UNIVERSITY OF SOUTHERN QUEENSLAND
FACULTY OF ENGINEERING AND SURVEYING

Automated Soil Compaction Machine for the Preparation of Californian Bearing Ratio and Proctor Specimens

Dissertation Submitted by
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Abstract

This Dissertation addresses the design, development and construction of an automated soil compactor for the preparation of California Bearing Ratio (CBR) and Proctor samples. The necessity for this machine is primarily due to an ever increasing number of workers compensation claims within the soil testing and certification industry. The technicians that are currently preparing substrate samples by means of a manual compaction hammer are subjected to extended periods of use of this apparatus, causing Repetitive Strain Injury and Occupational Overuse Syndrome in the shoulders, neck and elbows. Therefore, a mechanization of the manual compaction methods was required.

In addition to addressing the physical strain issues, the machine was also designed to fully comply with current Australian Standards. Multiple automatic machines are available on the market; however none achieve full compliance to the methods set out in AS1289. The design was therefore developed into a machine that mimics the manual compaction method exactly while eliminating the inherent human error of the manual method.

The prototype Compaction Machine has successfully passed product testing as a viable, accurate and efficient tool for use within the Civil Testing Industry while fully complying with the relevant Australian Standards. The machine's capabilities allow the unit to be used in researching more efficient compaction techniques; a very useful, promising future is ahead.

Key words: Californian Bearing Ratio, CBR, Proctor, Soil Compaction.

The Essence of Engineering.

I take the vision which comes from dreams
and apply the magic of science and mathematics,
adding the heritage of my profession
and my knowledge of nature's materials
to create a design.

I organise the efforts and skills of my fellow workers
employing the capital of the thrifty
and the products of many industries,
and together we work toward our goal
undaunted by hazards and obstacles.

And when we have completed our task
all can see that the dreams and plans have materialized
for the comfort and welfare of all.

I am an Engineer.
I serve mankind
by making dreams come true.

Konkan Railway Engineer – Name Unknown

India – Late 20th Century.

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

Limitations of Use

Professor Frank Bullen
Dean

Faculty of Engineering and Surveying

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Student Name: **Cameron Peter Walker**

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Signature

22nd October, 2010

Date

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Nomenclature and Definitions of Technical Terms

CBR:	Californian Bearing Ratio - a numerical descriptor of the load bearing capacity of a compacted soil or substrate.
Rammer:	Calibrated mass with impact face of 50mm diameter that is dropped onto uncompacted soil within a sample mould.
Drop Height:	The measured distance between the impact surface of the rammer and the surface of the uncompacted soil height at the intended blow site.
Compaction:	Compaction of the soil into the mould using a certified apparatus OR compaction of soil at a road construction site.
Penetration:	Measured difference in millimetres between the uncompacted soil height and the resting place of the rammer after a blow.
Mould Datum:	The location of the top surface of a compaction mould base when it is correctly positioned in the Mould Holder. The datum is used as a reference for determining cumulative layer thicknesses.
Drop Height Datum:	The location of the uncompacted or partly compacted material. The datum is measured before each rammer blow and around the future impact area in order to determine the ready position.
Ready Position:	The position of the rammer either 300 mm or 450 mm above the next impact point.
Rest Position:	The position of the rammer after it has impacted the material being compacted and come to rest on its surface.

Chapter 1 - Introduction.

"Design is directed toward human beings. To design is to solve human problems by identifying them, examining alternate solutions to them, choosing and executing the best solution."

Ivan Chermayeff, Graphic Designer, Founder, Chermayeff & Geismar Inc.

1.1 - Outline of the Study

Performing manual, repetitious or strenuous activities can have serious effects on not only the operator, but on the accuracy of any data collected throughout the process. Mechanical devices are often required to eliminate the inherent human error in these processes and by diligent analysis and understanding of the process as a whole; a device can be engineered to achieve an acceptable level of accuracy. On doing so, a consistent, repeatable result is also obtained.

It is the purpose and scope of this study that the design and construction of an automated soil compaction machine for the preparation of CBR and Proctor mould samples be successfully undertaken.

In chapter one, a brief overview discusses the current issues being experienced in the soil laboratories carrying out the compactions. The discussion provides a justification of the primary objectives of this study and forms the basis for all works herein.

Chapter two analyses a selection of the leading existing automated machines available on the market and investigates the limitations encountered with these models. Severity of the physical strain on the operators and the costs that can be accredited to work related injuries is also investigated to prove a basis for the cost benefit of the project. Being such a niche product, almost no expert literature exists on the development of the existing machines

The detailed machine specification is developed in Chapter three. This specification encompasses the design requirements and functionality that the machine must exhibit. Several additional features were added to the machine during construction, but these provided additional features that were not covered in the original signed off specification.

Chapter 4 provides details on the mechanical design and functionality of each of the four primary sub assemblies. The integration of the electronic control system is also discussed, outlining the operation of the machine from both the programming and operator perspectives.

The testing of the machine is then detailed in chapter 5 and

An example data set of the clients own machine trials are analysed. The summation of feedback from the client highlights some of the issues that required attention throughout the testing phase and the solutions to these issues that were implemented are discussed.

Chapter 6 draws the general conclusions with a retrospective overview of the project. Discussions on the non technical issues encountered throughout the project are also included with the evaluation of the overall level of success of the project concluding the study.

1.2 - Introduction

With the growth of the computer age, the availability of cost effective machine automation products is ever increasing. Complex tasks are being handled by smaller and smarter components that are readily available to the general public making automation of nearly anything possible.

These advances provide simplified solutions to everyday jobs making life in general easier both physically and mentally. There are still a large number of jobs that are extremely physically demanding – one of which that applies directly to this dissertation, is that of the soil technician.

In many soil laboratories, soil technicians undertake the manual compaction of soil samples into specifically design moulds. These samples are prepared in order to have the Californian Bearing Ratio – or CBR – taken.

The process involves a manual slide hammer that is used to compact the soil into the moulds. AS1289 is very specific on the apparatus and blow patterns used in this compaction. The slide hammer consists of an encapsulated mass – either 2.7 or 4.9 kg – that is lifted to a specified height, and then allowed to freefall onto the soil to achieve some localized compaction.

The process in itself is relatively simple, but when some moulds require in excess of 500 blows to complete the compaction, then the strain placed on the technician can be understood. On top of the sheer number of blows for each mould and the number of moulds in a day compounds the strain levels. The pressure to complete large capacities of moulds forces technicians to complete these blows at up to 80 blows per minute.

This dissertation encompasses the design and manufacture of a prototype machine that will conduct these compactions automatically, needing only to have minimal operator input and thus, mitigating the risk of repetitive strain injuries in this specific process.

1.3 - Research Objectives

The Primary objectives for the successful design and construction of the automatic compactor were developed to maximize the accuracy, reliability and research functionality of the unit. The primary objectives are:

- Successfully complete a soil compaction of a test specimen for CBR testing.
- Comply with all Australian Standards relevant to this compaction procedure.
- Measure drop height from the uncompacted soil at the position of the next rammer blow.
- Achieve repeatability of results to provide an industry wide benchmark.

1.4 - Conclusion

This dissertation aims to present both existing and potential future efforts in the production of a fully compliant automated compaction machine by encapsulating the industry knowledge of the post-processes involved with the compaction methods and addressing all major aspects in the design.

The work and research undertaken to complete this dissertation is expected to result in the successful manufacture of a saleable product that is fully compliant to the processes described in AS1289 and all other relevant Australian standards.

Chapter 2. Literature Review.

“Research your idea. See if there's a demand. A lot of people have great ideas, but they don't know if there's a need for it. You also have to research your competition.”

Magic Johnson

2.1 - Introduction

This chapter will review models that are currently available and the associated literature to establish the requirement of further design and innovation to the specific task of CBR and Proctor test specimen compaction. Extensive market research reveals that multiple automatic compaction machines have been developed and are readily available. Each of the available models offers slightly different features and functions, but none fully comply with the Australian Standard AS1289.

Available expert literature on such a niche area of industry was essentially unavailable. Exhaustive searches of literature outlining the progress made into the development of these machines yielded very little. Information on the CBR testing of soil substrates is more common; however the method of compaction of these samples is described in such great detail in AS1289, that all literature simply paraphrases the standard.

A small number of these non-compliant units are made in Australia while the vast majority of models are manufactured internationally. Small companies trying to satisfy the needs of their own employees have attempted and - to some extent - succeeded in making a machine that undertakes the compaction of the samples, but seem to lack the ingenuity or capital for the development of a fully compliant design.

Some of the older designs incorporate chain drives and still require a substantial amount of operator input, whereas some of the more current models replace the chain mechanism with pneumatics and are filled with “smart” pneumatic cylinders and PLC controllers. The single common feature that all of these machines lack however is the ability to achieve the specified rammer drop height from the uncompacted soil level as required by the Australian Standard.

2.2 - Industry Background

A primary contender in the manufacture of Civil Testing Industry is Controls; an Italian company that exports a large portion of the testing apparatus all over the world. Being a dominating industry leader with large financial backing, development of an accurate compactor could be expected. The compactor available from their range is a chain driven unit with microprocessor controller.

The Controls compactor shown in the photograph below (Controls, Product Guide and Catalogue . 2009) is the most commonly used compactor on the market today. This machine has a number of desirable features such as its compact size, however the chain drive is harsh on components and physical component failure from wear and fatigue is common.

Figure 1 - Controls Compactor Model "Compacto 33-T8504" and microprocessor controller

This unit uses a constantly forward rotating chain linked to latch assembly that is mounted on fixed box guides. The rammer itself is retained in a four rod guide and is manufactured with a thin toothed rack – similar to that in a steering assembly – that runs nearly the entire length of the rammer.

As the chain rotates the latch assembly cycles up and down the guides. Adjustable stops shift the latch into the contact position as it passes the bottom end of the cycle. The latch in the contact position engages into one of the teeth in the rack on the hammer and begins to lift the hammer.

Since the hammer is resting (penetrating) the soil, the latch engages and lifts the hammer. The upper adjustable stop contacts the latch assembly forcing the latch to retract. This action allows the rammer to fall to achieve another blow. By adjusting the upper stop position, the desired 300mm or 450mm drop can be achieved. This drop height does however include the penetration into the soil of the last blow.

The pitch circle diameter of the blows is changed by moving the rammer guide cage. The cage assembly swings with the latch assembly about a pivot point toward the rear of the machine and is driven by a small gear motor. Position is controlled by small contact switches.

As well as achieving a relatively level surface on the compacted sample, the unit does offer a reasonable amount of repeatability. The unit is quite compact and has a simple electronic safety switch integrated into the door.

From a control panel point of view, the “Compacto” is very basic with limited readout and no data capture capability. The unit is preloaded with blow patterns and layer counts, however drop height is set manually and there is no safety override in case the chosen blow pattern is incorrectly chosen for the diameter of the mould put into the machine.

Controls claims that “The Compacto digital compactors provide a fully automatic, uniform compaction, assuring repeatable test results while eliminating any operator fatigue. The unique original lifting mechanism of the rammer features a constant and precise fall height...” (Controls, Product Guide and Catalogue . 2009)

While this unit does in fact provide a constant fall height, it is a fixed height for each impact and does not account for variation in the penetration of the rammer between each blow.

The statement made by Controls advertising the unit outlines the driving factors for the development of these machines, but also highlights that the problems with existing models have not addressed in their design.

In the recent past, Geo-Con Products PTY Ltd has developed a pneumatic model of the compaction machine. The design was initiated by the Western Australian Main Roads Department. This unit again provides similar features to the Controls Compacto, while addressing the fast wearing components.

This unit does achieve a relatively repeatable compaction. It is easier to use than the Compacto but still lacks the ability to measure the drop height from the uncompacted soil surface and requires a substantial supply of compressed air – something that remote labs do not always have.

2.3 - Driving Factors

With an ever increasing understanding of workplace health and safety, a strong movement away from strenuous, repetitive physical exertion is well underway. The design of many machines is predominantly initiated in an effort to deal with these issues and designers are being trained into a culture where this is paramount.

Technicians conducting the manual compaction make up over four million dollars a year in work related strain injury work cover claims. (Work Cover Queensland, Work Cover Queensland Annual Report 1997/1998 1998)

Literature on repetitive strain injury (RSI) and occupational overuse syndrome (OOS) is plentiful. Ten years ago, 55% of all work cover claims were regarding back, neck and shoulder injuries and almost 10% of total claims were resulting from RSI or OOS. (Work Cover Queensland, Work Cover Queensland Annual Report 1997/1998 1998)

During 2009/10, 21,163 new claims – 22.9% of the total number of Work Cover Queensland claims – came from the manufacturing industry. 9111 – 9.9% of all claims – were resulting from RSI or OOS (Work Cover Queensland, Work Cover Queensland Annual Report 2008/2009 2009). Awareness of this type of injury has lead to a drop in RSI/OOS claims by 45.1% over the last ten years.

These reductions can be assimilated with a considerable drop in the cost and increase in availability of technical automation components. These factors have allowed the design and development of niche market, yet economical and affordable machines for the automation of more and more simple procedures in an effort to eliminate operator discomfort and injuries.

2.4 - The New Design

The Automatic Compactor was developed with all of these issues in mind. The design was to incorporate all that has been learned regarding problems in the compaction to produce a unit that was robust, accurate, efficient and most importantly, had all the features that would allow full compliance with the current Australian Standard.

It was realized during the design phase of the project, that with all of the positioning hardware being used to control the unit, the amount of data that was easily able to be captured was far beyond what anyone had intended.

2.5 - Process breakdown

The majority of the information required for the successful development of the Automatic compactor was supplied directly by Queensland Main Roads Department (QMRD). Mark Owttrim, Director of Material Services of QMRD was largely involved in the development of the scope of works for this project. The understanding of the compaction method and the procedures surrounding it - gained by their own internal research - provided a list of requisites and specifications that had to be met.

2.6 - Data Collection Systems

Many decades of data has been collected and stored from the CBR and Proctor tests. Understanding this and the implications of “rewriting the manual compaction method” was paramount. Critical to the success of the Autopak, one of the main objectives of the project was to develop the machine so as to produce samples compacted in such a way that the CBR test data from the compacted samples was directly comparable to that collected from the tests conducted on manually compacted samples in the past.

