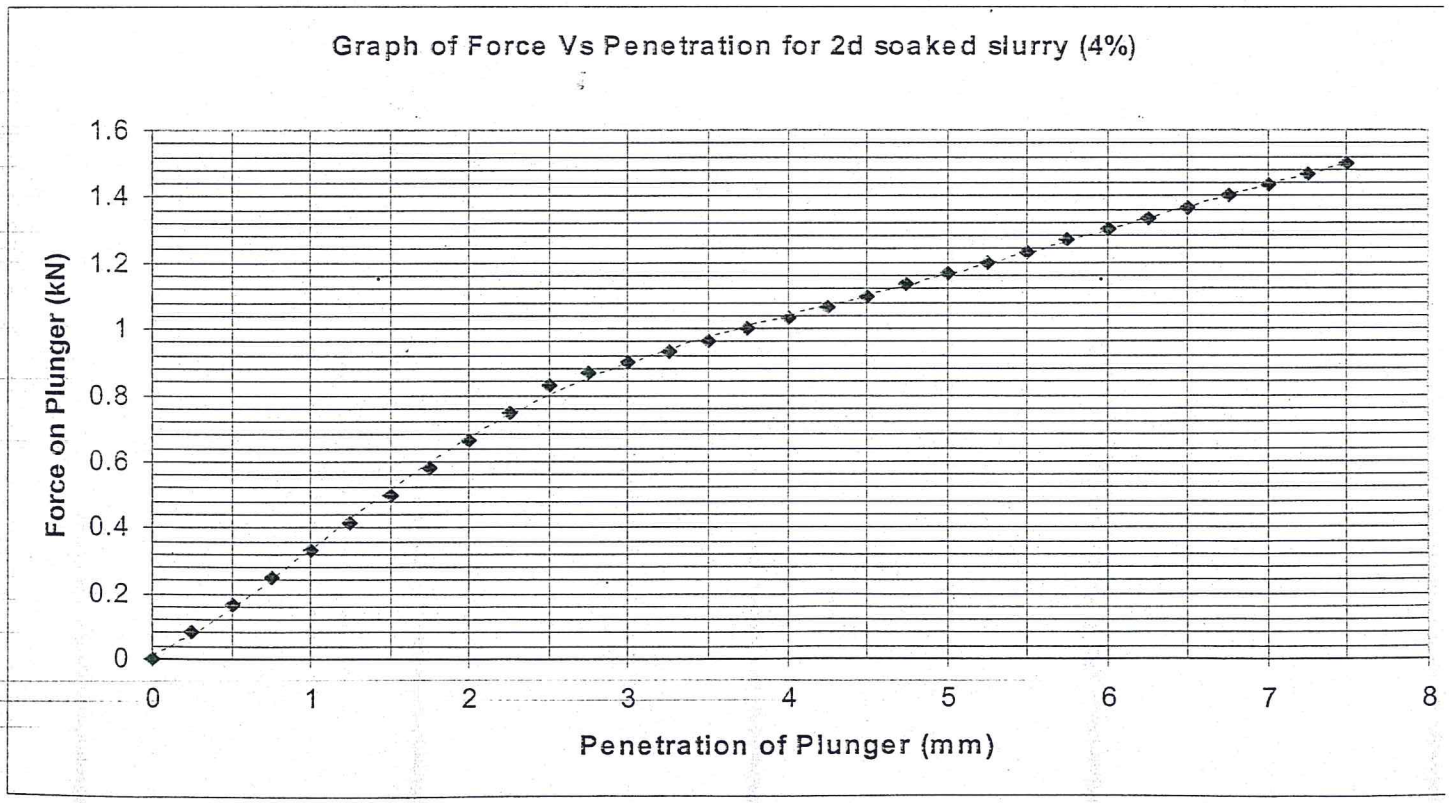

Graph of Force Vs Penetration for 3d soaked slurry (2%)
Force on Plunger (kN)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

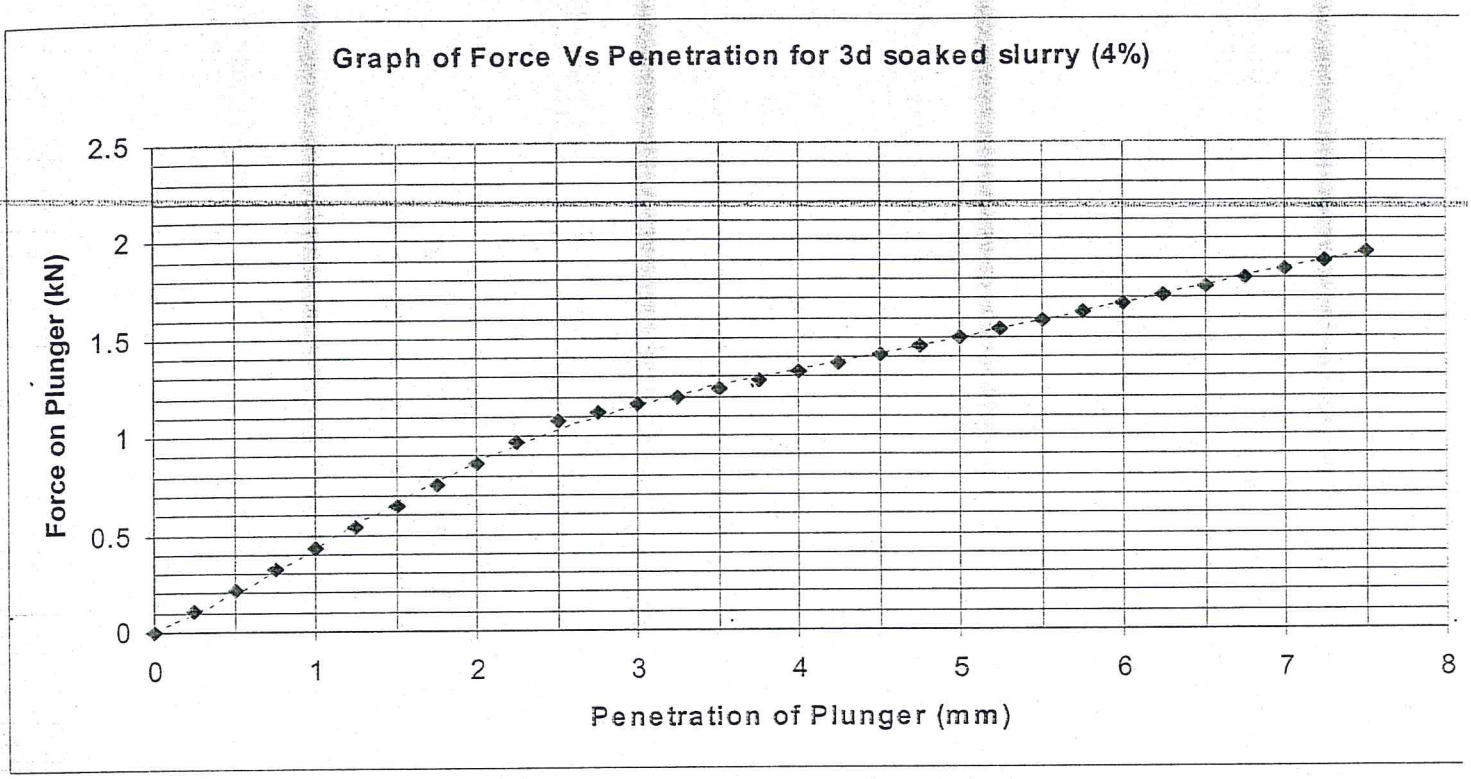

Graph of Force Vs Penetration for 4d soaked slurry (2%)
Force on Plunger (kN)
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

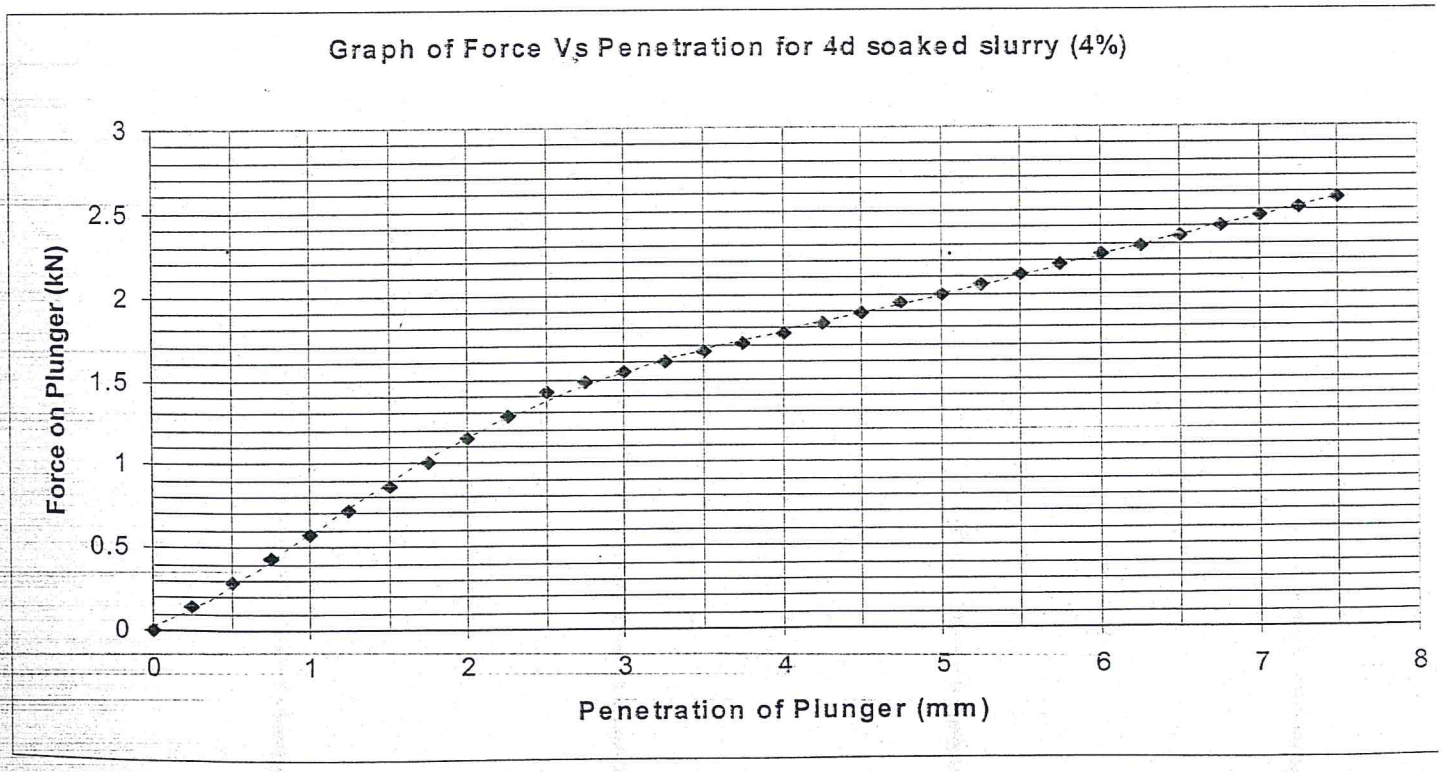

Graph of Force Vs Penetration for 7d soaked slurry (2%)
Force on Plunger (kN)
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