In order to address these objectives, QMRD insisted on automating the manual process as closely as possible. This decision was made on the basis of ensuring general market acceptance and was achieved primarily by designing the machines front line components to be very similar geometrically to the manual compaction hammer.

The Australian Standards are so explicit with the apparatus and methods that are to be used to conduct the manual compaction that the design of several core components of the Autopak was simply the manipulation and modification of non-critical geometry. The mass and impact surface of the rammer are prime examples of non-variable design. Other aspects of the rammer are quite different to the manual compaction hammers. These alterations were necessary to enable simplified machine movement while giving the machine a greater range of movement for possible research purposes.

During the concept phase, discussions on developing a machine that mimicked the velocity profile of the free falling rammer while using a shortened, powered thrust were tabled. QMRD however declined from these ideas for fears of industry rejection on the basis of historically slow technology acceptance within the industry. Too larger steps forward with machines such as these would not allow the industry to accept the automation of the process.

2.7 - Research Limitations

The research into the technical theory behind “ideal compaction” is heavily limited by the availability of research literature. While the compaction requirement itself has been around for many decades, industry leaders such as the Department of Main Roads have kept most of their data concealed in their own libraries.

Very little literature has been published on the methods surrounding compaction of the soil samples. The Australian Standards outline the methodology and apparatus requirements of how the manual compaction is to be carried out so concisely that the end output of the Automatic Machine is already known and quantifiable.

Chapter 3. Technical Requirements.

“Design is... above all an effort to improve reality... I always try to begin with considerations of its function... I ask myself, who needs it, which materials best suit its functions and so on...”

Gianfranco Frattini, Industrial Designer

3.1 - Background Information

Geo-Con Products was engaged to undertake the design, development and construction of an Automated Soil Compaction Machine for the preparation of proctor and CBR specimens. The project was initiated by Mr Mark Owttrim, Director of Material Services, Queensland Main Roads Department – Herston Laboratory.

The overall aim of this project is to design and manufacture a machine that automates the current manual method of the compaction of soil samples in preparation for assessing the Californian Bearing Ration (CBR). The machine must comply with all appropriate Australian Standards with a vision of setting a benchmark compaction that all soil laboratories must meet with their manual methods.

The functionality of this machine places it at the leading edge of research into this area. No other machines on the market fully comply with the Australian standards. By achieving full compliance, this machine allows reliable data collection on many aspects of the process. This data can then be used to build a much deeper understanding into the compaction of each sample and hopefully improve efficient of current field compaction methods.

It was primarily anticipated that the machine would eventually become the benchmark to which current manual compaction would be measured. The integration of laser measurement and linear transducers is used to undertake the majority of the measurement capabilities to ensure the accuracy of data produced.

Laser measurement has however provided an extra avenue of data collection that was not previously recognized. By using a laser to track the position of the rammer, it allows measurement of actual penetration of the rammer into the soil for each individual blow. This data - and its potential application - is providing new avenues of research for the Geotechnical industry.

Consideration of all of these aspects combined to develop of the Scope of Works for the Automatic Compactor. This chapter – Chapter 3 - forms the scope of works to which the machine was designed.

The Californian Bearing Ratio.

The Californian Bearing Ratio – herein written as the “CBR” - is a numerical descriptor of a soil or substrate’s load bearing characteristics. Over the past five decades, the test has become more widely used and accepted as a reliable source for comparing soils from any construction sites. With limited accuracy, the CBR is still the most widely accepted method of classification and therefore, the majority of design is based around this grading.

The CBR is often tested after soaking the sample in water. By submerging the compacted specimen in water for several days, a CBR of the material in its worst load bearing state – being completely water logged - can be taken allowing a worst case approach to be taken. This allows a far better understanding –and therefore final design - of the road base as it simulates the construction area after it has been subjected to high moisture levels from rain or flooding. (Queensland Geotechnical Services, Soil Testing 2010)

To gauge a sample’s CBR, a pre-prepared soil sample is compacted into a mould as defined by methods in (Australian Standards, AS1289.5.1.1 2003a) and (Australian Standards, AS1289.5.2.1 2003). The mould is then placed in a machine that forces a piston of specific diameter – nominally 49.6mm - into the compacted soil at a rate of one millimetre per minute. An integrated load cell in the piston shows the resultant resistive load that the soil is applying to the piston. These loads are recorded at regular time intervals for calculating the CBR.

the penetration increases, the resultant load increases steadily until a critical load or a critical depth limit of penetration is reached. If the penetration reaches 12mm, the test is stopped as this is deemed to have provided enough data to calculate the CBR accurately.

If the load remains steady for a period of time during the test, the test is also deemed complete as the maximum load limit of the soil has been reached. It is at this point the soil can no longer support the load and essentially gives way – behaving fluidly and flowing out from beneath the piston.

Generally the data is graphed manually by the attending technician. Figure 1 (M. Reza Emami Azadi, CBR Test Results of Well Graded Gravel-Sand Mixed With Clay (GSCW) Soil Samples 2004) below shows the data plot of a CBR test. The reactive force on the plunger is represented in kilonewtons on the y axis and penetration is represented on the x axis. The point at which the reaction load becomes steady is clear and the test is stopped at this point.

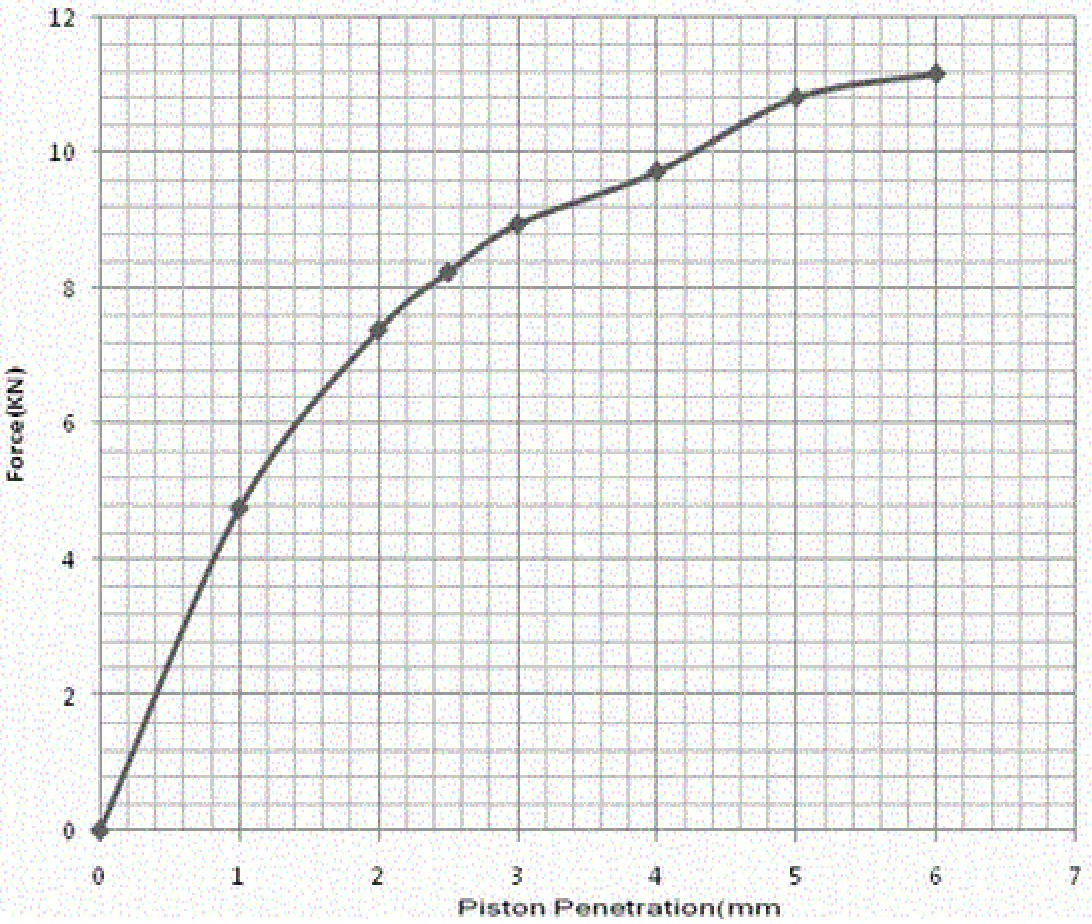


Figure 2 - CBR Test Graphical Result

The accuracy and repeatability of these results is determined largely by the preparation and compaction of the substrate into the mould. Herein is the requirement for the removal of human error.

Soil Compaction

For accurate, repeatable results, the compaction of the soil into these moulds must be as close to identical as possible. The measure for this compaction is based on the amount of energy delivered to the soil by the compaction process. Using the mass of the rammer and the drop height, the energy transfer is calculated and must fall within a designated tolerance.

The amount of energy delivered by each blow would ideally be that of the mass free falling. Frictional interference is a major contributing factor to the repeatability problems currently being experienced.

In current compaction methods, a large amount of human error is present and while results from the same technician show some degree of repeatability, the results obtained from identical samples compacted by different technicians can vary substantially.

Three different sized moulds, two different masses and multiple compaction methods requiring varying blow patterns are defined in the standard. The size and type of mould used is dependent on the material for which the CBR is being calculated. The governing factor in each case is the average aggregate size of the sample.

The preparation and compaction of these moulds is detailed in AS1289.5.1.1-2003 Part 4, item J. The following method for one specific type of material has been summarized from this standard as a general representation of the compaction method.

1) After assembling the mould as per AS1289.5, a portion of the prepared material is placed in the mould. This amount of material shall compact to between 38mm and 43mm.
2) A standard compaction hammer is used to administer the required 25 evenly distributed blows. The rammer is to free fall from 300mm.
3) A second layer of material is added so as to achieve a compacted soil height of between 77mm and 82mm.
4) The layer is then compacted as per step 2).
5) The third layer is added to achieve a compacted height of between 116 and 120mm.
6) The layer is then compacted as per step 2).
7) The mould is partially disassembled and then prepared for the CBR test.

(Australian Standards, AS1289.5.1.1 2003a)

These height limitations are required as the amount of energy per cubic meter of soil delivered in compacting the sample must fall within required tolerances. Any samples that do not meet these height requirements are discarded and cannot be used for any further testing.

3.2 - General Requirements

The mechanical compactor was designed to be the mechanization of the manually operated rammer while removing operator induced errors and variability of interpretation.

The compactor design was to deliver a device that not only meets the apparatus requirements of state, national and ultimately international standards, but incorporate features that emulate the process monitoring and control that can be provided by hand tool users.

The production mechanical compactor had to be a genuine replacement for manual compaction in terms of technical features, ergonomics, safety, and efficiency - not just an alternative means of achieving compaction.

The compactor also had to be able to provide standard and modified compaction for a range of mould types and layer configurations. In addition, for particular tests, the device had to be capable of delivering a user definable number of rammer blows at the technician’s discretion.

3.3 - Rammer

The compactor needs to accommodate the requirements of two rammer types, standard and modified as detailed in Table 1. A single rammer is to be used with the versatility to switch between either type by adding or removing a ballast of nominal mass 2.2kg, such that the masses and tolerances specified in Table 1 are achieved.

Changing between drop heights is to be achieved by the machine's electronic interface.

Rammer access - including removal - is required in order to carry out dimensional and mass checks for calibration.

Rammer Type	Standard	Modified
Impact face diameter (mm)	50 +/- 0.4	50 +/- 0.4
Impact face area (mm^2)	1964 +/- 31	1964 +/- 31
Mass (kg)	2.7 +/- 0.01	4.9 +/- 0.01
Delivered energy/blow (J)	7.94 +/- 0.08	21.62 +/- 0.08
Input energy (J)	596 +/- 14	2703 +/- 60
Drop Height (mm)	300 +/- 2.0	450 +/- 2.0

Table 1. Rammer Specification

3.4 - Moulds and Mould Holder

A mould support assembly is required to accurately locate and securely hold the moulds described in Table 2. Moulds must not move during rammer blow delivery.

The mould support assembly, while allowing the mould to rotate and slew to achieve the rammer blow patterns described in Rammer Blow Distribution, must provide a level rigid foundation equivalent to either-

- a sound concrete floor about 100mm or more in thickness; or
- a concrete block of at least 100kg mass.

The top surface of the mould holder is to be located 900 mm above floor height to facilitate mould filling and transfer.

Mould Type	**A**	**B**	**C**
Typical assembled height	180	210	250*
Mould internal diameter	105.0 +/- 0.5	152.0 +/- 1.0	152.0 +/- 1
Mould height (mm)	115.5 +/- 0.5	132.5 +/- 0.5	178.0 +/- 1
Nominal volume (cm3)	1000 +/- 15	2400 +/- 35	-

* A spacer disc, 150mm diameter and 61mm high is used with this mould

Table 2. Mould Specification

3.5 - Energy Input

The compactor must deliver either a prescribed input energy measured in kJ/m^3 or a user definable value as allowed by the scope of state, national and international test methods.

The energy is to be delivered via a free falling rammer (refer to Table 1) dropping vertically a set distance, either 300mm or 450mrn, to strike the surface of the material under test. The energy input is defined in methodology in terms of rammer type, mould diameter, number of rammer blows per layer and number of layers. Refer to Table 3 for examples. For particular tests, the energy input is user definable in terms of number of blows per layer.

The compactor must be configurable on a test method basis with scope to change variables such as number of layers and blows where applicable. Refer to Configuration.

Test Method	Rammer	Mould Type	Number of Layers	Number of Blows per Layer
AS1289.5.1.1	standard	A	3	25
		B	3	60
AS1289.5.2.1	modified	A	5	25
		B	3	100
AS1289.6.1.1	standard	CBR	3	53, 11 - 66*
	modified	CBR	5	88, 11 - I 10*
Q110A	standard	A	3	25
		B	3	60
Q110B	modified	A	3	42
		B	3	100
Q115	standard	A	3	8 – 32*
	modified	A	3	8 – 32*
Q113A	standard	CBR	3	53
Q113B	modified	CBR	5	88
Q113C	standard	CBR	3	11 – 66*
	modified	CBR	5	11 – I 10*

*minimum value only

Table 3. Compaction Requirements

3.6 - Rammer Blow Distribution

Rammer blow distribution patterns are generally prescribed in methodology and vary depending on the mould diameter and to a lesser extent on the compaction standard. The blow patterns and delivery cycles for various mould types and a single layer are detailed in Table 4.

Test Method	**Q110A** **AS1289.5.1.1**	**Q110B** **AS1289.5.2.1**	**Q113A** **AS1289.6.1.1**	**Q113B** **AS1289.6.1.1**	**Q110A**	**Q110B**
Mould Type	A		B/CBR			
Number of blows per Layer	25	42	53	88	60	100
Cycle no. 1	8	8	8+1	8+1	8 +3	8 + 3
Cycle no. 2	8	8	8+3	8+1	8+3	8 +3
Cycle no. 3	9	8	8+3	8+1	8+3	8+1
Cycle no. 4	-	9	8+3	8+3	8+3	8+3
Cycle no. 5	-	9	7+2	8+3	8 +3	8+3
Cycle no. 6	-	-	-	8+1	4+ 1	8+3
Cycle no. 7	-	-	-	8 + 3	-	8 + 3
Cycle no. 8	-	-	-	8 +3		8 + 1
Cycle no. 9	-	-	-	-		8 +3
Cycle no. 10	-	-	-			1

Delivery Points: circumferential; central area

Table 4. Layer Rammer Pattern and Delivery Cycles per Layer

Notwithstanding the above requirements, rammer blows are to be delivered using the following schedule appropriate for the number of cycles, delivery points, and blows:

Cycle 1:

- Circumferential: blow I — 0°, blow 2 - 180°, blow 3 - 90°, blow 4 - 270°, blow 5 - 135°, blow 6 - 315', blow 7 - 225° and blow 8 - 45°.
- Central area; blows are located in the central area of the mould such that they overlap by one half diameter with each previous blow.

Cycle 2:

- Index the Mould Holder 22-5° clockwise;
- Deliver the first circumferential blow with indexed position, subsequent blows are delivered following a clockwise index of 45° before each; and
- Central blows are delivered as per cycle I

Cycle 3:

- Index the Mould Holder 11-25 'clockwise;
- Deliver the first circumferential blow at the indexed position, subsequent blows are delivered following a clockwise index of 45° before each; and
- Central blows are delivered as per cycle 1

Cycle 4:

- Index the Mould Holder 22-5° clockwise;
- Deliver the first circumferential blow at the indexed position, subsequent blows are delivered following a clockwise index of 45° before each; and
- Central blows are delivered as per cycle I

Cycle 5:

- Index the Mould Holder 33-75' clockwise;
- Deliver the first circumferential blow at the indexed position, subsequent blows are delivered following a clockwise index of 45° before each; and
- Central blows are delivered as per cycle 1

Cycle 6:

- Index the Mould Holder 22-5° clockwise;
- Deliver the first circumferential blow at the indexed position, subsequent blows are delivered following a clockwise index of 45° before each; and
- Central blows are delivered as per cycle 2

Cycle 7:

- Index the Mould Holder 11-25 'clockwise;
- Deliver the first circumferential blow at the indexed position, subsequent blows are delivered following a clockwise index of 45° before each; and
- Central blows are delivered as per cycle 3

Cycle 8:

- Index the Mould Holder 22-5° clockwise;
- Deliver the first circumferential blow at the indexed position, subsequent blows are delivered following a clockwise index of 45° before each; and
- Central blows are delivered as per cycle

Cycle 9:

- Index the Mould Holder 33-75' clockwise;
- Deliver the first circumferential blow at the indexed position, subsequent blows are delivered following a clockwise index of 450 before each; and
- Central blows are delivered as per cycle 5

Cycle 10:

- Central Blows Delivered as per cycle 1

Following the compaction of each layer, the Mould Holder shall be indexed by the amount shown in Table 5.

Cycles Per Layer	Index Angle
3	22.50
5	22-50
6	11.250
8	33.75
9	22.50

Table 5. Mould Holder Indexing

3.7 - Special Features

The following features are essential in order to achieve good practice and meet test method requirements.

Rammer Blow Delivery

The optimum delivery frequency is 90 blows per minute. While this frequency can be achieved for manual compaction, it is recognized that a lesser value, minimum 30 blows per minute, may have to be accepted for mechanical compaction. Once compaction of a layer has commenced the full number of blows for a particular layer shall be delivered uninterrupted unless the operator intervenes.

Mould - Rammer Clearance

Rammer blows delivered at the circumference of a mould must not strike or touch the mould. The clearance between the internal wall of any mould and the outer edge of the rammer must not exceed 2.5mm.

Rammer Face Cleaning

The compactor is to incorporate a facility to remove adhering earthen material from the rammer face after each rammer blow.

Manual rammer face cleaning by the operator must be available on an intervention basis during a delivery cycle. (Activating the PAUSE switch will return the rammer to the ready position with the safety guard being retracted to facilitate cleaning. Refer to Controls.)

Surface Height Reference Device (SHRD)

A lightweight SHRD shall be used in the determination of the:

- Rest position of the rammer after each blow; and
- Cumulative layer thickness after each compaction cycle.

The SHRD is a "C" shaped section concentric with but not physically connected to the rammer. Key requirements are detailed in Table 6.

The ends of the "C" section are to be separated by a nominal 45 mm gap and orientated to be a minimum and equal distance from the internal wall of any mould in the Mould Holder.

Rammer Type	Standard	Modified
Mass (g)	1330 ± 5	1510 ± 15
Contact Area (mm 2)	680	680
External Diameter (mm)	75 ± 1	75 ± 1
Range of movement (mm)	350	350

Table 6. SHRD Details

The range of movement of the SHRD must be such that it can be positioned as follows:

- on the top surface of any mould base plate, to set a mould datum for compaction; and
- on un-compacted or partly compacted material up to a level equal to the top of any mould collar, to set a drop height datum before raising the rammer to the ready position.

Note: If in determining the datum, a Type A mould is detected when either a Type B or CBR mould has been configured, the START switch shall be disabled and an error message displayed.

3.8 - Drop Height Measurement

Prior to each new rammer blow and while the rammer is being raised, the SHRD shall be lowered onto the surface of the material under test, around the area to be impacted. The rammer has achieved the required drop height once the electronically measured distance from the surface of the SHRD, in contact with the material, to the rammer impact surface is the same as that specified for the test being, performed. Refer to Table 1.

3.9 - Cumulative Layer Thickness

The cumulative layer thickness for each layer shall be determined using the rest position information for each of the rammer blows for the last cycle delivered during the compaction of any layer- The rest positions are compared to the datum for the top surface of the mould base and an average cumulative thickness is calculated and stored for the layer. The first layer compacted is designated layer I with subsequent layers being labelled in numerical order. Refer to Table 7 for cumulative layer thickness ranges.

Test Method	Rammer	Mould Type	Cumulative Layer Thickness Range (mm)				
			Layer 1	**Layer 2**	**Layer 3**	**Layer 4**	**Layer 5**
AS1289.5.1.1	standard	A	38-43	77-82	116-120		
		B	44-49	89-94	133-138	-	-
AS 1289.5.2. 1	modified	A	23-28	47-52	70-75	93-98	116-120
		B	44-49	89-94	133-138	-	-
AS 1289.6. 1.1	standard	CBR	39-44	78-83	117-122	-	-
	modified	CBR	21-26	45-50	67-72	92-97	117-122
AS 1141.51	standard	A	38.5	77.0	115.5		
AS 1141.51'	modified	A	23.1	46.2	69.3	92.4	115.5
Q110A	standard	A	38-43	77-82	116-120	-	-
		B	44-49	89-94	133-138		
Qll0B	modified	A	38-43	77-82	116-120	-	-
		B	44-49	89-94	133-138	-	-
Q1 15*	standard	A	38.5	77.0	115.5	-	-
	modified	A	38.5	77.0	115.5	-	-
Q113A	standard	CBR	39-44	78-83	117-122	-	-
Q113B	modified	CBR	21-26	45-50	67-72	92-97	117-122
Q I13C*	standard	CBR	39	78	117	-	-
Q113C#	modified	CBR	23.4	46.8	70.2	93.6	117

* 3 equal layers # 5 equal layers

Table 7. Compacted Layer Thickness Ranges

3.10 - Controls

The compactor shall require a minimum of operator interaction with the exception of configuration, mould location, rammer ballast charges and mould filling.

While the following controls are provided as suggestions, the functionality contained herein is required:

- Lever – selection of the rammer drop height. Refer to Table 1.

  *Note an electronic interface is preferred, refer to Configuration.
- ON-OFF switch to:
- power electronic components;
- power any hydraulic supply; and connect any compressed air supply.
- START switch to:
- first activation; establish the datum for the top surface of the empty mould base; and second and subsequent activations; start rammer compaction for each layer.
- Note: Tamper proof sensors will trigger disabling of the START switch if the drop height setting
- and/or rammer mass do not match configured parameters.
- PAUSE switch to:
- interrupt operation by holding or returning the rammer to the ready position and retract the safety guard; and
- subsequent activations toggle between restarting compaction and interruption as described above
- STOP switch to:
- cut power to all electric components;
- cut power to any hydraulic supply and depressurize the system; disconnect any compresses air supply and depressurize the system.

Following the first activation of the START switch, the following option will be displayed on the process controller screen as a keyboard action similar to below.

TERMINATE and ABANDON TEST

3.11 - Configuration

After setting the ON-OFF switch to the ON position, the operator will be prompted by the process controller to log-on and configure the compactor. At the completion of the compaction of a mould the operator will be prompted to again log-on in order to continue or log-off to end the session. (Automatic log-off should occur following a period of inactivity.)

Log-on: - User ID

- Password

Configuration: - Unique Compaction Number (UCN)** allocated by system

- Sample Reference Number
- Compaction Point Number
- Mould Number
- Stabilizing Agent Type and Rate (entered once)
- Test Method[1] (pick list)
- User Definable, parameters* (as allowed by test method, for example; mould type, Number of blows per layer)

* Ideally, selecting the Test Method and if required the Rammer Type will set a flag in the process controller to physically set the rammer drop height without further action by the operator.

** A UCN is to be assigned for each new test.

Where the option exists to input rammer blows per layer, the same number of blows must be used on each layer. Rammer blows per layer can only be entered in multiples of 8 for a Type A mould and multiples of I I for Type B and CBR moulds.

All information and parameters are stored with the Sample Reference Number and UCN.

Ongoing Operation

At the completion of the compaction of a mould, the compliance outcomes will be displayed and the operator will be prompted to again log-on. If the same user logs on, the previous configuration again will be displayed with the Compaction Point Number being incremented by one. If a different operator logs-on, the requirements will be as per start-up.

3.12 - Process Control

Process control is to be achieved using a PLC with a menu driven touch screen graphic user interface (GUI).

Following user configuration the process controller shall continuously monitor rammer drop height and rammer mass. Any time there is a misalignment between any configured and monitored settings the START switch shall be deactivated and an error message displayed.

- In addition to the functionality described in the Controls section the process controller shall: Control the lowering and lifting of the SHRD including the determination of the:
  - Mould Datum le. the top surface of the mould base plate; and
  - Drop Height Datum for raising the rammer to the ready position prior to release.
- control the positioning of the safety guard such that it is in place during the operation of either the SHRD or rammer
- control the release, cleaning and lifting of the rammer to the ready position
- continuously monitor the position of the SHRD and rammer
- monitor the activation of the control switches and initiate actions based on predetermined response protocols
- set the drop height of the rammer (Refer to Controls and Configuration)
- store, display and report data
- calculate cumulative layer thicknesses
- integrate operation and monitoring with the configured Test Method requirements
- provide status reports throughout and following mould compaction, refer to Status Reports
- provide the functionality to either terminate a mould compaction or abandon a test
  - Terminate: the rammer is returned to the ready position with the safety guard retracted-, the configured information is retained.
  - Abandon: the rammer is returned to the ready position with the safety guard retracted; the configured information is deleted.
- Have a facility to calculate materials qualities based on system feedback and operator inputs.

Status Reports

Status reports are to be provided following configuration, during compaction and at the completion of the rammer compaction of a mould.

Configuration Report

After configuration the following shall be displayed on the computer screen:

- user name
- sample reference number
- compaction point number
- Mould number
- stabilizing agent type and rate
- test method details
  - method number and title
  - rammer type (standard or modified)
  - rammer drop height (300 mm or 450 mm)
  - mould type (A, B or CBR)
  - number of layers (3 or 5)
  - number of blows per layer (See Table 3)
- Any error messages, e.g. "actual rammer mass and/or drop height do not align with configured settings"

The above will remain on screen throughout the test. In Process Report

After the second activation of the START switch, measurement of elapsed time in minutes and seconds shall commence and be displayed together with the number of delivered rammer blows for each layer (1-n).

The layer number and layer height range for the layer being compacted shall also be displayed.

At the completion of the compaction of the layer, the cumulative layer thickness shall be reported beside the appropriate range with PASS or FAIL. The number of blows will also be displayed

Should FAIL be reported the operator will be promoted with;

Press TERMINATE to abandon the test, or press ENTER to continue.

If ENTER is pressed, a variation to test method and the circumstances surrounding the event will be stored with the configuration information together with the date and time.

At the completion of compaction of the mould (final hammer drop for the last layer), the elapsed time measurement shall be stopped and stored with the configuration information.

3.13 - Compaction Report

At the completion of moulding, the process controller shall prompt for the operator to obtain a hard copy report. Such a report shall contain all stored information including the configuration information, the date of compaction and start and elapsed times.

Safety

The mechanical compactor shall comply with all appropriate state and federal acts, regulations and standards for electrical and mechanical equipment.

In addition to state WH&S requirements, there is also a need to comply with the requirements of AS4024.1. Design of controls, interlocks and guarding — Guards — General requirements for the design and construction of fixed and movable guards.