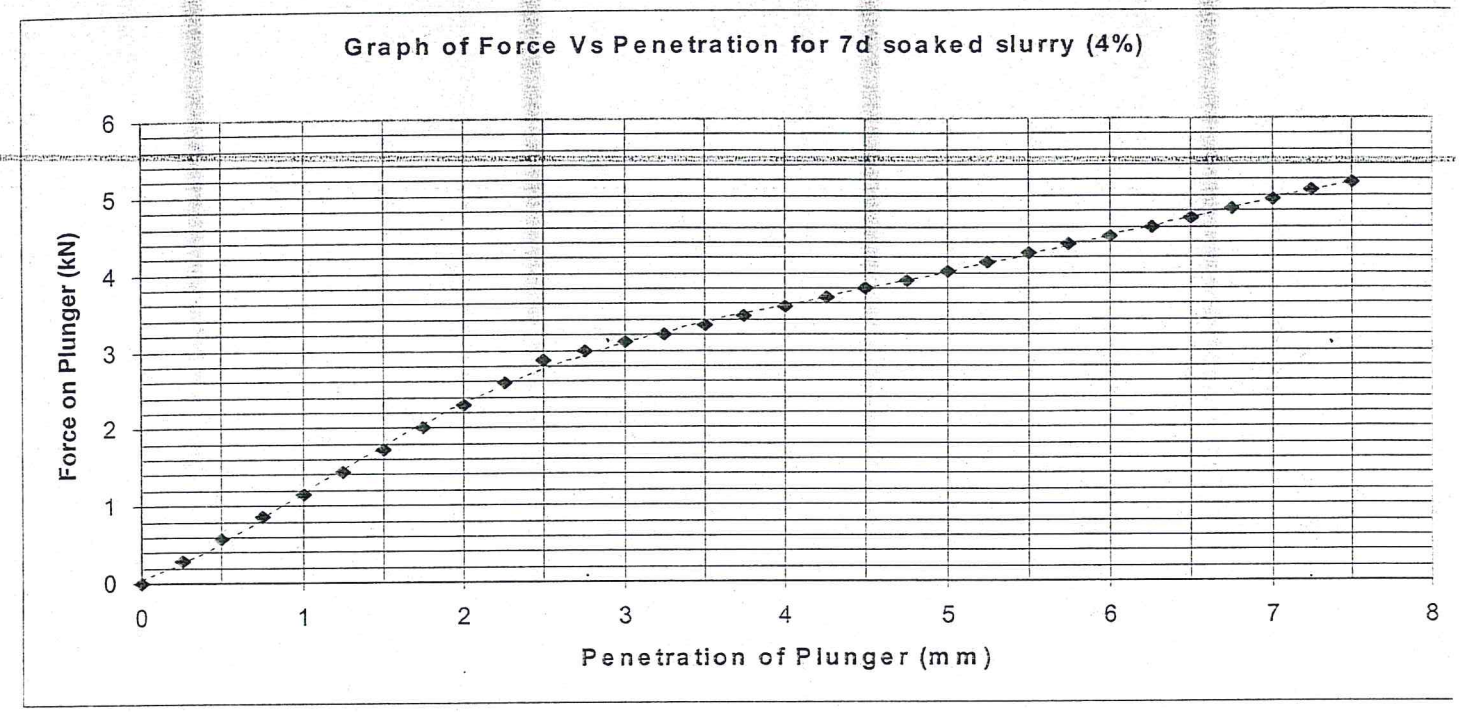

Graph of Force Vs Penetration for 14d soaked slurry (2%)
Force on Plunger (kN)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

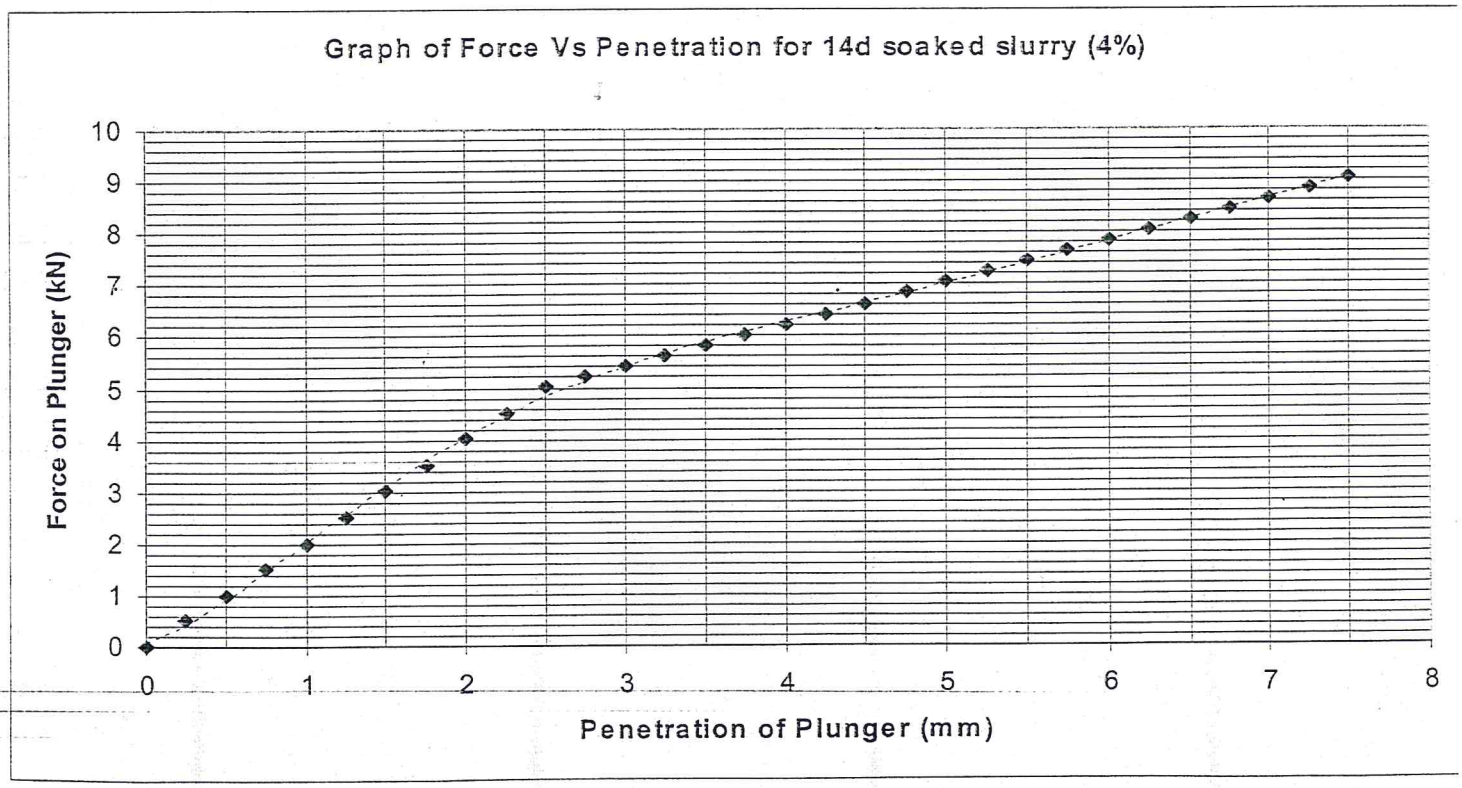

Graph of Force Vs Penetration for 1d soaked slurry (4%)
Force on Plunger (kN)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

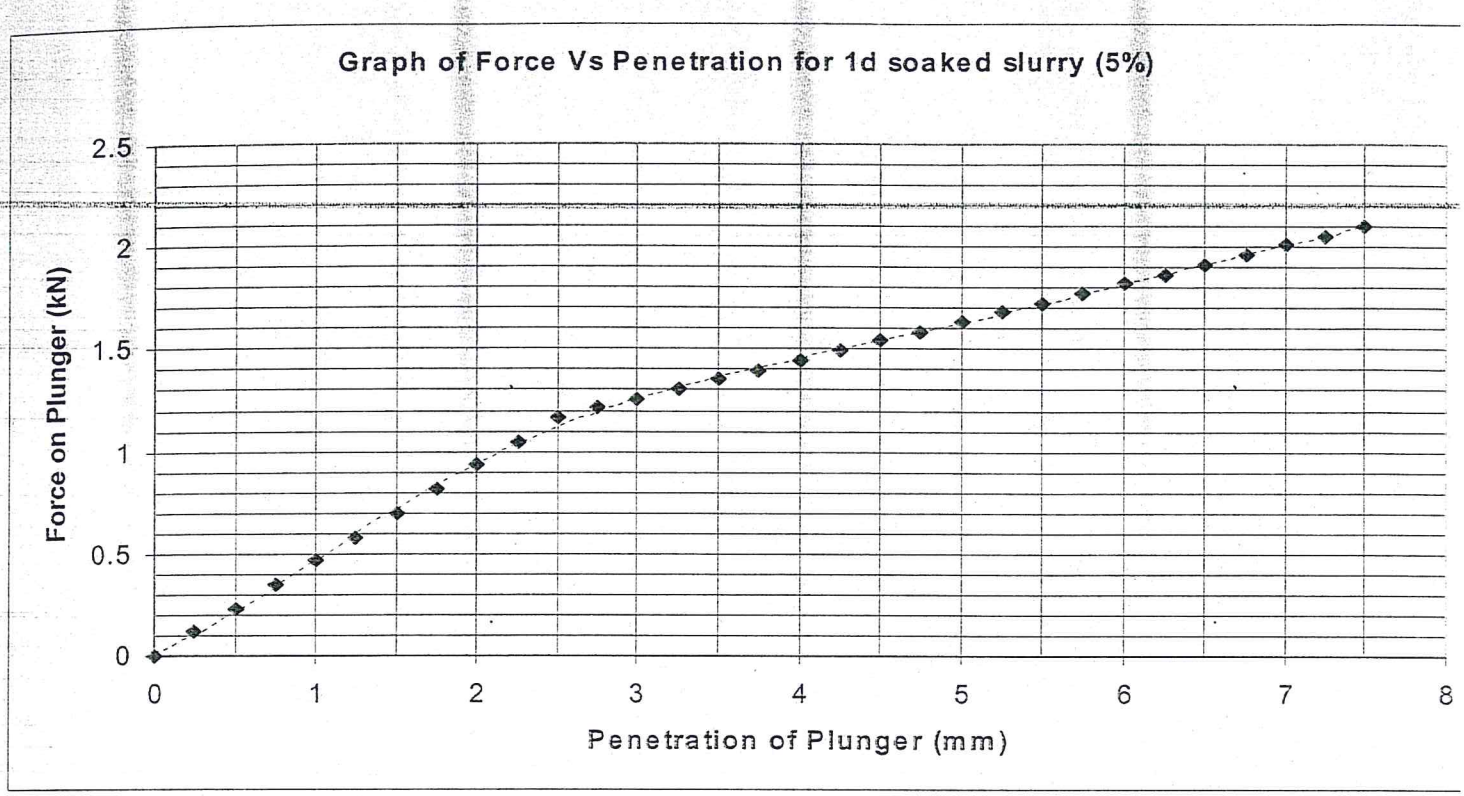

Graph of Force Vs Penetration for 2d soaked slurry (4%)
Force on Plunger (kN)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

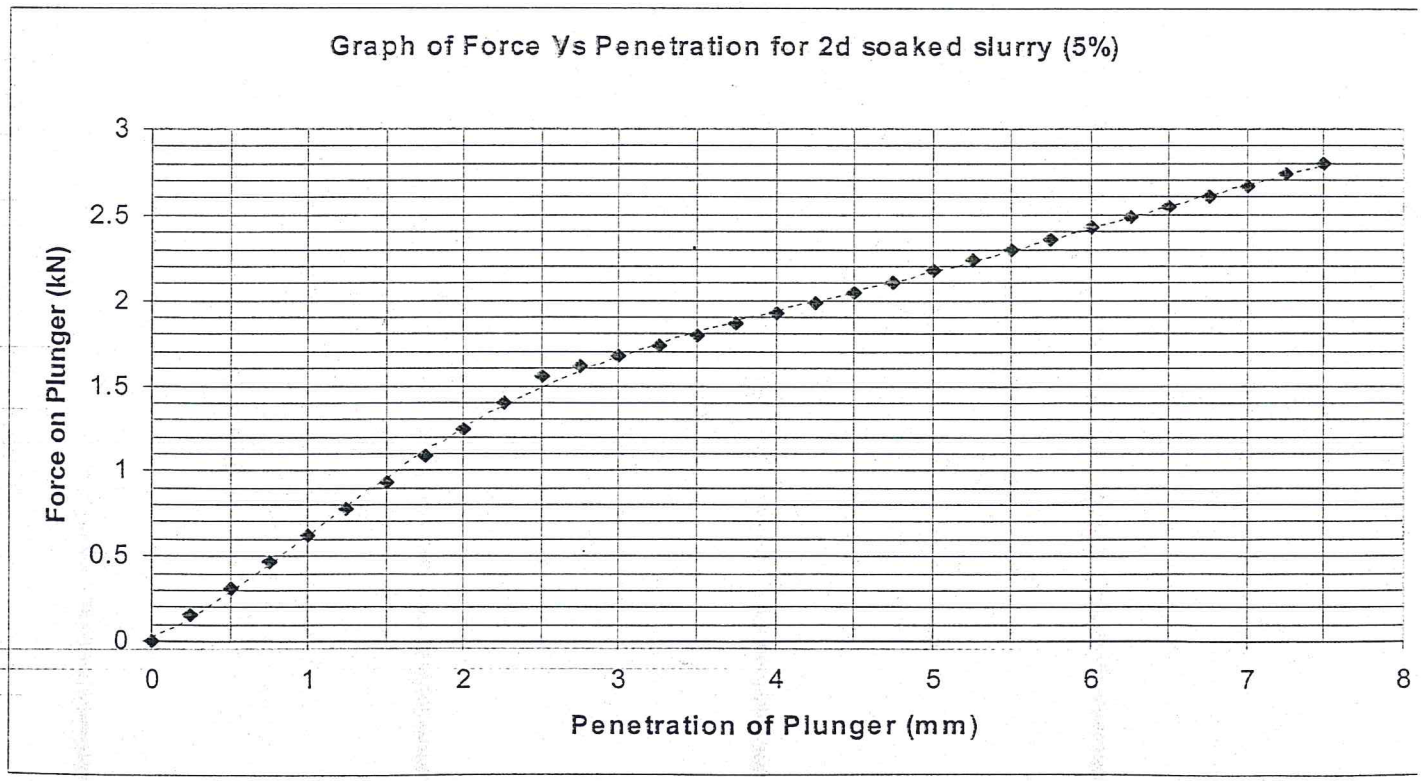

Graph of Force Vs Penetration for 3d soaked slurry (4%)
Force on Plunger (kN)
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

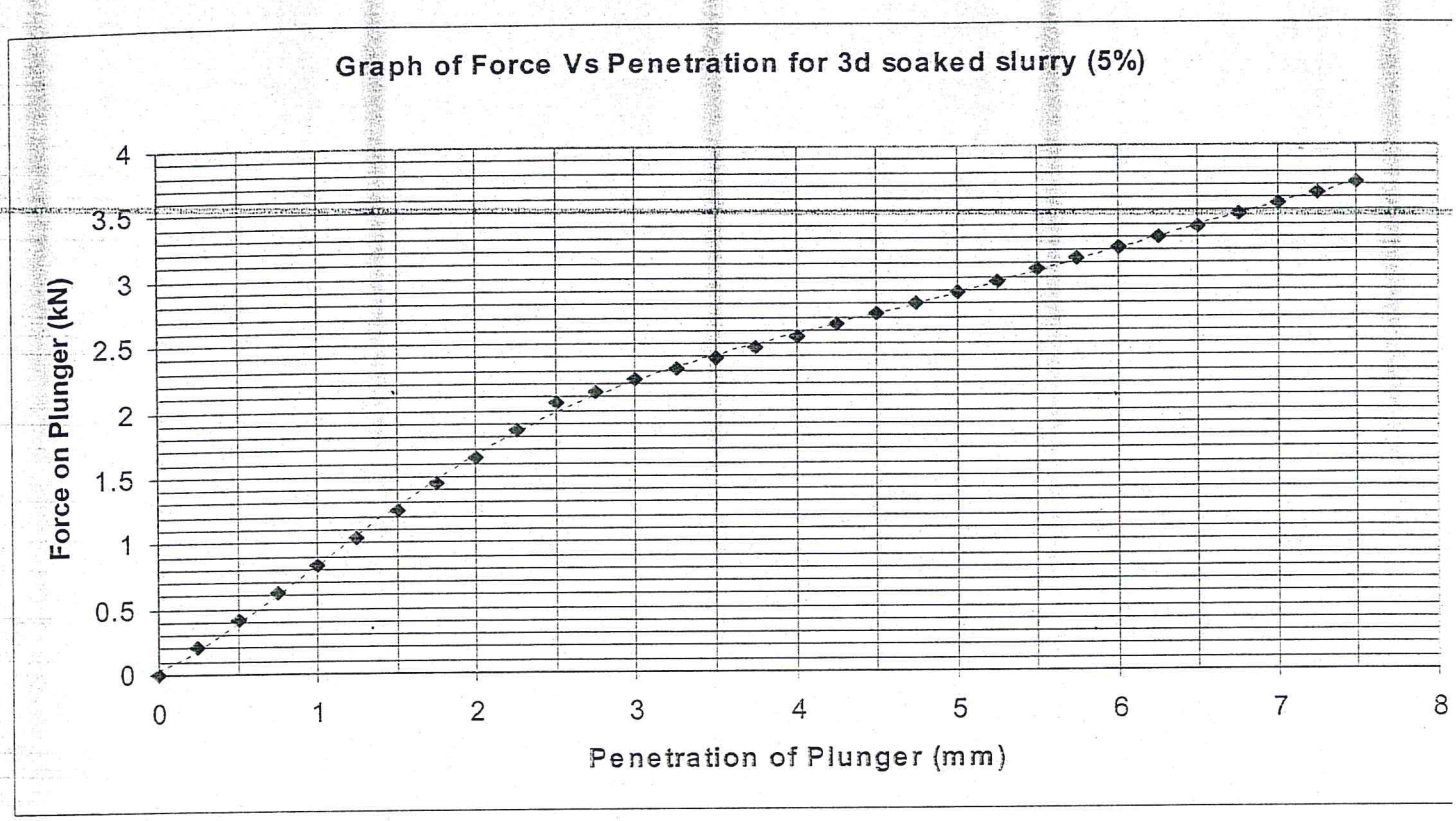

Graph of Force Vs Penetration for 4d soaked slurry (4%)
Force on Plunger (kN)
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

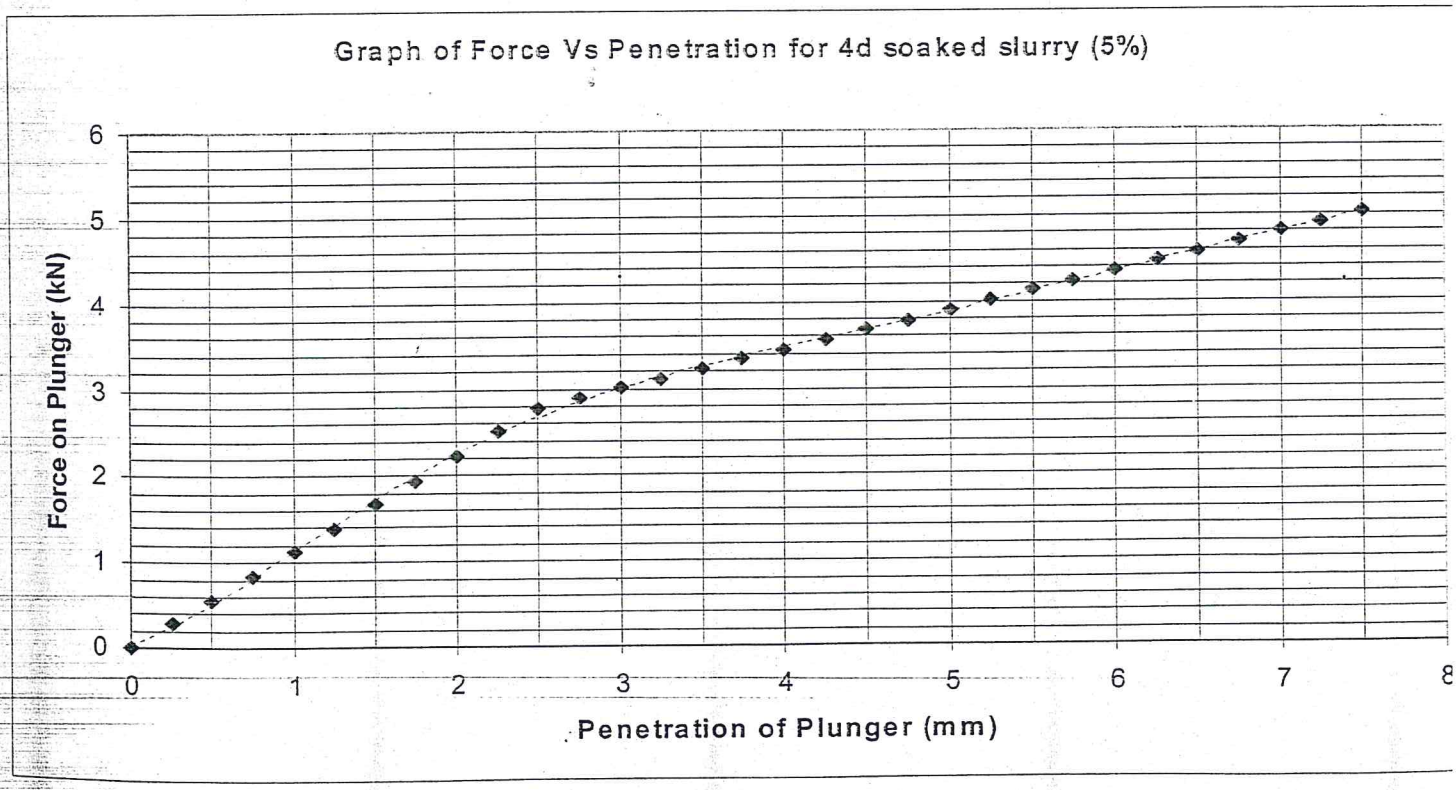

Graph of Force Vs Penetration for 7d soaked slurry (4%)
Force on Plunger (kN)
0
1
2
3
4
5
6
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