3.14 – Post-Specification Additional Features

During the manufacture and construction of the compactor, a number of modifications were made. The majority of these modifications had no effect on the functionality of the compactor, but were made to increased reliability.

Initially, a graphite impregnated bush was used as a guide for the rammer. Positioned to support the upper end of the rammer, this served to keep the hammer relatively upright after a blow so as to allow the gripper to pass over the rammer shaft without collision. During manufacture, it was decided that to keep in accordance with the client's wishes, the nylon guide would be removed and a steel guide very closely resembling the handle of a manual compaction hammer would be used in its place. The steel guide was a step closer to the replication of the manual method and was easily implemented.

Linear bearing rods used to as guides for the height sensor cage were remanufactured to allow them to span between support plates and be fastened at both ends. The extended guide rods now connected two of the primary aluminium flanges together and increased stability and structural integrity.

The result not only increased rigidity of several protruding components, it allowed the cage, bearings and flanges to become a single sub-assembly. With some careful machining of the two aluminium flanges, the subassembly simplified the final alignment of the rammer, gripper and cage substantially by forcing alignment of the rammer guide and the cage within the subassembly itself.

The most beneficial of all the additions to the original design, was laser tracking the position of the rammer. This function was the last of the variations that were made and was originally designed to act as a failsafe to ensure that the rammer was being held in the gripper jaws correctly. It was also recognised that the laser would double as a self calibration feature, zeroing the length offset between the gripper and the impact face of the rammer.

It was not until after the installation that it's most valuable function – being able to calculate actual penetration - was realized. Having the ability to know how much on average the sample layer was compacting allowed the weight of material required to achieve the target layer thickness to be forecast and subsequently displayed on the readout.

Lost time due to miscalculations or errors on the technician's part will be minimised as the amount of material required was now calculated and not estimated.

Chapter 4. The Design

“A designer knows he has achieved perfection not when there is nothing left to add, but when there is nothing left to take away.”

Antoinè De Saint-Exupéry

4.1 - Design Requirements and Limitations

QMRD had developed a clear picture of what was required prior to engaging Geo-Con Products. No fixed general arrangement had been completed; however a list of requirements had been set down and discussed within QMRD. This list was not definitive as it varied throughout the entire design process as problems and ideas came to light. While in the concepts stage, several of the items were discarded completely, while the importance of other items was fortified and enhanced with confidence in possible solutions at hand.

The priority for this machine was that it was to comply fully with AS1289. The most important feature highlighted within the standards was that of measuring the required drop height of the rammer from the uncompacted soil level at the intended blow location.

Another key item was the physical size limitations of the machine. Many of the soil laboratories are very remote and are in small demountable buildings. It was decided very early on in the process that the machine would have to be able to fit through a standard door way to ensure that it would be easily delivered to any site with minimal difficulties. This proved to be one of the most difficult limitations and was discovered only when the detailed design was well underway.

QMRD also insisted that the soil level sensor was to resemble that of the manual compaction hammer. The theory behind this decision was that if the parts of the machine that touched the soil looked the same as the manual hammer, then acceptance into the market would be much easier – this being prerequisite for the successful sale of a production machine.

The machine also had to comply with current safety standards. All guarding was designed in accordance with AS4024 to ensure a safe, but user friendly machine was delivered.

4.2 - Concepts

During the conceptual design stage of the Automatic Compactor, the machine was dealt with in four subassemblies; the base, the mast, the gripper and the rammer/sensor cage.

The base was to provide a footing for the machine that would also house all components to allow the positioning of the mould. The footprint of the machine had to conform to the requirement of fitting through a standard door. A heavy platen was to also be incorporated. The platen was to provide a heavy mass and clamping position for the moulds to mitigate as much energy loss of each blow from an inertial aspect.

The mast provides the framework for the gripper. Height restrictions were also imposed on the mast as an overall machine height was not to exceed 2350mm. The mast was also to be designed to allow disassembly from the base to aid in transportation and manoeuvrability. This became of lesser importance as the project continued as the overall machine was eventually made to lie on its back during transport. Also incorporated into the mast was the guidance for the gripper, the freefall rammer and the sensor cage.

The gripper was to hold onto the rammer to allow lifting into position at the drop height, releasing the rammer to allow free fall, then find the rammer and collect it ready for the next blow. The mechanism to deal with sample adhesion to the rammer was required as part of the subassembly.

The rammer and sensor cage, although two separate components, were already predominantly designed as these items are so defined by the standards. It was insisted upon by the client that the surface of the sensor cage be exactly the same as that of the manual compaction hammer. Some modifications would be allowed for the rest of the cage; however the weight of the cage was to remain identical.

Progression of the concept began and the general arrangement of the design agreed upon with the next step to investigate the best system to actuate the machine. Three primary sources of motion exist; electrical, hydraulic and pneumatic.

With a large percentage of other laboratory machines being hydraulic, a level of comfort was found in using hydraulics. Laboratories do have some level of understanding of hydraulic systems and technicians would be more able to fault find if required. The initial concept leant itself to the use of hydraulic motion.

Three dimensional modelling software Solid Edge was used to start modelling the concept. Basic stroke lengths of all the moving parts were determined and the initial design started to take shape. A number of estimations were made to allow a concept model to be made. Details such as the masses of components that were to be moved as part of normal operation were unknown but were roughly calculated with an included contingency factor to start sizing hydraulic cylinders.

By using hydraulics, the overall size of the cylinders to be used is greatly determined by the stroke length. Allowances were made from the estimated force requirements as to diameters and the model was essentially built around these items.

Figure 3 below shows the first concept model. Hydraulic cylinders are in place and the general layout is clearly understood.

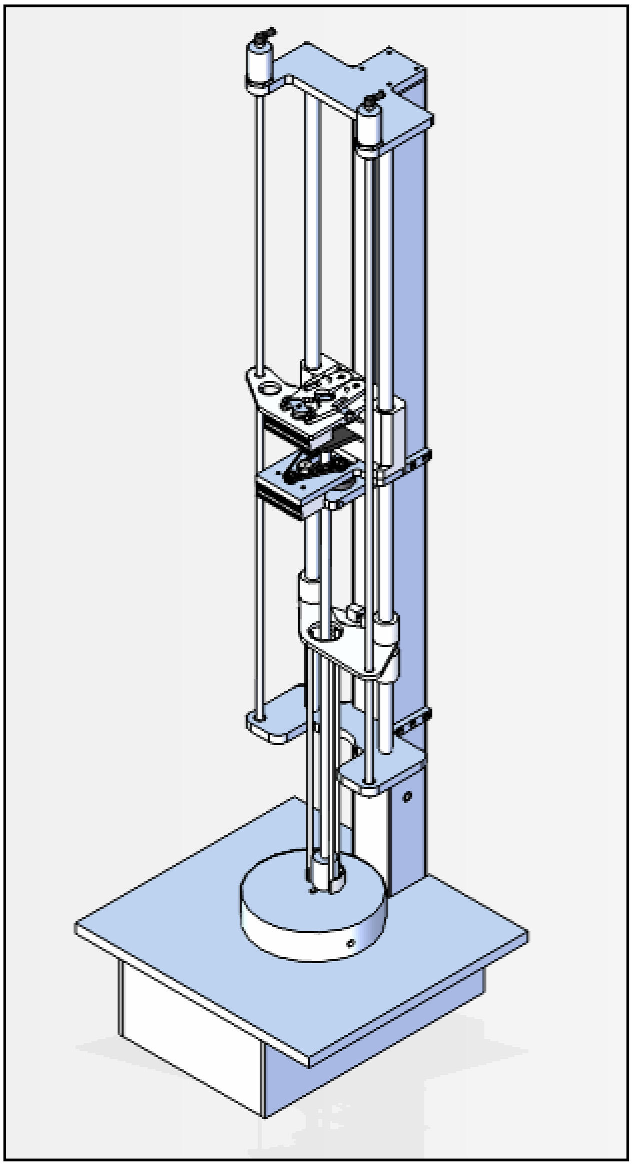


Figure 3 - Initial Concept 3D Model

As the model progressed, a much more accurate calculation was made on the forces required to move the machine. At this stage, a hydraulics manufacturer was engaged as specialty cylinders had to be manufactured.

Several weeks of design on behalf of the hydraulics manufacturers saw the unit evolve with customized IO controlled valve banks and custom design cylinders to allow for the speed they were to achieve. It was at this stage that final cost estimates of the proposed system were provided for production machine sets. The estimated price of the proposed hydraulic system for each individual machine exceeded the target float price of the entire unit. Unrealistic expectations of guaranteed order quantities within set time frames and the ownership of intellectual property from the hydraulics manufacturer – although already specified in the original agreement – saw the termination of any further works on the hydraulic outfitting of the unit.

Alternate systems were analysed and investigation into the combination of electrical and pneumatic systems yielded the most favourable outcome. The machine was to be predominantly electric with minimal pneumatics to address the availability of large amounts of compressed air in the laboratories.

This system did however mean the requirement of three phase power to the unit. The speeds that the drives were to move would require far too much power to allow single phase use.

The concept model had to be readdressed to accommodate relatively large electric drives. Adhering to set space limitations meant some ingenuity in their mounting however initial calculations proved it to be possible.

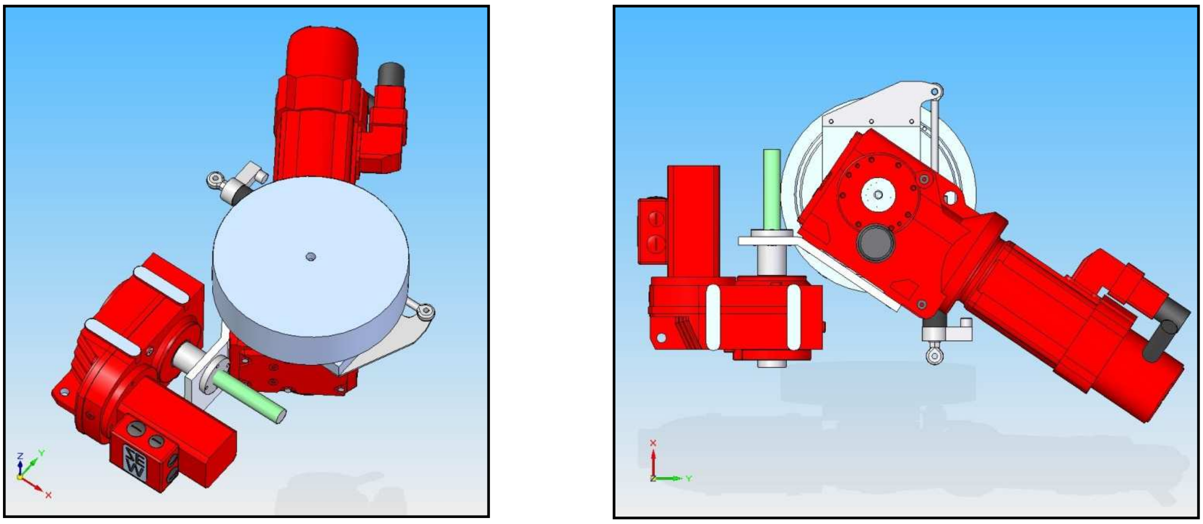
4.3 - Machine Sub Assemblies

The Base Assembly

The base assembly was the first subassembly to be fully designed. The base was the determining factor for overall size and internal space was very limited.

The platen was designed to be substantially heavier than the rammer with the aim if minimizing energy loss through impulse. The platen itself was made from 300mm diameter, 75mm thick mild steel disc. After machining, the platen weighed just over 40kg. The platen was positioned directly onto the top plate of the base assembly. Only a thin lubrication film separated the two surfaces. No bearings were used as the reliability of bearings being hammered eccentrically constantly is low.

The overall layout of the base assembly components can be seen in Figure 4 below.



Isometric view

Bottom View

Figure 4 - General arrangement of motion components in the base assembly

The drive shaft, motor and gearbox that were directly mounted to the platen increased the mass of the platen assembly to over 65kg. The base housing itself was constructed from 20mm thick mild steel plate weighing in excess of 125kg. Comparatively, the mass difference between even the heavier rammer at 4.9kg, and the base assembly of 197kg was large enough to satisfy the requirements.

Figure 5 below shows the base assembly model with all components in place. Space was very limited causing motor and gear box combinations to be mounted at obscure angels.

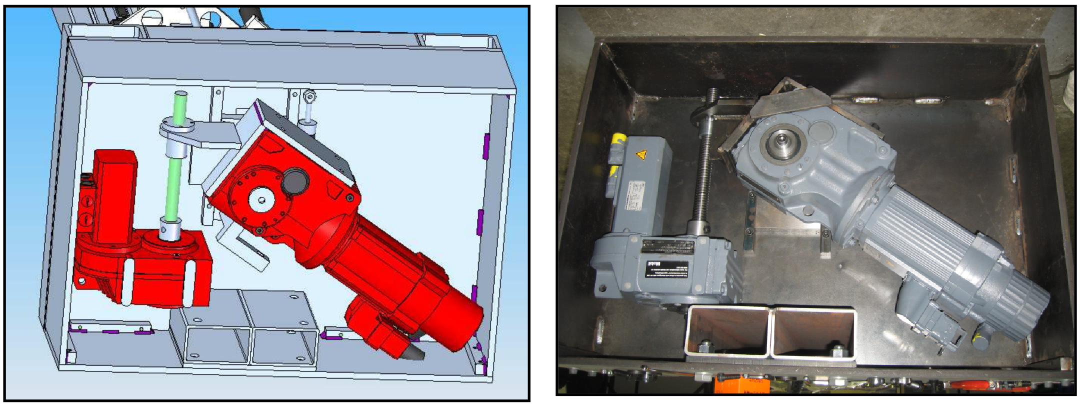


Figure 5 - General Arrangement of the base assembly viewed from below – model and as built.

With the calculations of forces and speeds required to move the mould and the platen, the motors, gearboxes and drives could be specified.