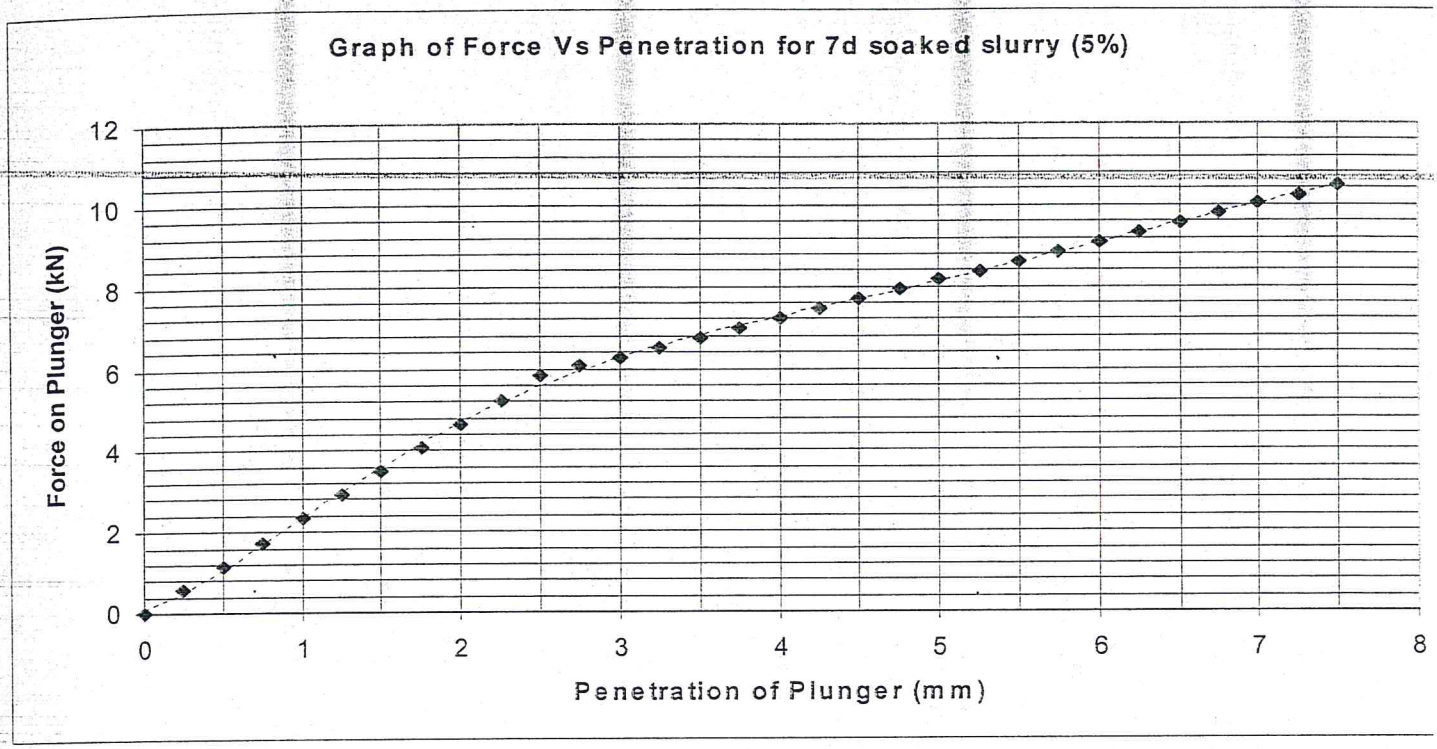

Graph of Force Vs Penetration for 14d soaked slurry (4%)
Force on Plunger (kN)
0
1
2
3
4
5
6
7
8
9
10
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

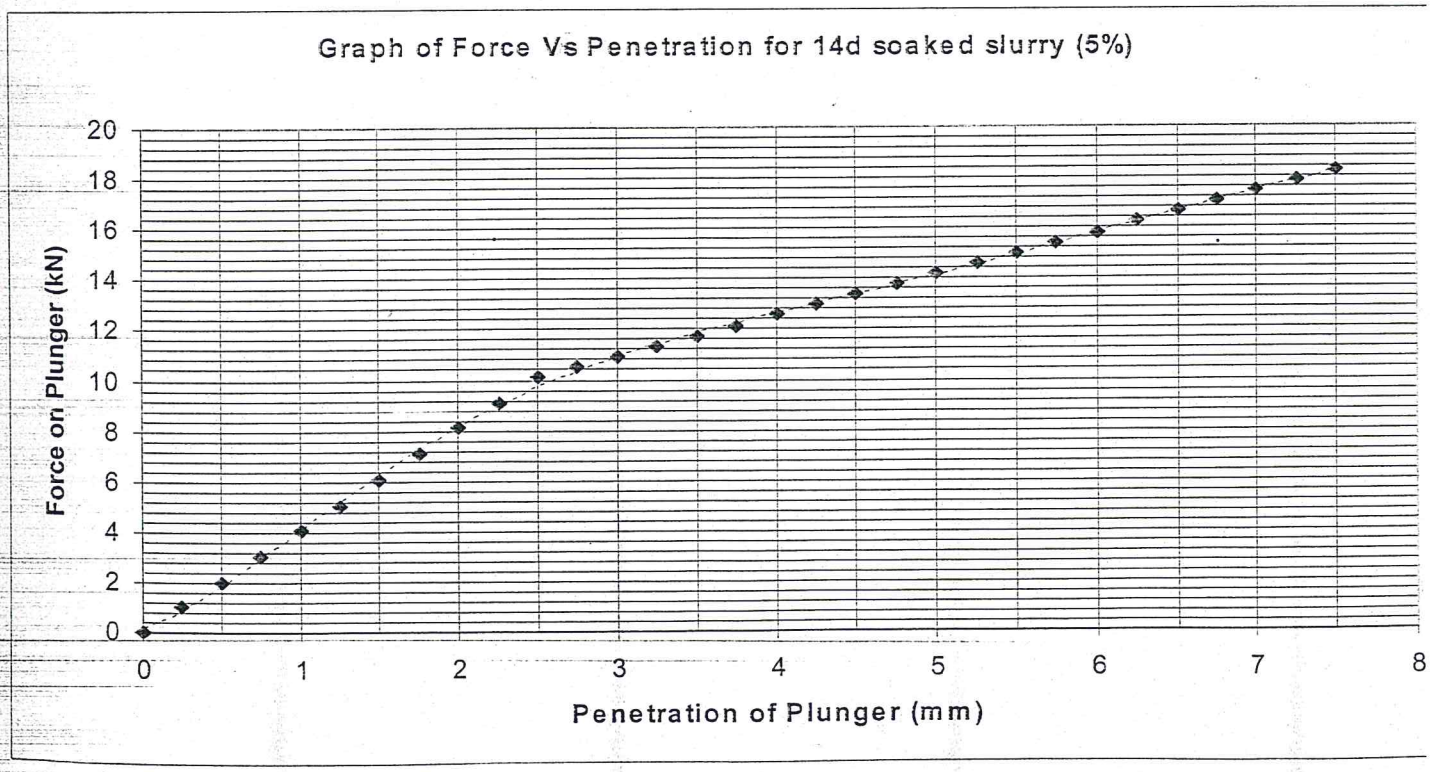

Graph of Force Vs Penetration for 1d soaked slurry (5%)
Force on Plunger (kN)
0
0.5
1
1.5
2
2.5
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

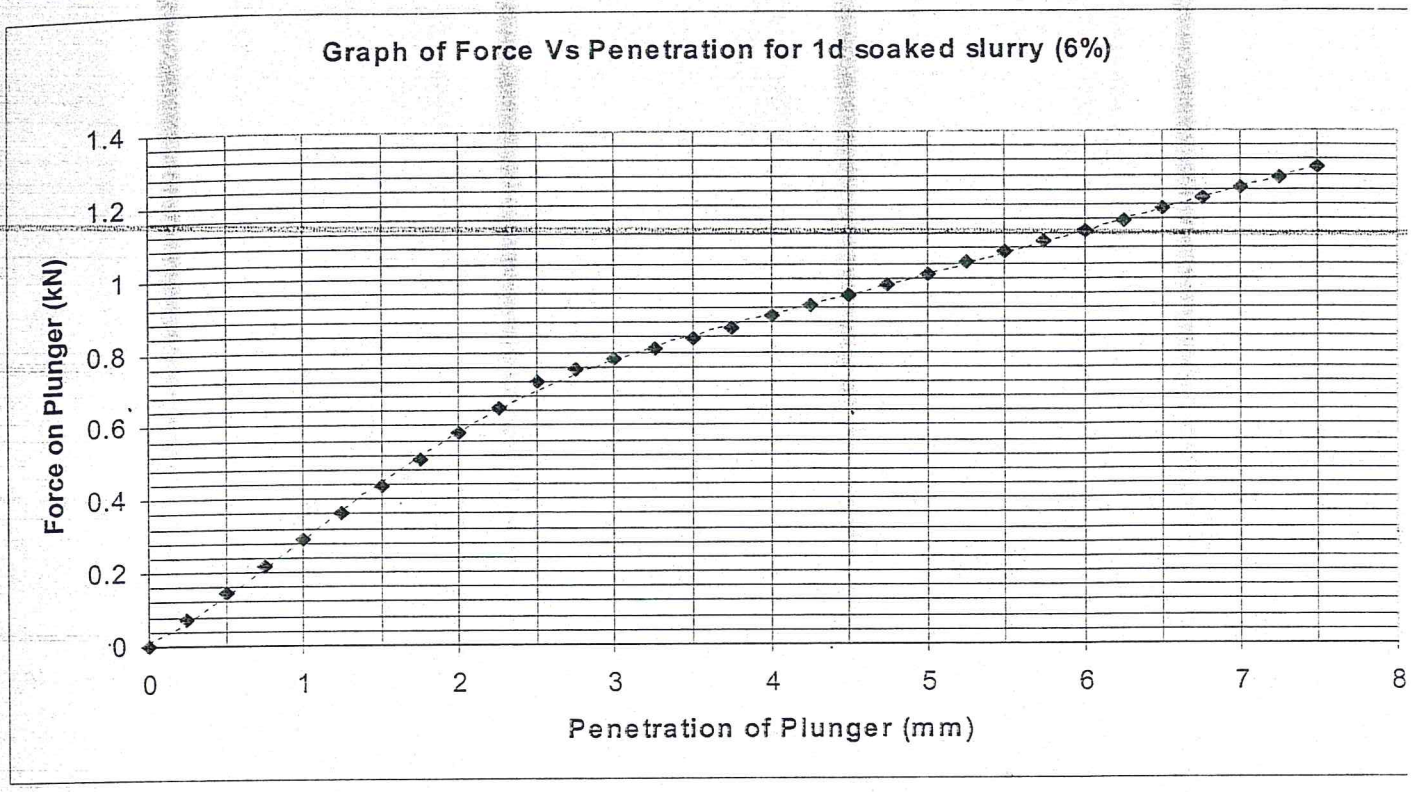

Graph of Force Vs Penetration for 2d soaked slurry (5%)
Force on Plunger (kN)
0
0.5
1
1.5
2
2.5
3
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

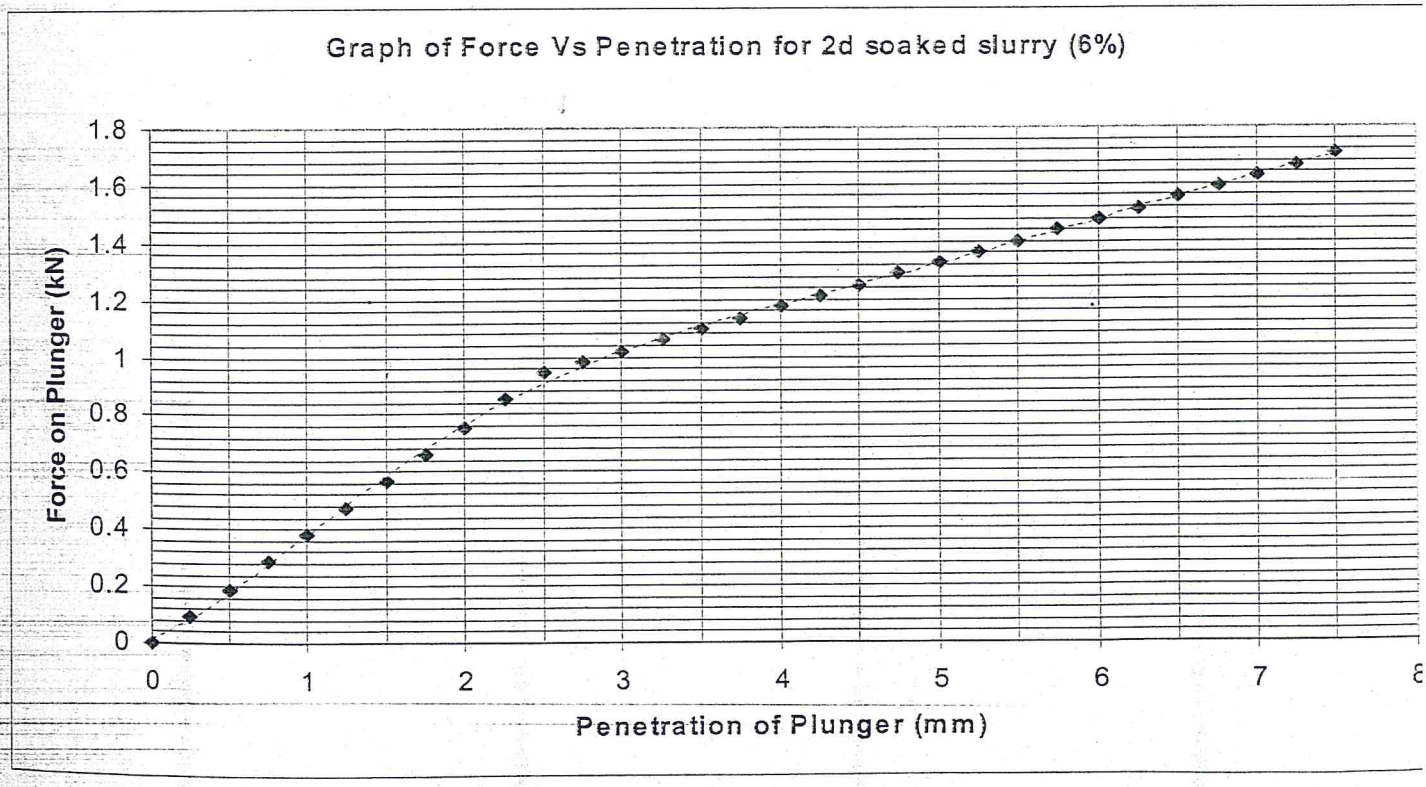

Graph of Force Vs Penetration for 3d soaked slurry (5%)
Force on Plunger (kN)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

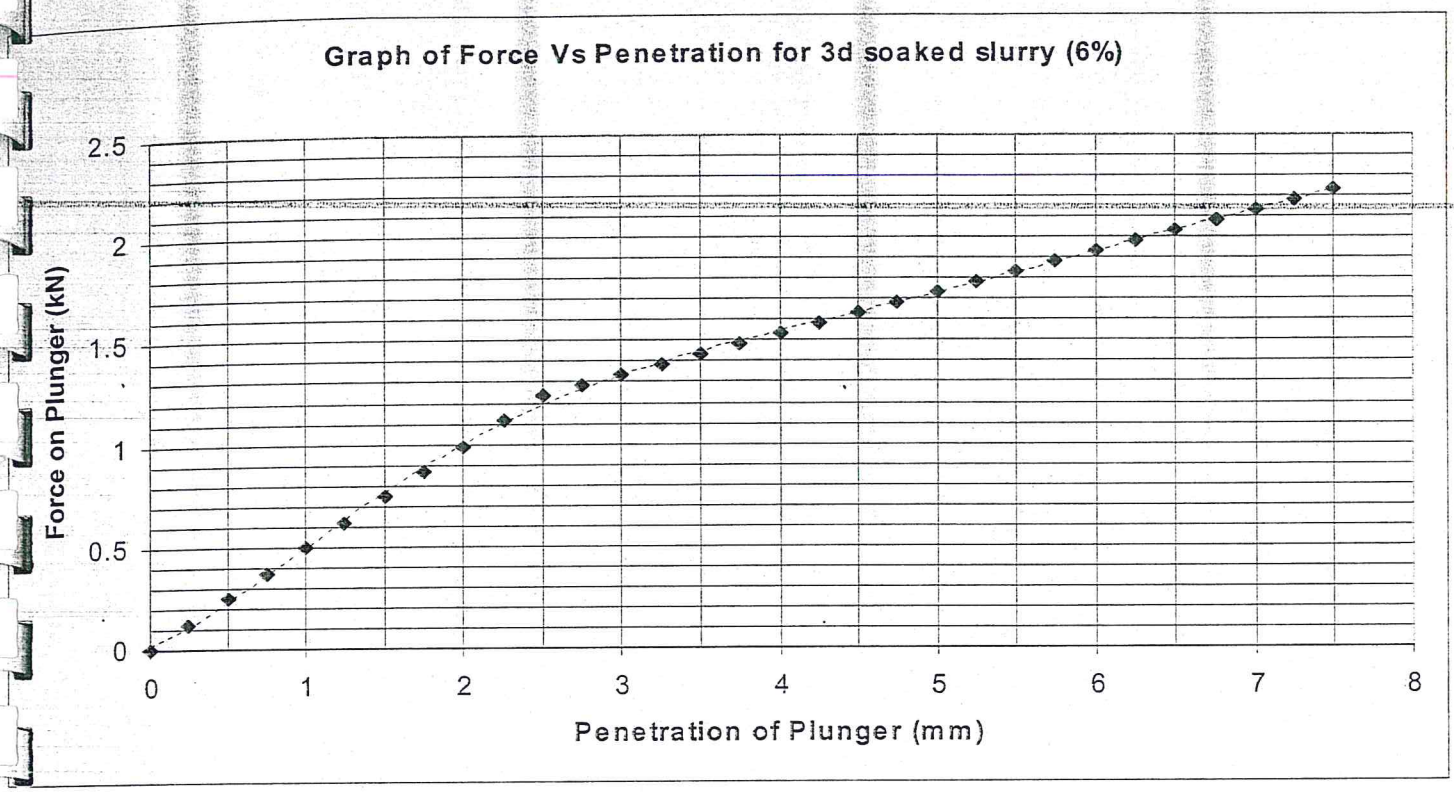

Graph of Force Vs Penetration for 4d soaked slurry (5%)
Force on Plunger (kN)
0
1
2
3
4
5
6
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

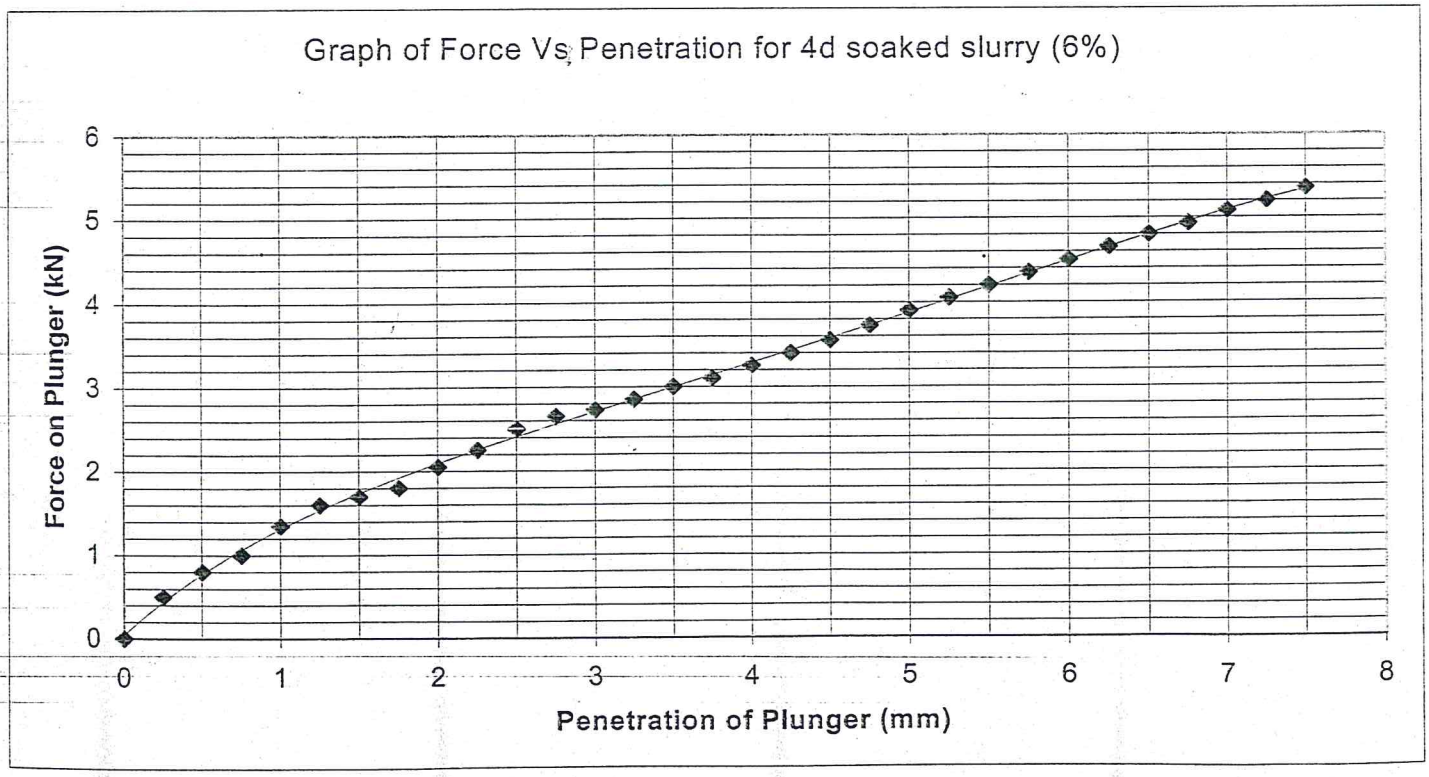

Graph of Force Vs Penetration for 7d soaked slurry (5%)
Force on Plunger (kN)
0
2
4
6
8
10
12
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