The drive required to rotate the platen was calculated to be a 1.25kW SEW KA47 motor coupled to a 25.91:1 reduction worm gear box. The motor gear box combination was also fitted with a shaft mounted 24volt disc brake, bonded gears, a thermostat and an RH1L resolver. The gearbox was direct mounted to the platen shaft and rotation of the gear box was restrained using an adjustable torque arm arrangement. The motion was controlled by 1.5kW SEW MDX61 Movidrive frequency inverter. The angular position of the platen was controlled by the resolver.

To provide the linear movement of the platen to alter the blow pitch circle diameter, a 1kW SEW FAF37 motor with a shaft mount 24volt DC disc brake was coupled with a 31.69:1 reduction worm box. This combination was used to drive a 30mm trapezoidal thread; 4mm pitch lead screw to provide the required linear motion. The motion was controlled by 1.5kW SEW MDX61 Movidrive frequency inverter.

The position of the driven assembly - and thus the mould - was constantly measured using a 150mm stroke linear transducer mounted directly to the platen assembly. This was to eliminate any error in position from distortion of the motor mounts, lead screw or lead nut flange. It also provided a feedback comparing the motor revs with the actual movement to ensure the motor was actually moving the platen.

To ensure true free fall of the rammer, a large amount of time was spent in the alignment of the rammer guide and the cage. The mast assembly is designed to bolt against a machined surface that is perpendicular to the surface of the platen. The addition of levelling bolts on the base ensures that the whole machine is installed and operates level and interference to the free falling rammer is minimised.

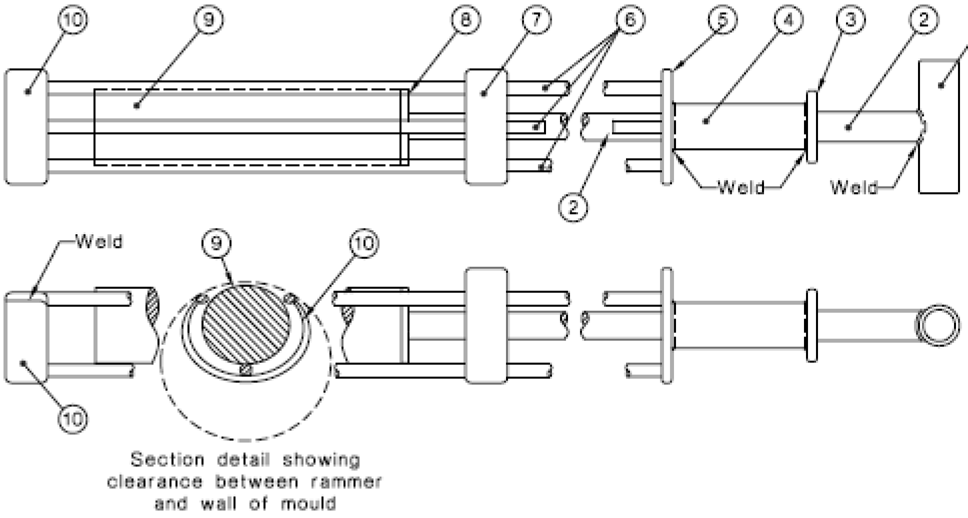
4.4 - The Rammer and Cage.

The rammer has a specified diameter of 50mm and mass of either 2.7 or 4.9kg. To allow for machine simplification, the length of the rammers including their shafts was to be identical. The only difference being that the 4.9kg rammer would have a longer head to account for the extra mass.

To ensure that the rammer was gripped in the same position every time, the top end of the rammer rod required a protrusion that would allow it to be located into a set of gripper jaws. A simple conical bolt on end was designed to allow positive centralised location in the jaws while providing near instant separation between the gripper jaws and the hammer when the rammer is released.

The final rammer design yielded a 16mm diameter rod, threaded into a 50mm diameter, lead counterbalanced mass giving an overall hammer length of 1153mm.

The cage was designed to be as close geometrically to the manual compaction hammer cage as defined by the Australian Standards. (Australian Standards, AS1289.5.1.1 2003b) Figure 2.)



PARTS LIST AND TYPICAL DIMENSIONS

1	Handle	Ø 30 × 3 thick, black low-carbon steel tube 90 long
2	Rod	Ø 19 bright low-carbon steel rod
3	Guide washer	5 low-carbon steel flat Ø 40
4	Tube	Ø 26 × 3.2 thick, black low-carbon steel tube 90 long
5	Frame washer	5 low-carbon steel flat Ø 75
6	Guides	Ø 8 low-carbon steel rods—3 no.
7	Full ring	25 × 3 low-carbon steel flat
8	Washer pad	Ø 45 leather
9	Rammer	Ø 50 bright low-carbon steel bar
10	Part ring	25 × 3 low-carbon steel flat

NOTE: This design has been found satisfactory, but alternative designs and materials may be employed provided that the essential requirements in Table 1 are met.

DIMENSIONS IN MILLIMETRES

Figure 6 - Manual hammer geometry as determined by AS1289

A linear transducer is attached to the cage to allow the machine to measure the uncompacted surface height of each blow, and then to calculate the position of the gripper assembly relative to the sensor to achieve the desired drop height.

The cage runs on a single precision ground stainless steel guide with two outrigger runners to stop rotation. Initially the two outrigger guides housed linear bearings. However alignment issues and eccentric loading caused these bearings to bind. The outriggers were converted to graphite impregnated nylon bushes and the linear bearings were combined into a single, central block running on a precision ground shaft. The increase in length of contact with the shaft lowered the effects of the moment caused by the eccentric loading and corrected the binding problem. Figure 8 below shows the configuration of the cage assembly.

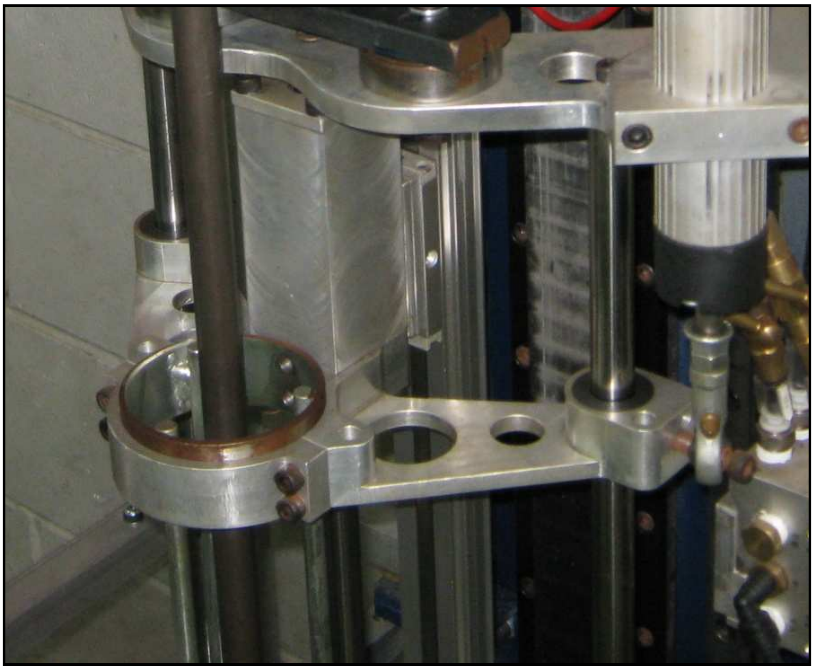


Figure 7 - Cage Bearing Arrangement

The cage was then weighed and recalibrated to the weight of the manual compaction hammer cage again to recreate impacts encountered with the placement of a manual hammer cage.

The Gripper Assembly.

The gripper assembly was designed to act similar to that of a human hand. A billet aluminium block forms the frame of the assembly. Bearings are pressed into the housing directly while the housing itself provides support and location for the jaws.

A series of jaws (Figure 8) grab the hammer shaft and stabilize it. Jaws on the top of the assembly provide the contact surface used to lift the rammer by the conical rod extension. The primary jaws have inserts that have been designed to allow symmetrical release of the rammer by separating parallel to each other. These jaw inserts made from aluminium and are classed as consumables. The double ended design doubles the life of each individual jaw. Replacing these inserts requires only a 5mm Allan key.

A small set of spring loaded secondary jaws allow the conical end of the rammer rod to slip through onto the primary jaws, but clip shut over top of the rammer to eliminate any risk of overthrowing the rammer as it decelerates into the drop position. Overthrow is a major contributing factor to inaccuracies in the manual test. The manual equivalent of overthrow is back hammering. Lifting the hammer so fast into the top of the cage on the upstroke causes the cage to lift off the soil slightly, extending the drop height.

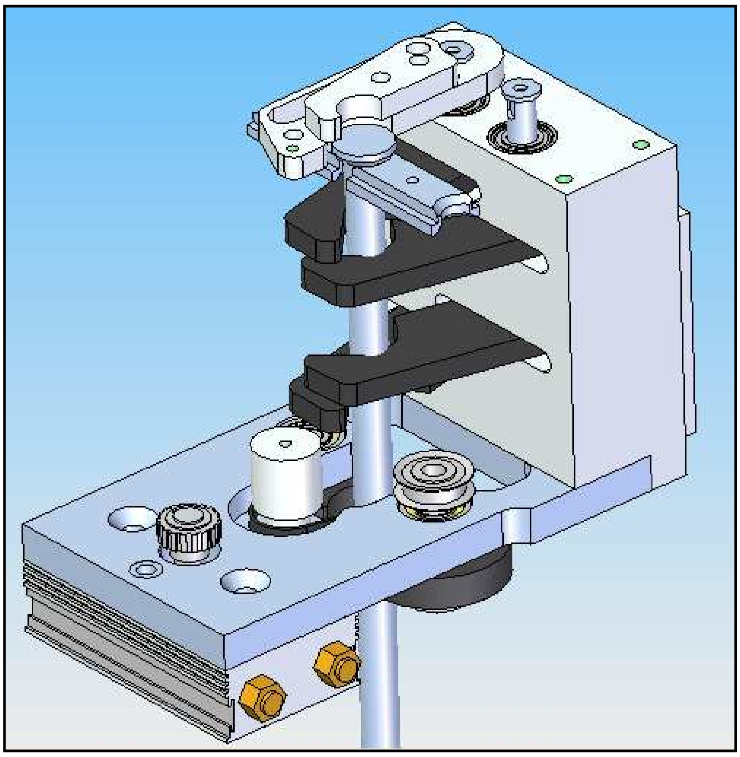


Figure 8 – Cut away view of Jaws Retaining and Stabilizing the Rammer

Two further sets of jaws – shown in black in the above figure - act as stabilizers griping the shaft, keeping it centrally located in the release jaws. The stabilizer jaws are manufactured from high density nylon to reduce operational noise and resist against wear. All jaws are keyed and are driven by the same two shafts and are actuated by a pneumatic gripper. The gripper jaws are attached to the free end of the primary lifting jaws. A reed switch in the gripper ensures that the jaws are open during the collection of the rammer. Features such as this protect the machine against damage as failure to open the jaws would result in the rammer rod being forcibly driven into the closed jaws.

A photo eye perpendicular to the correct rammer position is included in the gripper assembly to signal that the rammer is in place and to continue the compaction cycle process.

A rotary pneumatic actuator and a set of scalloped wheels - driven via a timing belt - allow the rammer to be twisted immediately after a blow in the event of adhesive material building up on the face of the rammer. This is standard procedure in the manual methods. This function is selectable by the operator during setup of the test. Once selected, the rotation of the hammer occurs on every nth blow as designated by the operator.

The whole assembly is hard mounted to an SEW SL2-P-050M linear motor. This motor provides linear motion only. This motor is actually two separate parts; a magnetic track, and the armature itself. The magnetic track is bolted to a flat surface – in this case the mast – and the armature travels along the magnetic track on linear bearing rails. Separation of 1mm plus or minus 0.2mm between the magnets and the armature is critical for correct operation. The attraction force between the permanent magnets and the armature once energized reaches 4300 Newtons. Four SHS25 linear bearing blocks ensure the gap is held constant.

As power is applied to the armature, the electromagnetic flux of the armature tries to align itself with the permanent flux of the magnets. Controlling the frequency of the armature controls the speed at which the drive travels along the track. When the power is switched off, there is no attraction magnetic attraction. In this application, the motor is running vertically. To mitigate risk of not only injury, but damage to the machine, Nexen rail brakes were installed.

The Nexen rail brake is a spring actuated, air released brake that is designed to clamp onto the linear bearing rail. If power is lost to the linear motor, or air pressure is lost, the Nexen brakes grip the rail locking the drive at that position. This is required for safety certification. The internal components can be seen in the cutaway view in Figure 9. (Norman G Clark, RBR Series Rail Brake 2000)

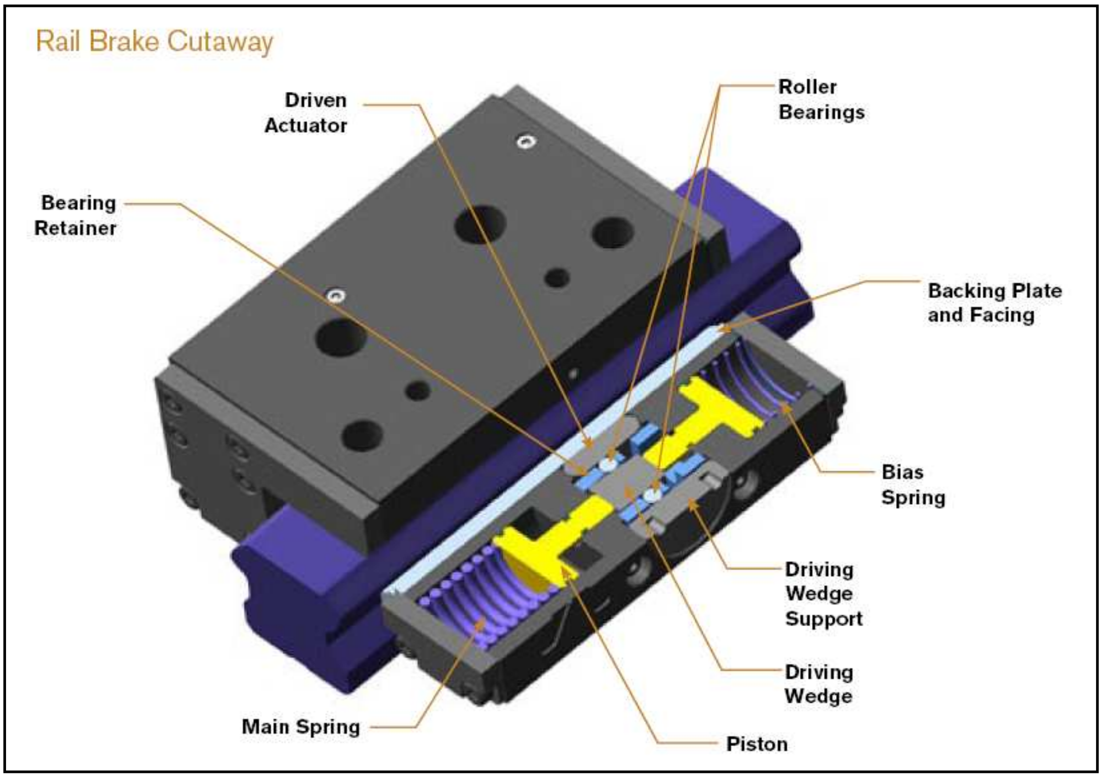


Figure 9 - Nexen Rail Brake cutaway view

The Mast Assembly.