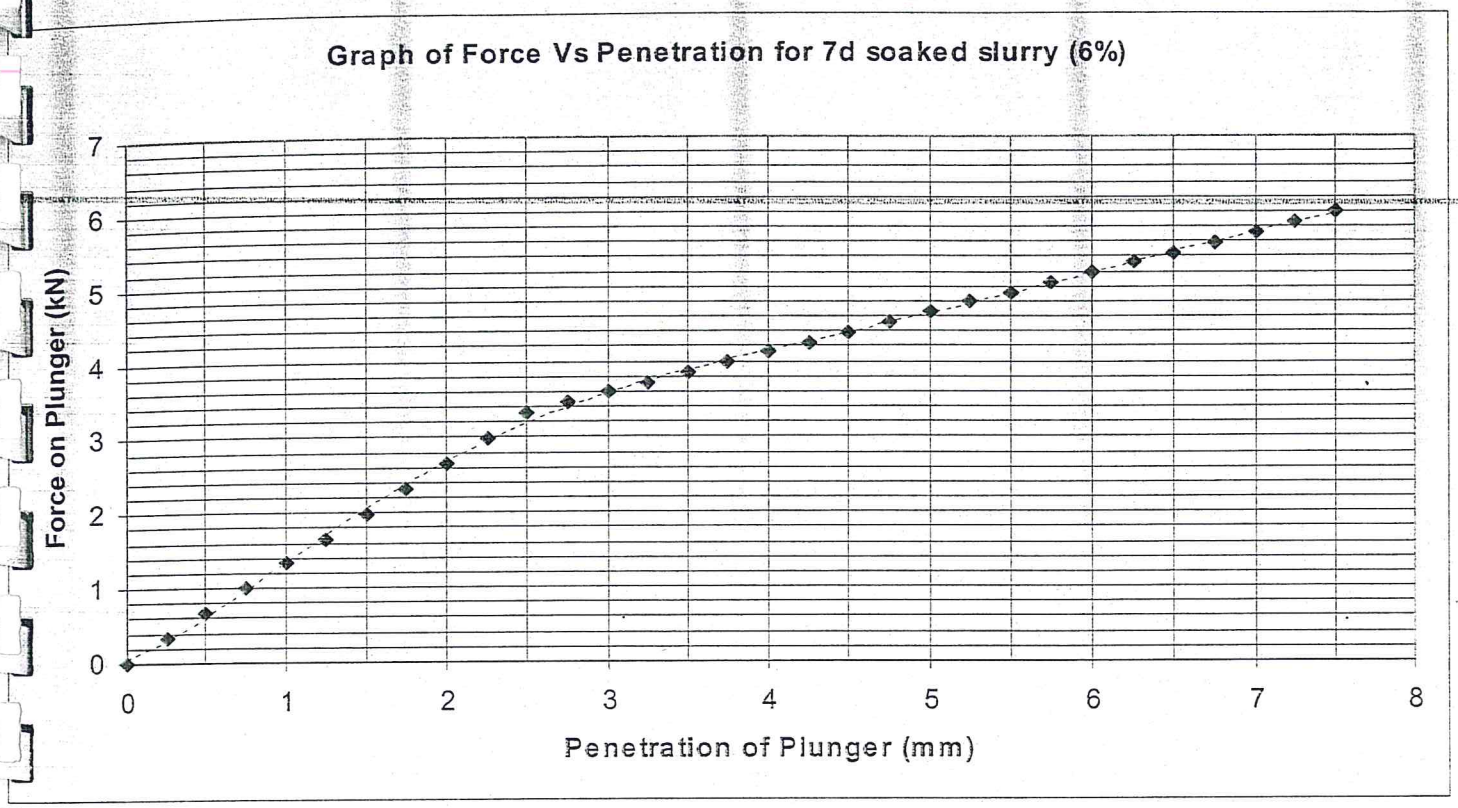

Graph of Force Vs Penetration for 14d soaked slurry (5%)
Force on Plunger (kN)
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

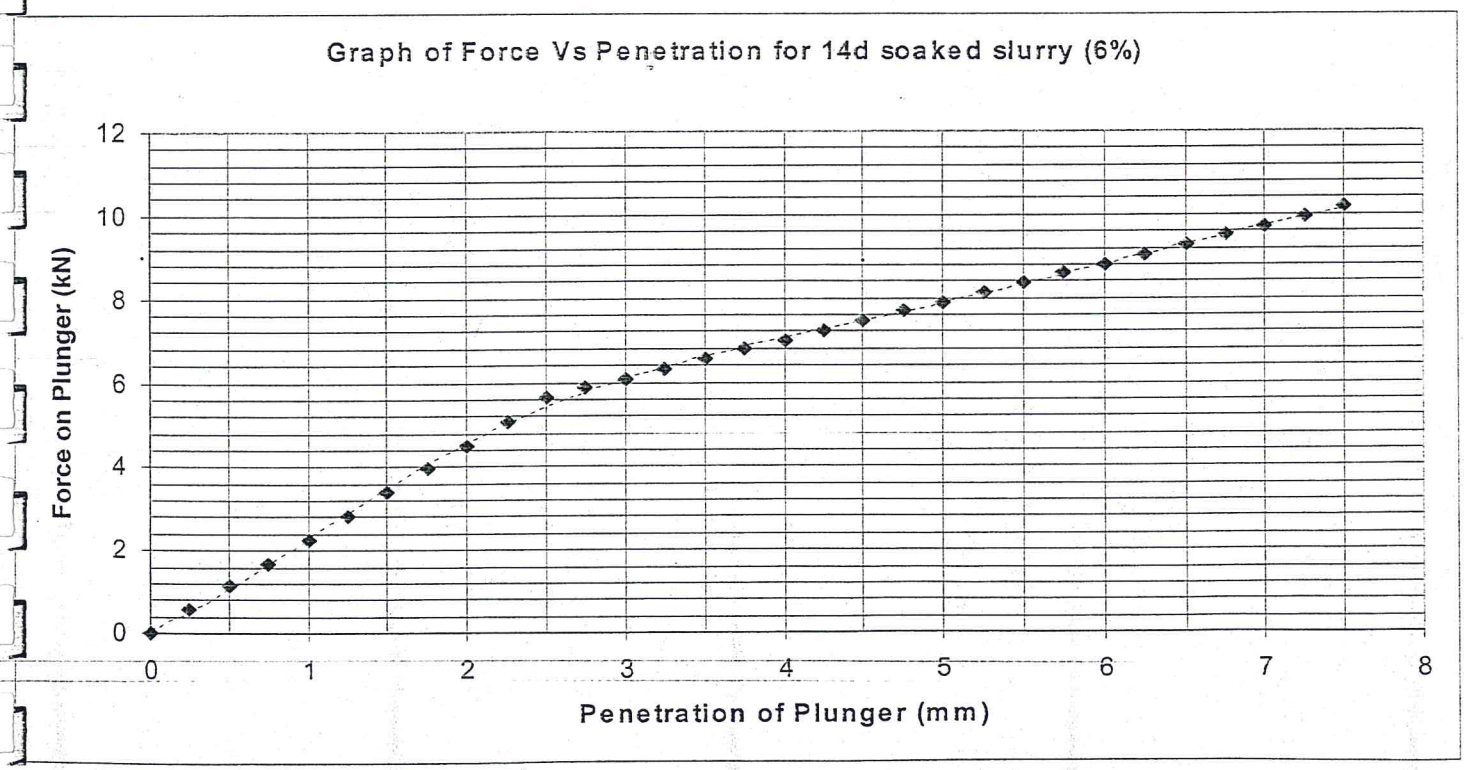

Graph of Force Vs Penetration for 1d soaked slurry (6%)
Force on Plunger (kN)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

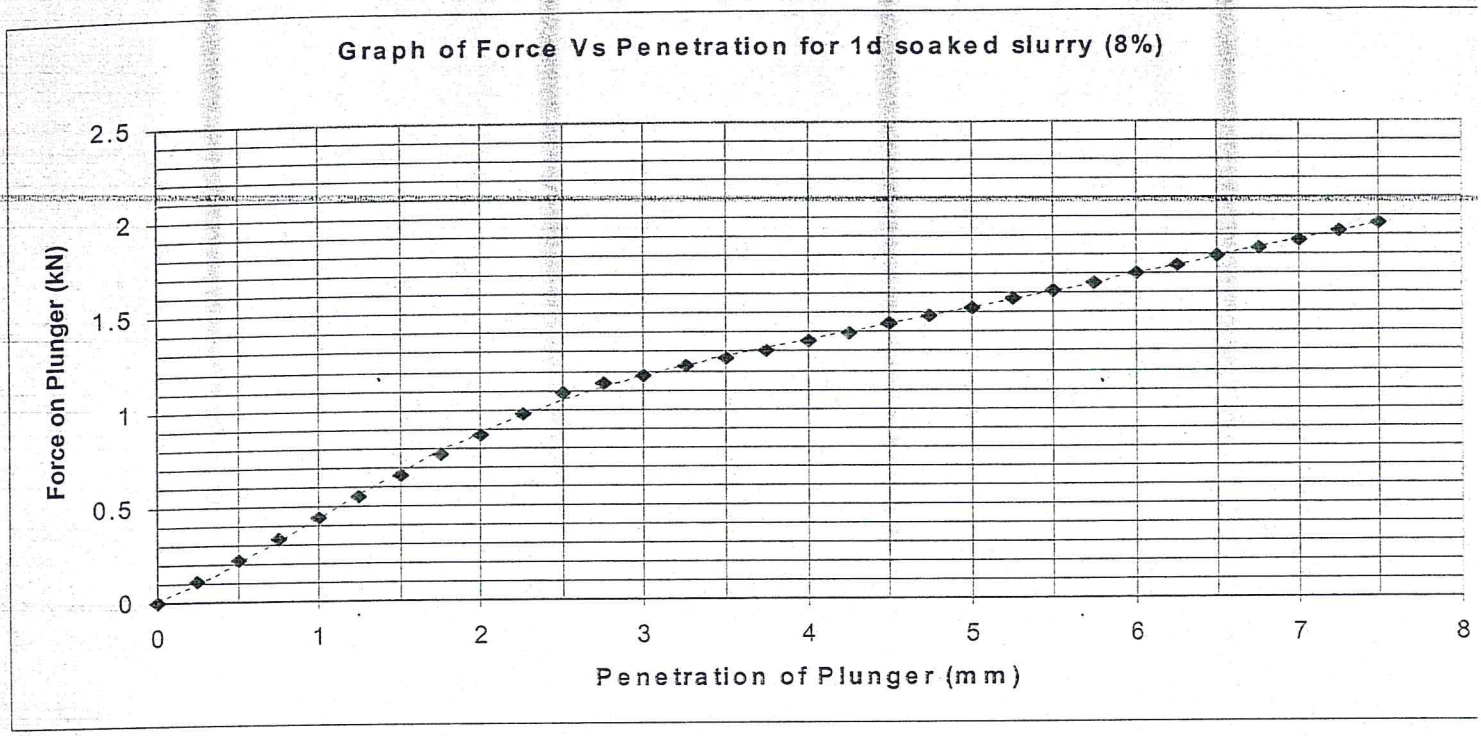

Graph of Force Vs Penetration for 2d soaked slurry (6%)
Force on Plunger (kN)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

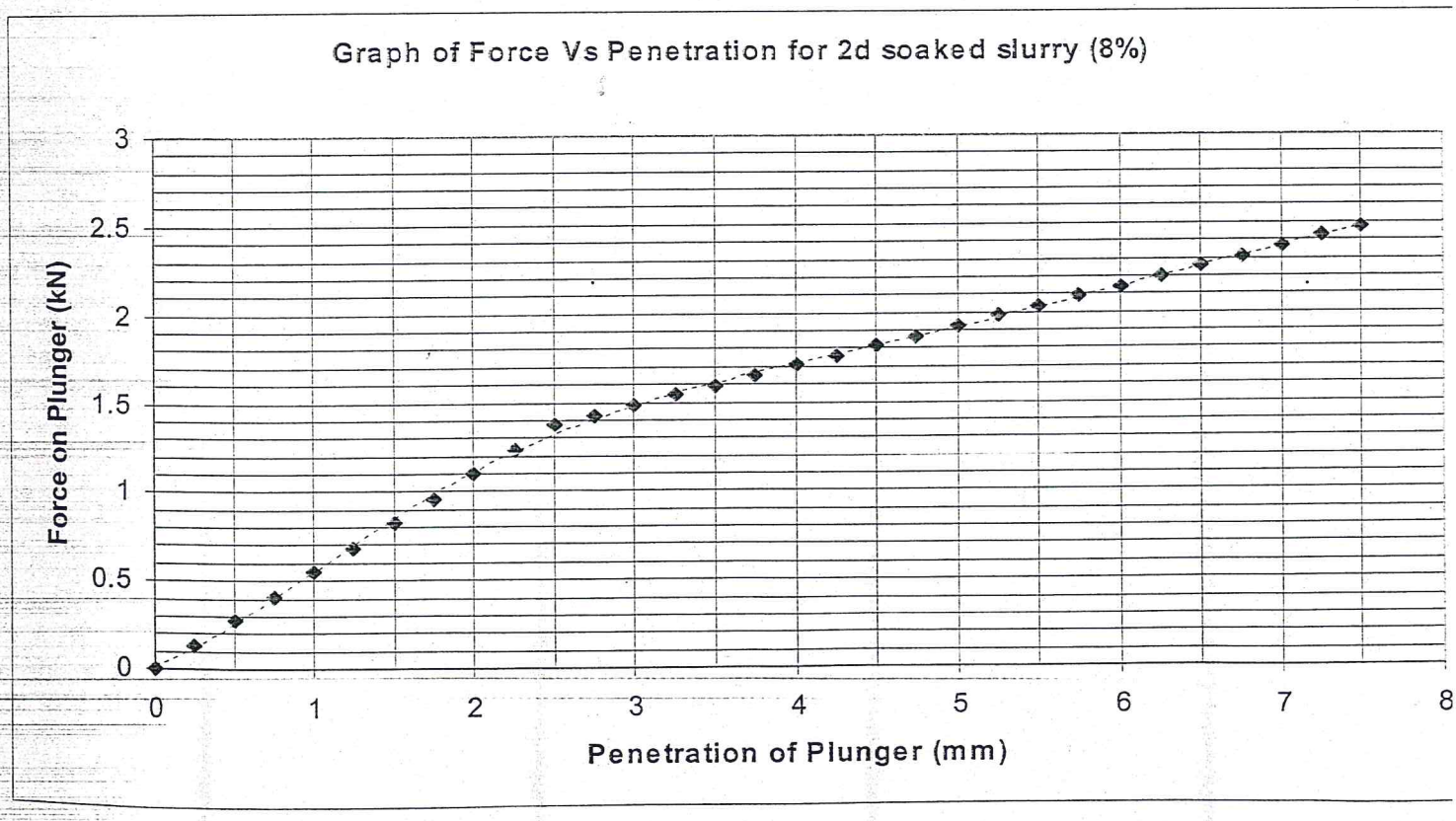

Graph of Force Vs Penetration for 3d soaked slurry (6%)
Force on Plunger (kN)
0
0.5
1
1.5
2
2.5
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

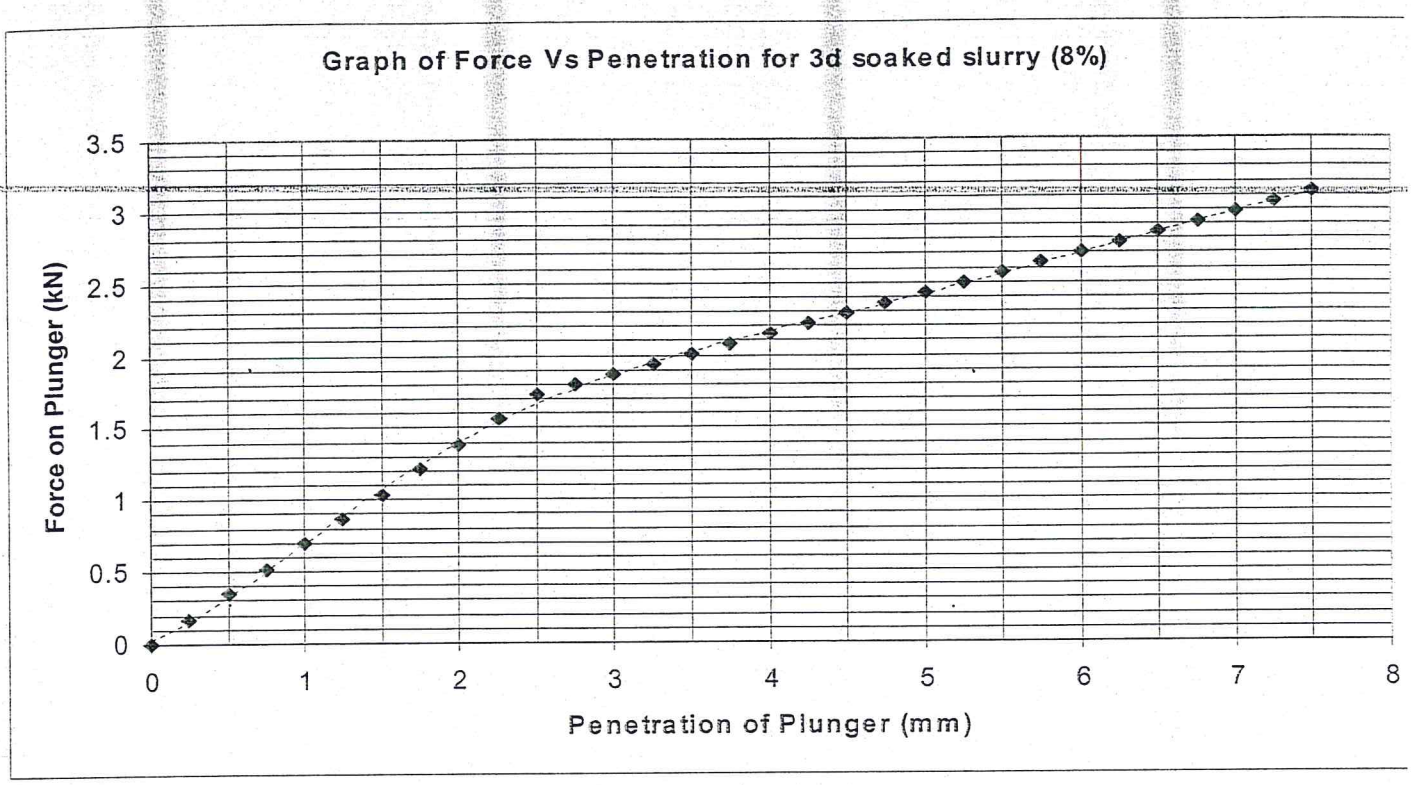

Graph of Force Vs Penetration for 4d soaked slurry (6%)
Force on Plunger (kN)
0
1
2
3
4
5
6
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)