The mast assembly is the back bone of the entire machine. The stiffness of the mast is not only critical to the correct operation of the linear motor but is also critical to the stability of the machine. To increase stiffness, the mast was manufactured from two lengths of 150x75x5 RHS welded together (Figure 10). The mast is subjected to an eccentric load reciprocating at velocities approaching 2.3 meters per second. Basic calculations were undertaken regarding the stiffness but no dynamic analysis has been completed. A full FEA design will be conducted on the mast for the saleable machines.

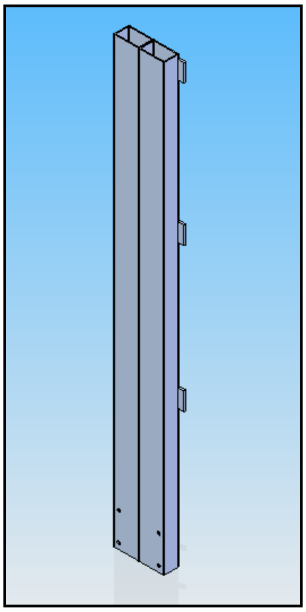


Figure 10 - Dual RHS Members forming the Mast

4.4 - Control Components

A separate control box was required to house the power supply, variable frequency drives and the user interface. A sloped upper face on the control box adheres to the 5S system when considering lean manufacturing. In laboratories, any horizontal space is either used as a shelf, or rapidly collects dust. The slope also aids in the overall ergonomics, reducing glare on the touch screen and minimizing risk of damage to the screen.

Inherently, the control panel can accept up to 6 of the compacting units. The initial capital outlay for the machine can be offset by savings in labour and the reduction of lost time at work from technicians suffering from repetitive strain injury or Occupational Overuse Syndrome. Simultaneous operation of 6 units would allow 2 operators to undertake 6 compactions with little physical effort. Each machine would only require having each mould topped up with substrate for each layer as required. This equates to one third of the labour required to complete each compaction.

The machine is controlled by a PLC with a Red Lion touch screen as the user interface. Ladder control logic was used in programming to simplify the fine tuning of the end machine. Ladder logic allows the follow on effects of changes to the program to control downstream sequences. One such example is timing of all the different systems and their interaction. The machine has been programmed to allow ramping of the speed of the whole process. Altering the speed of one process automatically increases the speed of the other processes. Currently the machine is producing thirty blows per minute; however this is expected to be increased with no physical changes to the design to approximately 45 blows per minute.

Apart from an emergency stop, no other controls are on the machine. An emphasis on simple operation has been made to minimize the amount of training required for operators, leaving the technical programming behind the scenes. Each different combination of mould and compaction method has been built into the machine using a recipe system.

On powering up the machine, the operator is presented with a boot screen that runs through a series of software tests. Once boot up is complete, a screen requesting login is presented to the operator. Logging into the system provides traceability and allows a quality assurance program to be put in place.

Once Login is complete, the operator is prompted to configure the compaction. Entry of a unique, seven digit compaction identification number (CIN) is required. The numbering convention for this input is still being finalized to ensure that it is truly unique. Investigation into a unique, non programmable prefix, unique to each individual machine is in progress but the process for the numbering will be left predominantly to the consumer.

The operator is also prompted to fill in various details regarding the sample being compacted. The following is a list of data required for entry prior to starting the compaction.

- Sample Reference Number – a sample tracking number
- compaction point number – a reference to the samples moisture content
- mould number – number stamped on the mould to allow differentiation between moulds
- Stabilising Agent Rate – an additive to the soil as part of the preparation
- Stabilising Agent Type – Details of what agent was used

The Test Method Index, Test Name, rammer type and mould type are then individually selected from lists. These items are used to determine which “recipe” is to be used to set up the machine for the compaction. Providing lists to choose set options from reduces time and again further simplifies the use of the machine.

A summary screen is then displayed to allow the operator to check the details are correct before proceeding. Once these values have been accepted by the operator, the operator is prompted to press the LIFT button to ready the machine for accepting the empty mould. This lifts the rammer up, applies a safety mechanism to block the hammer form dropping, then presents the platen to the front of the machine ready for the mould. The mould is then located on the central spigot on the platen and secured to ensure all blows are correctly positioned and no spinning of the mould occurs.

The machine then displays real time information on the current layer, current blow, which cycle is in progress and the elapsed time.

This process can be followed using the series of screenshots from the machine in Appendix 3.

Cycle Sequencing

A number of simultaneous movements are made by the machine to condense the period of each cycle to a minimum. The process follows the following steps:

1. Cage lowers and touches the soil
2. The rammer is adjusted to drop height
3. The rammer is released and a blow is made
4. The rammer and cage are lifted off the soil surface
5. The mould is indexed

To visualise how the cycle could be condensed, a cycle flow was created.

	Cycle No												
Action	Cycle 1						Cycle 2						Cycle 3
Table	▨												
Indexing							▨						▨
sensor		▨		▨	▨			▨		▨	▨		
hammer			▨		▨	▨			▨		▨	▨	
Sensor Reading	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

Cycle time to be no more than 2 seconds per cycle.

Overall Travel is minimum 750mm PREFERED 800mm.

Table 8 - Cycle Sequencing Table

4.5 - Data Capture

Relative to the data collected from manual compactions, the Automatic Compactor generates and stores copious amounts of data. Every movement that the device makes is logged to provide absolute satisfaction that the process is being carried out exactly as required. Some of this data may prove to be useless, but for quality assurance, the verification is there if required.

The data that is definitely of use is that of the penetration of each blow. The use of a laser measurement system focused on the top of the rammer rod allows us to track the exact position of the rammer at all times. The current system is only capable of three or four measurements during the fall of the rammer leaving limited data sets. However, it is envisaged that the system be upgraded to a much higher frequency system that could allow up to 50 measurements to be taken in the time it takes for the rammer to fall.

This system is a direct lead into the velocity profiling of the rammer. The incorporation of these systems into at least a research model would provide solid comparison data to compare any new concept machines with.

On the current prototype, the following data is being captured:

- All information entered on the configuration screen
- Absolute position of the mould with respect to the blow circle diameter
- Relative angle of rotation of the mould
- The uncompacted soil height at the blow site
- The absolute height of the rammer when in the drop height position
- The actual penetration of each blow
- The current being drawn from each motor including peak current

Some data that is being recorded is being calculated by the machine. The drop height position is calculated on the fly by comparing the position of the sensor cage and the position of the gripper assembly. A known correction factor similar to that of a tool length offset in a CNC machine is used to calculate the required position of the gripper that will achieve the correct drop height from the bottom of the hammer to the soil surface.

4.6 - Calibration

The collection of the various data is a great advantage. The extent of the uses for the data collected and the resulting applications is unknown. However, the data that is being produced is worthless unless the measurements are accurate.

Many aspects of the machine must be calibrated and certified as accurate before the unit can be used in a professional environment. All measurement devices on the machine will be certified by NATA prior to sale with regular ongoing checks necessary for the normal working life of the machine.

Along with electronic components, the rammer needs calibration on manufacture and must pass certification also. Table 1, AS1289.5.1.1 details the various tolerances on the standard rammer. Table 1, AS1289.5.1.1 provides similar details of the modified rammer.

Chapter 5. Findings

“Checking the results of a decision against its expectations shows executives what their strengths are, where they need to improve, and where they lack knowledge or information.”

Peter Drucker

5.1 – Product Testing

Once assembled, the machine was powered up and connected to a laptop. The laptop served as platform that allowed easy manipulation of any of the signals. By doing this, each system could be checked individually.

The first and most important step was to define the operational limits of travel. The limits were set up in the program by inching the mechanisms and visually determining the limit. These values were programmed into the configuration file to ensure that no input from the operator could result in over-travel. Overt-ravel of any of these items would result in severe damage to the machine.

During product testing, one of the limits - that of the power screw that moves the platen linearly – failed to stop the drive. The motor gearbox combination driving the power screw had so much torque that it first bent the 30mm diameter screw then completely sheared it off. After the failure of this soft limit, proximity sensors we also installed on all critical motion paths as a secondary precaution.

A programming bug was deemed to be the cause.

Once all of the individual systems had been checked and set up, the combination movements defined by the timing schedule (Table 8) were tested. The speed of the cycle was set to approximately 20 seconds per blow to allow visual inspection of each movement while leaving sufficient time to stop the process if a collision or other problem was imminent.

A CBR mould half filled with bubble wrap and cloth was used throughout the initial setup. This provided a pliable surface that would absorb the impact but not damage the rammer.

Eventually, as confidence in the control system grew, the cycle speed was increased. Some small programming alterations were made to tighten the cycle period. Simply adjusting the overlap of the different movements enabled the most efficient cycle length to be found.

The speed was ramped to 30 cycles per minute. And multiple recipes were selected and allowed to run. Overall, the design specification had provided enough detail that no technical problems were encountered.

Once the operation of the machine was proved, the software was uploaded to the PLC and trials using the actual control were undertaken. At this stage, no data was being collected as the soils that were being used were randomly selected from the factory grounds.

Several adjustments were made to the physical machine to accommodate slight variations between the 3D model and the actual linear motor. The machine was then painted to stop surface corrosion and to improve the prototypes appearance. Once all safety systems had been checked, the machine was sent to the client for product trials.

Product trials have been run for a three month period and are expected to conclude after four months. Daily use of the machine provides great opportunity for the operators to make notes and supply invaluable feedback and bug identification.

Overall, feedback was positive. Initial concerns with respect to the machines capabilities and operation slowly disappeared. Side by side trials were completed comparing results of a technician’s manual compaction with those of the machine. These results were carefully documented forming the beginning of a database that will eventually be used to prove statistically and categorically that the automatic compactor is fit for industry service.

5.2 - Data Output

Trials were conducting using a split sample of substrate taken from various construction sites. The samples were separated 4 times through a riffle box to ensure a homogenous sample was used.

The sample was then compacted into 4 moulds. Two of which were compacted by a technician and two compacted by the Automatic Compactor. Soil samples were prepared prior to splitting to mitigate any variables in throughout the tests.

All four samples were then tested to determine the samples CBR. Table 9 below shows the tabulated results for comparison.

CBR Four Sample Comparison

Standard	AS 1289.6.1.1
Mould Used	CBR
Rammer	Modified
Date	12-Aug-10
Technician	[redacted]
Laboratory	Herston

	Technician		AutoPak	
	Mould 1	**Mould 2**	**Mould 3**	**Mould 4**
Layer 1	25	26	25	23
Layer 2	47	46	50	49
Layer 3	70	69	70	70
Layer 4	94	97	95	93
Layer 5	121	118	120	121
Calculated CBR	62	64	63	62

Table 9 - CBR Comparison of Operator and Automatic Compactor

The results show a smaller variation in CBR’s taken on samples compacted in the machine than those that were compacted manually. This testing procedure was made standard for all further tests.

The data report that is generated by the machine is exported directly as a comma separated value file or .csv. Copious amounts of data come from each test. The data is of very little use in the .csv format and until a suitable post processor can be written, limited use of this data can be expected.

Chapter 6. Conclusions

“Success represents the 1% of your work which results from the 99% that is called failure.”

Soichiro Honda

6.1 - Project Review

The development of the specification for the machine was key to the success of the project. Errors, misinterpretations and omissions in the specification yield a product that does not quite do the job. The specification for the Automatic Compactor took longer to write and finalize than the actual manufacture of the prototype.

Having an accurate and concise specification expedited the conceptualisation process. A complete understanding of what the machine had to do meant that all aspects of the design were heading in the same direction.

From concept to 3D model was iterative. As one system was developed, another had to be modified to accommodate it. The result was the evolution of the design through four major redesign steps, with hundreds of intermediate modifications to small parts of the machine.

With modern day 3D modelling software, Solid Edge in this case, the production of workshop drawings is a simple task. The model allows complete confidence in the drawings that are produced as the individual parts and the connection to other parts can be inspected visually before any material has been purchased.

Manufacture was predominantly by CNC machine allowing complex, yet accurate parts to be manufactured. The ability to machine curved surfaces adds greatly to the aesthetic appeal of the machine and also allows maximum weight reduction without forgoing structural integrity. Blind bearing pockets deep inside billet components were possible – a huge plus when trying to keep dust and contaminant away from bearings.

Electronic fit out was left to professional electronics contractors as this was well beyond our internal capacity.

Proof of concept was carried out in house, but the machine was released to the client to be used in a laboratory situation for product testing and operational trials.

After several hundred trial compactions, the Automatic Compactor is still performing well. Operator scepticism has turned into a serious interest in the further production of and implementation of more machines.

As with any design, the prototype highlighted a number of design issues that will require correction before the production grade machine will be manufactured. Some of the issues were fabrication related while others were essentially purchased components that did not perform well in this environment.

Problems encountered.

As with any prototype, the design is not flawless. Rigorous testing and heavy use is the only real way to fully understand the shortcomings of a design.

The most serious problem that was encountered was the use of the Nexen Rail Brakes. At nearly one thousand dollars each, both units showed excessive wear within the first few days of operation. With meticulous alignment and correct setup, the units still wore prematurely. The solution was the manufacture of our own spring actuated, pneumatic release brakes. These were much less complex than the Nexen units, but allowed greater clearances and by far less maintenance.

The project, from concept to manufacture, provided other non technical issues also. Scope creep - essentially the client changing their mind after the specification has been written – was one aspect that had to be monitored closely. Any client has the right to change their mind, however the costs, both time and capital, associated with these requests need to be fully understood by all parties involved prior to action being taken.

In the case of the Automatic Compactor, the client handled these requests well, providing extra capital to fund the modifications. The timeframe for manufacture was only slightly affected and was controlled by clear communication of forecasting updates.

Design Enhancements

With ongoing production, design enhancements can also be considered. The use of cast housings drastically reduces fabrication hours and much more aesthetically pleasing geometry can also result.

The covers and guards on the prototype were made from clear polycarbonate allowing safe visual inspection of all parts of the machine during operation. The prototype cover was fitted with filtered air fans to keep the main enclosure positively pressurised to eliminate the ingress of dust and grit. The production machines are yet to have a suitable cover designed to suit. It is envisaged that a positively pressurised, sheet metal housing with inspection ports will be fitted to protect both the operator from the machine, and the machine from the harsh laboratory environment during normal use.

It's believed that the control panel can be condensed into a more compact enclosure, with the view to having a control panel small enough to integrate into the machine itself

6.2 - Conclusions

The design and manufacture of the Automatic compactor has been successful. It has been proven by extensive testing in a real laboratory environment that the automatic compactor can successfully complete a soil compaction of a test specimen for CBR or Proctor testing with a high level of confidence in the end result.

The key primary function that separates this machine from all others on the market is that of measuring the uncompacted soil level at the position of the next rammer impact and adjusting the drop height of the rammer to within the required tolerances. The successful inclusion of this feature has gained the machine full compliance with all Australian Standards relevant to this compaction procedure.

The elimination of human error from the compaction method has now provided an industry wide benchmark that manual technicians must be able to meet. The documented repeatability of the results acquired to date provides a high level of confidence in the success of this design.

Overall, the design includes functionality to complete all primary objectives as set out in chapter 1. The machine:

- Can successfully complete a soil compaction of a test specimen for CBR testing.
- Fully complies with all Australian Standards relevant to this compaction procedure.
- Measures the rammer drop height from the uncompacted soil at the position of the next rammer blow.
- Achieves repeatability of results to provide an industry wide benchmark.

The machine is thus suited to be used in every laboratory that conducts CBR and Proctor tests. Main roads have estimated that internally, four machines will be required immediately for the Brisbane area, with a further 29 expected for the South East Queensland region over the next two years.

With the immediate benefits obtained from the use of the Automatic Compactor, Main Roads Queensland will encourage all of its laboratories to take on the technology with the expectation that it will soon become industry standard. Constant pressure on businesses everywhere from Occupational Health and Safety to reduce the physical stress that technicians are subjected to was predominantly the catalyst of the entire project. The solution to this problem is now very close to full scale production and is expected to be taken on readily by the industry.

6.3 - Recommendations for Future Works

Several avenues of future work have been identified.

The successful design of the Automatic Compactor has allowed the acquisition of a large amount of data that until now, has been impossible to collect. The data set that is of most interest is that of actual measured penetration of each and every blow. While this data is currently being used by the machine, the research of into technical applications is still required. Research into the possible applications may allow the development of a more accurate understanding of how various soil compositions react under impact and allow identification of the most economical site compaction methods for a particular site. The opportunity exists to investigate and develop other uses for the data output also.

Another avenue for development is for a much smaller machine that has a driven rammer to create the impact, rather than the currently specified free fall impact. The Automatic Compactor was developed to prove to the industry that a machine can accurately replicate the manual compaction and exhibit good repeatability. With the Automatic Compactor being used to set a standard datum, a machine that uses an entirely different impact method can be designed and the data collected from that machine can be compared to the results from the Automatic Compactor. Mapping of the velocity profile of the free fall rammer would allow the recreation of the impact using a short powered stroke system.

Shortening the stroke and thus the cycle time would allow the development of a high speed bench top machine that would accurately reproduce the compaction.

Continual development of any design is paramount to its success and survival in the marketplace. The future of the Automatic Soil Compactor is promising, however, like every machine; the perfect solution is in the continual evolution of the design.

Works Cited

AZADI, M. REZA EMAMI. 2004. *CBR Test Results of Well Graded Gravel-Sand Mixed With Clay (GSCW) Soil Samples* [Online]. Available: http://www.ejge.com/2008/Ppr0815/Ppr0815.htm [Accessed].

CLARK, NORMAN G. 2000. *RBR Series Rail Brake* [Online]. Available: http://www.ngclark.com.au/products/nexen/LinearProducts/RailBrakes.htm [Accessed].

CONTROLS. 2009. *Product Guide and Catalogue* .

QUEENSLAND, WORK COVER. 1998. *Work Cover Queensland Annual Report 1997/1998.*

QUEENSLAND, WORK COVER. 2009. *Work Cover Queensland Annual Report 2008/2009.*

SERVICES, QUEENSLAND GEOTECHNICAL. 2010. *Soil Testing* [Online]. Available: http://qldgeotechnical.com.au/main/page_soil_testing.html [Accessed].

STANDARDS, AUSTRALIAN 2003a. AS1289.5.1.1 *Soil Compaction And Density Tests.*

STANDARDS, AUSTRALIAN 2003b. AS1289.5.1.1 *In:* 2, FIGURE (ed.) *Soil Compaction And Density Tests.*

STANDARDS, AUSTRALIAN 2003. AS1289.5.2.1. *Soil Compaction And Density Tests.*

Appendices

<u>Appendix 1 – Project Specification</u>

Project Specifications and Limitations Outline

For the Design and Construction of an

Automatic Soil Compactor.

Aim:

To design, construct and provide proof of concept of an automatic soil compactor that accurately imitates the use of existing manual apparatus, for the compaction of soil into CBR, Proctor and 2ltr steel moulds for the purpose of gauging the “Californian Bearing Ratio” of the compacted Soil – a test to measure the pressure required to penetrate a soil or substrate with a plunger of specified diameter.

Objectives:

Machine must:-

1. Fully comply with current Australian Standards.
    a. Measure drop height from un-compacted soil level site of impending blow.
    b. Follow specified “recipes” that include blow pattern and quantity, number of required soil layers and mould type.
2. Eliminate existing manual handling issues
3. Collect data of each impact including actual penetration from each impact
4. Provide repeatable results as to provide a reliable datum for manual testing
5. Be able to accommodate multiple international standards to allow overseas compliance by “recipe” program addition.

Proposed lines of Investigation:

1. The Primary energy source – Pneumatic, Hydraulic, Electric or a combination of these.
2. Balancing impact frequency with compaction efficiency with cost effective drive solutions
3. Equipment to accurately gauge the height of the un-compacted soil level
    a. Machine Vision
    b. Laser Scanning
    c. Physical “touch gauge”
4. Control System
    a. PC / IO based
    b. PLC based

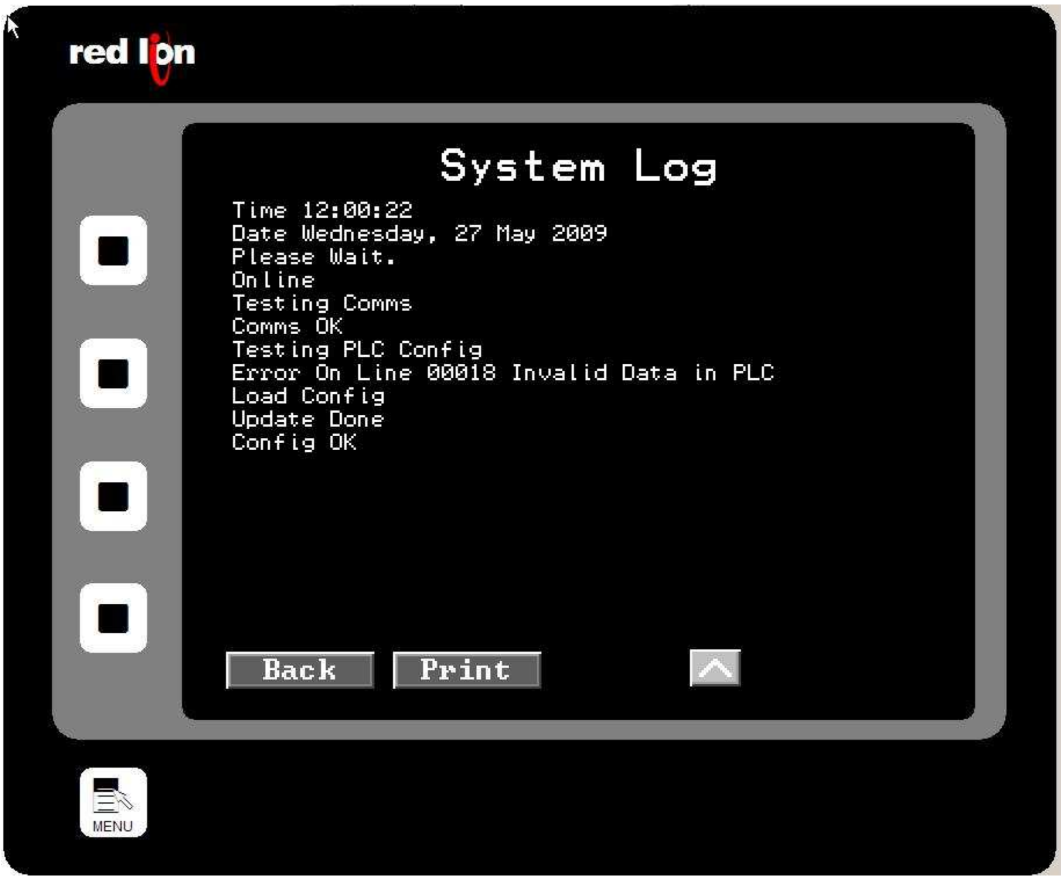
As an Industry project, there are a number of constraints with having a design that is viable for production and sale. I anticipate that some areas of the design I can look into in great detail for the purposes of this project – and perhaps incorporation into the production model to achieve a “research model” for research and development use within larger companies. Queensland Main Roads Department being the instigating client for the design.