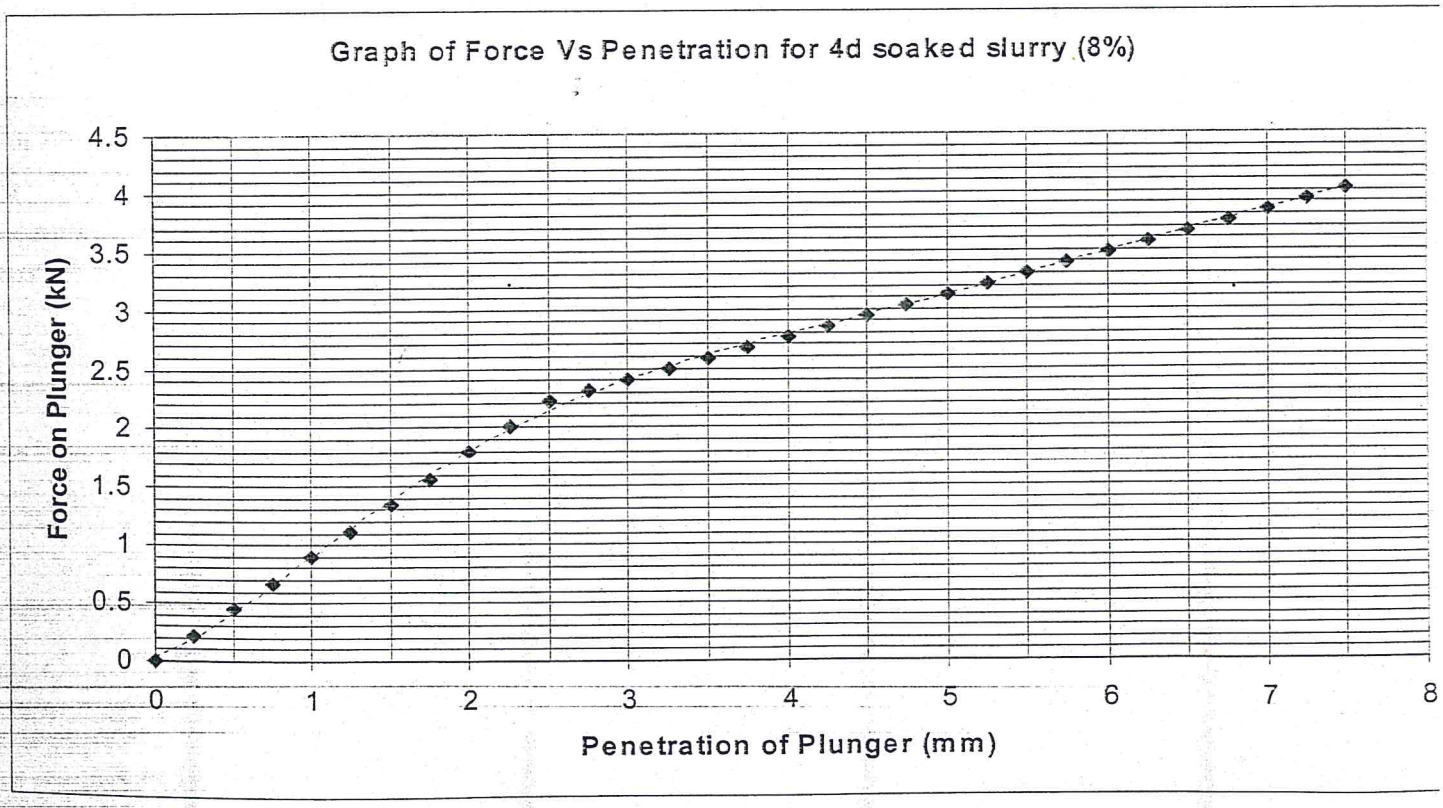

Graph of Force Vs Penetration for 7d soaked slurry (6%)
Force on Plunger (kN)
0
1
2
3
4
5
6
7
Penetration of Plunger (mm)
0
1
2
3
4
5
6
7
8

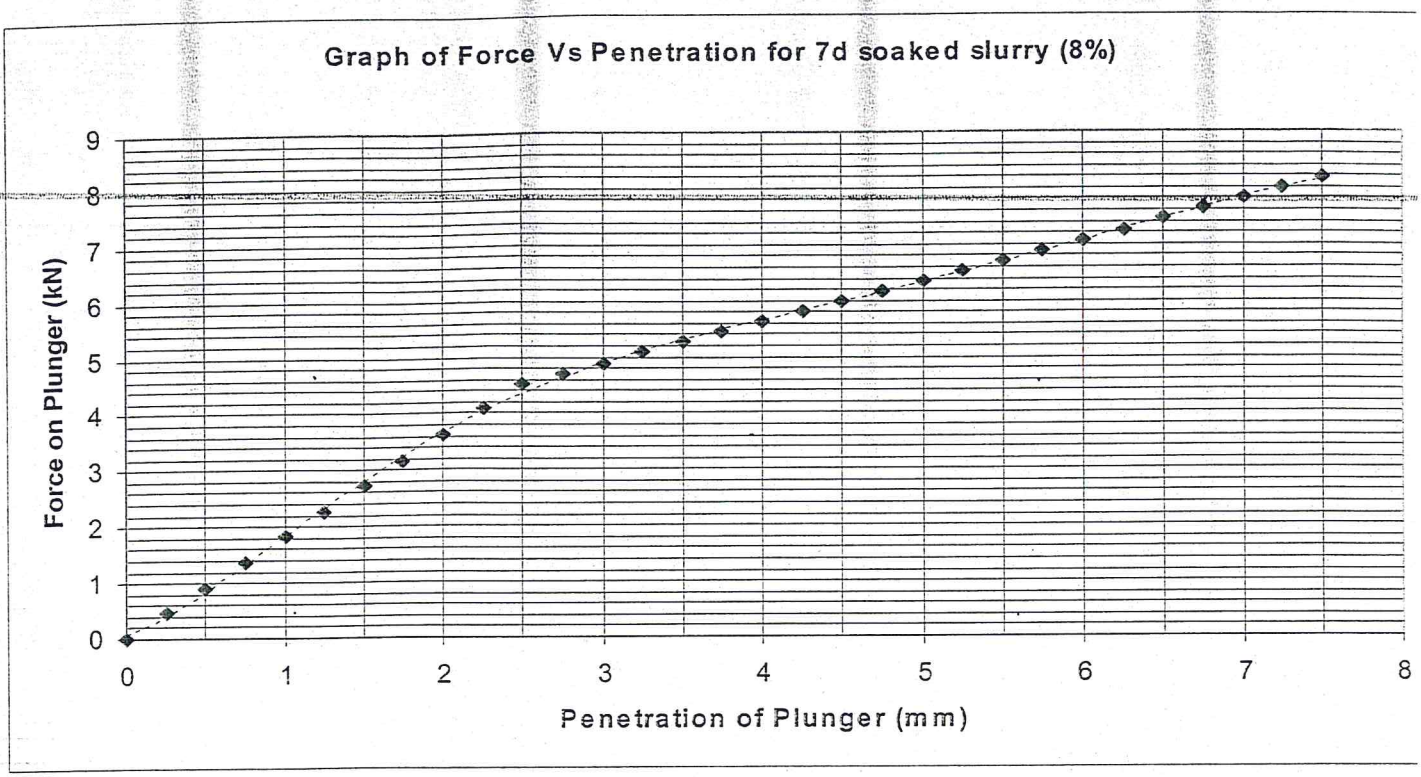

Graph of Force Vs Penetration for 14d soaked slurry (6%)
Force on Plunger (kN)
0
2
4
6
8
10
12
Penetration of Plunger (mm)
0
1
2
3
4
5
6
7
8

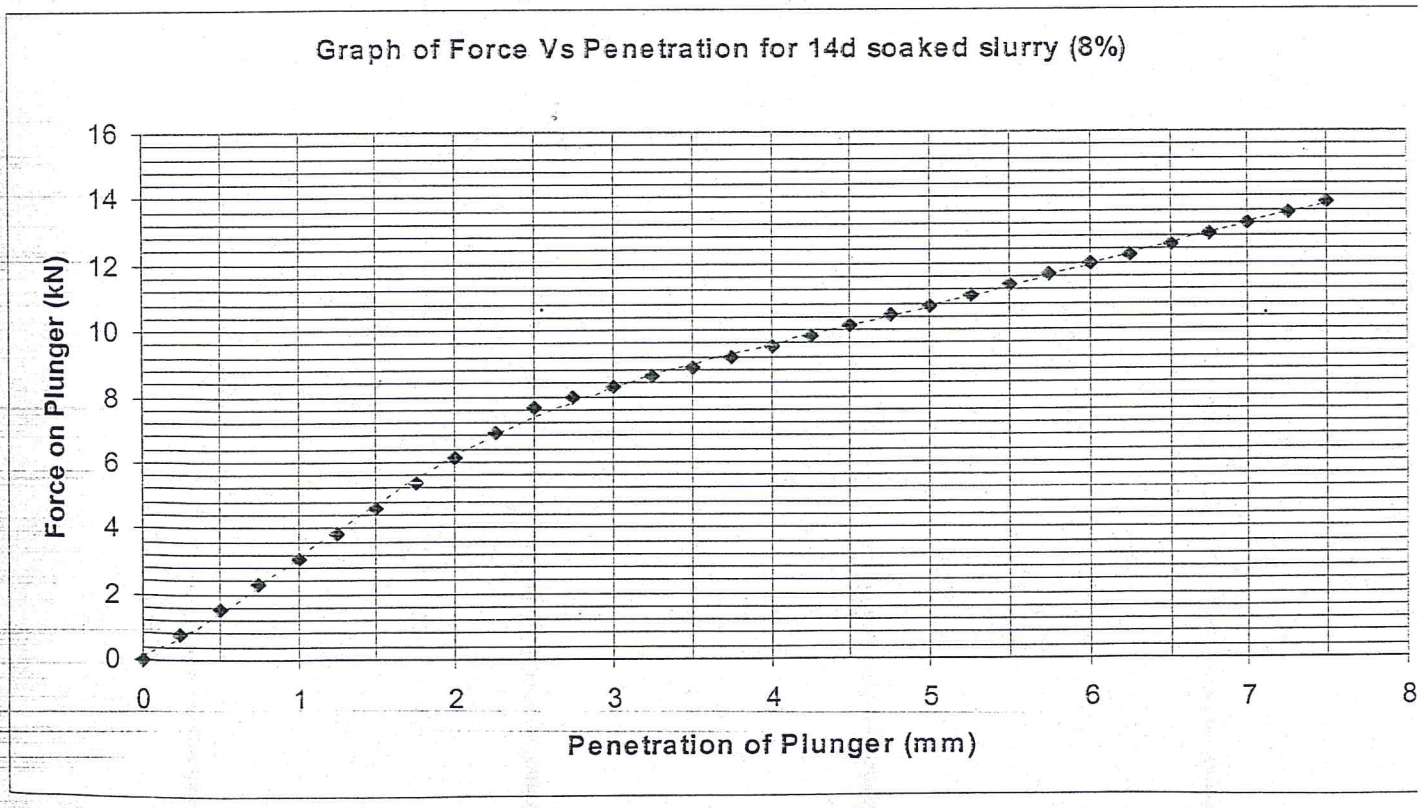

Graph of Force Vs Penetration for 1d soaked slurry (8%)
Force on Plunger (kN)
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)


Graph of Force Vs Penetration for 2d soaked slurry (8%)
Force on Plunger (kN)
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)


Graph of Force Vs Penetration for 3d soaked slurry (8%)
Force on Plunger (kN)
0
0.5
1
1.5
2
2.5
3
3.5
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)


Graph of Force Vs Penetration for 4d soaked slurry (8%)
Force on Plunger (kN)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
1
2
3
4
5
6
7
8
Penetration of Plunger (mm)


Graph of Force Vs Penetration for 7d soaked slurry (8%)
Force on Plunger (kN)
0
1
2
3
4
5
6
7
8
9
Penetration of Plunger (mm)
0
1
2
3
4
5
6
7
8


Graph of Force Vs Penetration for 14d soaked slurry (8%)
Force on Plunger (kN)
0
2
4
6
8
10
12
14
16
Penetration of Plunger (mm)
0
1
2
3
4
5
6
7
8