Appendix 2 –Recipe Matrix

Appendix 2 - Recipe Matrix for all Mould and Standard Combinations

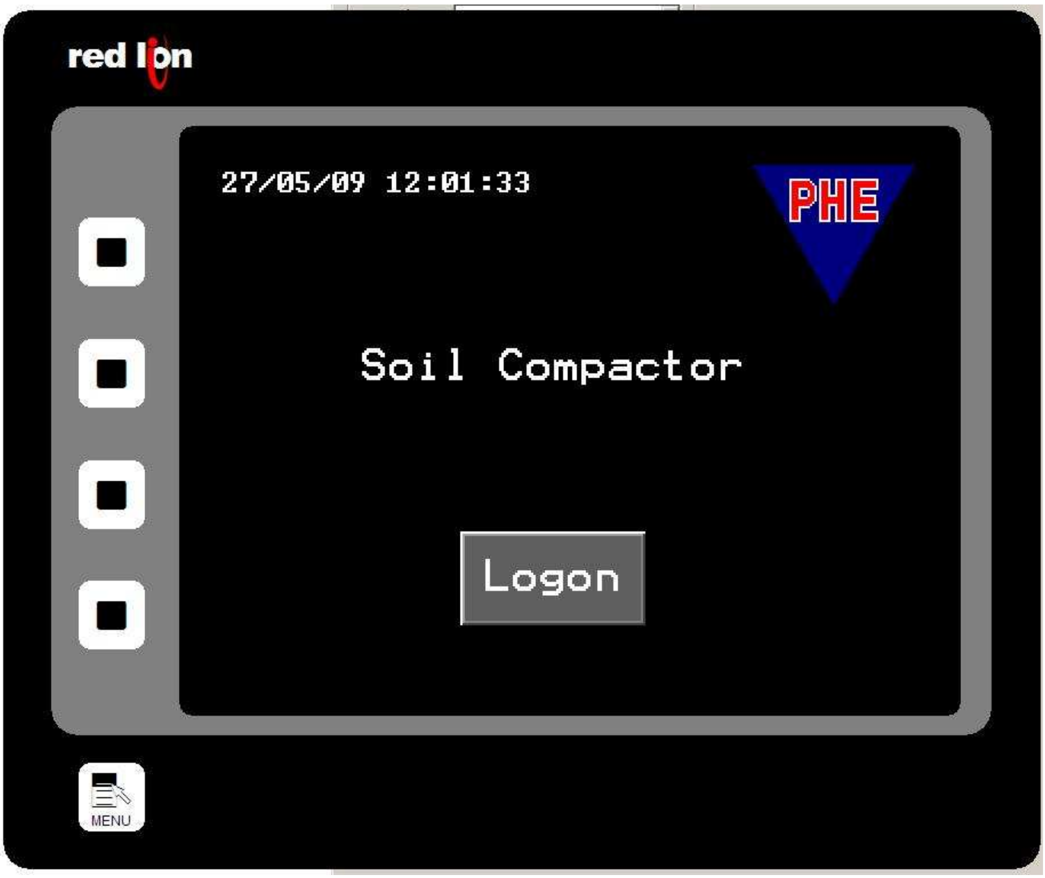
Test Method	AS1289.5.1.1	AS1289.5.1.1	AS1289.5.2.1	AS1289.5.2.1	AS1289.6.1.1	AS1289.6.1.1	AS1289.6.1.1	Q110A	Q110A	Q110B	Q110B	Q115	Q115	Q113A	Q113B	Q113C	Q113C
Rammer	Standard	Standard	Modified	Modified	Standard	Standard	Modified	Standard	Standard	Modified	Modified	Standard	Modified	Standard	Modified	Standard	Modified
Mould	A	B	A	B	CBR	CBR	CBR	A	B	A	B	A	A	CBR	CBR	CBR	CBR
Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Blows Default	25	60	25	100	53			25	60	42	100			53	88		
Blows Min						11	11					8	8			11	11
Blows Max						66	110					32	32			66	110
Layers	3	3	5	3	3	3	5	3	3	3	3	3	3	3	5	3	5
Layer 1 Min	38	44	23	44	39	39	21	38	44	38	44	38.5	38.5	39	21	39	23.4
Layer 1 Max	43	49	28	49	44	44	26	43	49	43	49	38.5	38.5	44	26	39	23.4
Layer 2 Min	77	89	47	89	78	78	45	77	89	77	89	77.0	77.0	78	45	78	46.8
Layer 2 Max	82	94	52	94	83	83	50	82	94	82	94	77.0	77.0	83	50	78	46.8
Layer 3 Min	116	133	70	133	117	117	67	116	133	116	133	115.5	115.5	117	67	117	70.2
Layer 3 Max	120	138	75	138	122	122	72	120	138	120	138	115.5	115.5	122	72	117	70.2
Layer 4 Min			93				92								92		93.6
Layer 4 Max			98				97								97		93.6
Layer 5 Min			116				117								117		117
Layer 5 Max			120				122								122		117
Cycle 1	8(1)	11(11)	8(1)	11(11)	11(11)	11(11)	11(11)	8(1)	11(11)	8(1)	11(11)	8(1)	8(1)	11(11)	11(11)	11(11)	11(11)
Cycle 2	8(2)	11(12)	8(2)	11(12)	11(12)	11(12)	11(12)	8(2)	11(12)	8(2)	11(12)	8(2)	8(2)	11(12)	11(12)	11(12)	11(12)
Cycle 3	9(21)	11(13)	9(21)	11(13)	11(13)	11(13)	11(13)	9(21)	11(13)	8(3)	11(13)	8(3)	8(3)	11(13)	11(13)	11(13)	11(13)
Cycle 4		11(12)		11(12)	11(12)	11(12)	11(12)		11(12)	9(22)	11(12)	8(2)	8(2)	11(12)	11(12)	11(12)	11(12)
Cycle 5		11(15)		11(15)	9(25)	11(15)	11(15)		11(15)	9(23)	11(15)	8(5)	8(5)	9(25)	11(15)	11(15)	11(15)
Cycle 6		5(24)		11(12)		11(12)	11(12)		5(24)		11(12)	8(2)	8(2)		11(12)	11(12)	11(12)
Cycle 7				11(13)		11(13)	11(13)				11(13)	8(3)	8(3)		11(13)	11(13)	11(13)
Cycle 8				11(12)		11(12)	11(12)				11(12)	8(2)	8(2)		11(12)	11(12)	11(12)
Cycle 9				11(15)		11(15)	11(15)				11(15)	8(5)	8(5)			11(15)	11(15)
Cycle 10				1(26)		11(12)	11(12)				1(26)	8(2)	8(2)			11(12)	11(12)
Cycle 11						11(13)	11(13)					8(3)	8(3)			11(13)	11(13)
Cycle 12						11(12)	11(12)					8(2)	8(2)			11(12)	11(12)
Cycle 13						11(15)	11(15)					8(5)	8(5)			11(15)	11(15)
Cycle 14						11(12)	11(12)					8(2)	8(2)			11(12)	11(12)
Cycle 15						11(13)	11(13)					8(3)	8(3)			11(13)	11(13)
Cycle 16						11(12)	11(12)					8(2)	8(2)			11(12)	11(12)
Cycle 17						11(15)	11(15)					8(5)	8(5)			11(15)	11(15)
Cycle 18						11(12)	11(12)					8(2)	8(2)			11(12)	11(12)
Cycle 19						11(13)	11(13)					8(3)	8(3)			11(13)	11(13)
Cycle 20						11(12)	11(12)					8(2)	8(2)			11(12)	11(12)
Cycle 21						11(15)	11(15)					8(5)	8(5)			11(15)	11(15)
Cycle 22						11(12)	11(12)					8(2)	8(2)			11(12)	11(12)
Cycle 23						11(13)	11(13)					8(3)	8(3)			11(13)	11(13)
Cycle 24						11(12)	11(12)					8(2)	8(2)			11(12)	11(12)
Cycle 25						11(15)	11(15)					8(5)	8(5)			11(15)	11(15)
Cycle 26						11(12)	11(12)					8(2)	8(2)			11(12)	11(12)
Cycle 27						11(13)	11(13)					8(3)	8(3)			11(13)	11(13)
Cycle 28						11(12)	11(12)					8(2)	8(2)			11(12)	11(12)
Cycle 29						11(15)	11(15)					8(5)	8(5)			11(15)	11(15)
Cycle 30																	
Cycle 31																	
Cycle 32																	

Appendix 3 – Touch Screen Interface Sequence

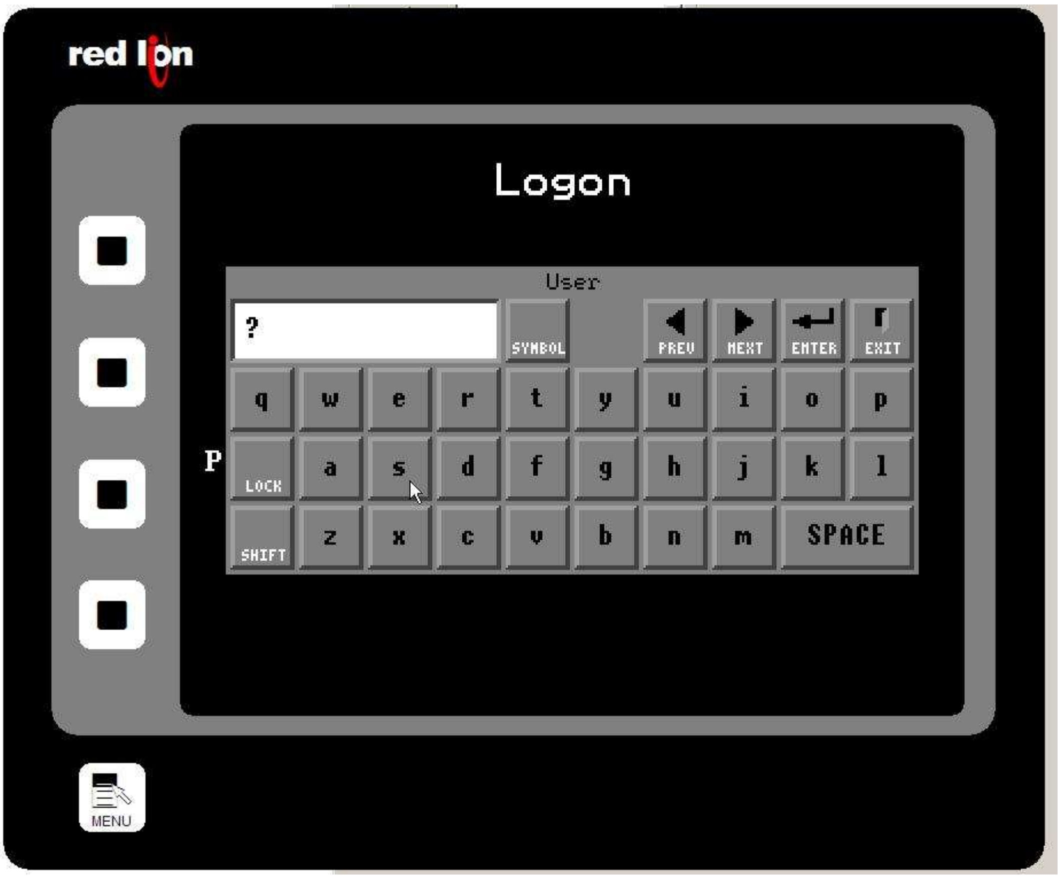


```
Time 12:00:22
Date Wednesday, 27 May 2009
Please Wait.
Online
Testing Comms
Comms OK
Testing PLC Config
Error On Line 00018 Invalid Data in PLC
Load Config
Update Done
Config OK
```

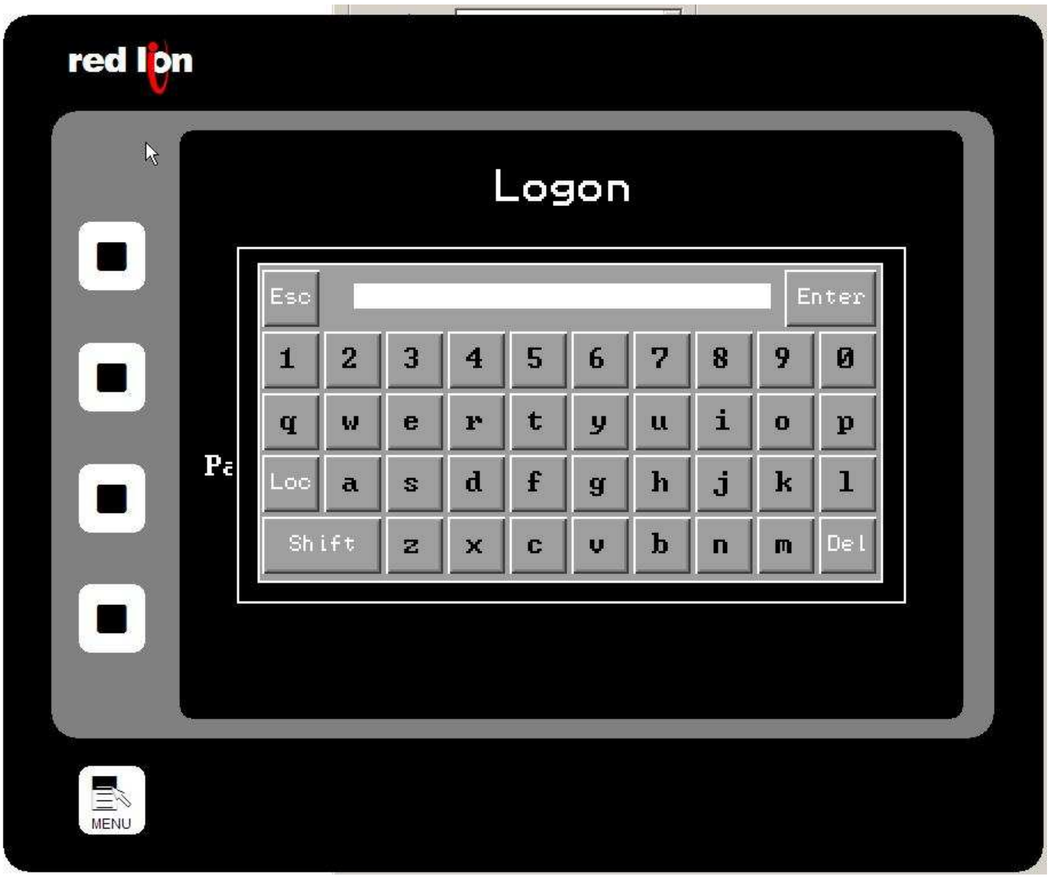
Screen 1 – System Boot



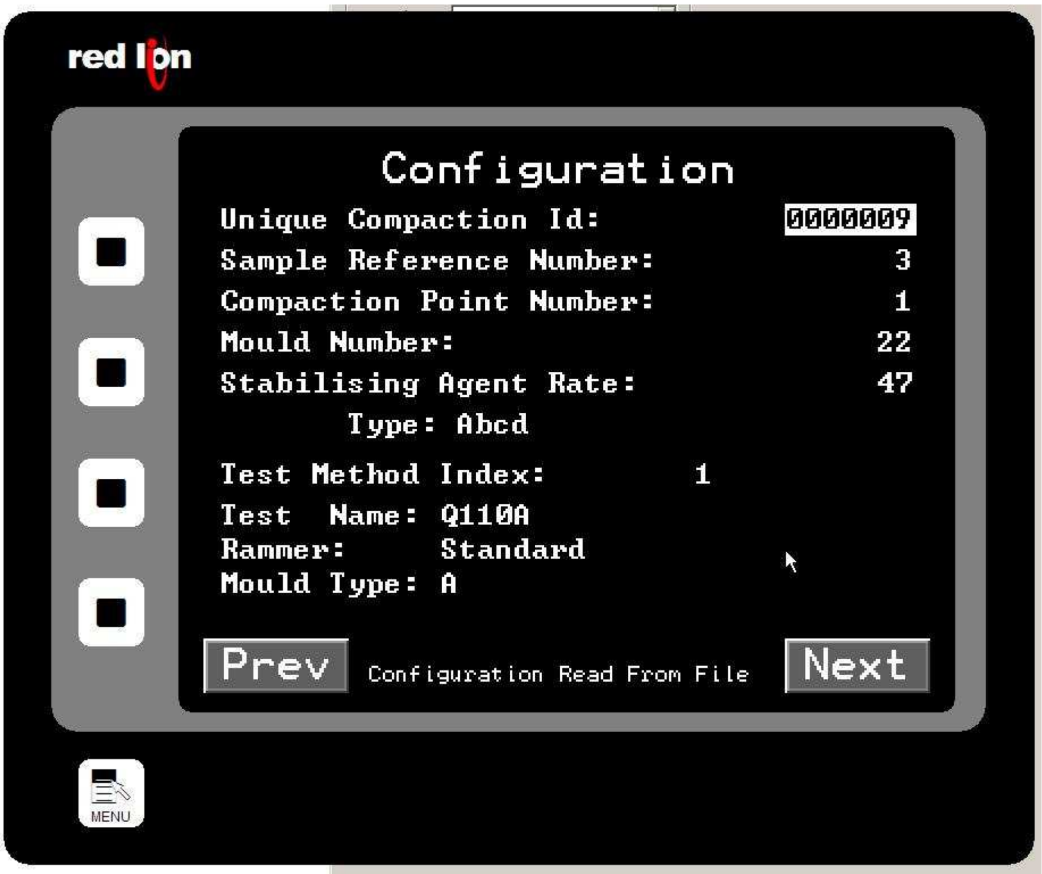
Screen 2 – Ready Screen



Screen 3 – Operator Logon – Username



Screen 4 – Operator Logon – Password



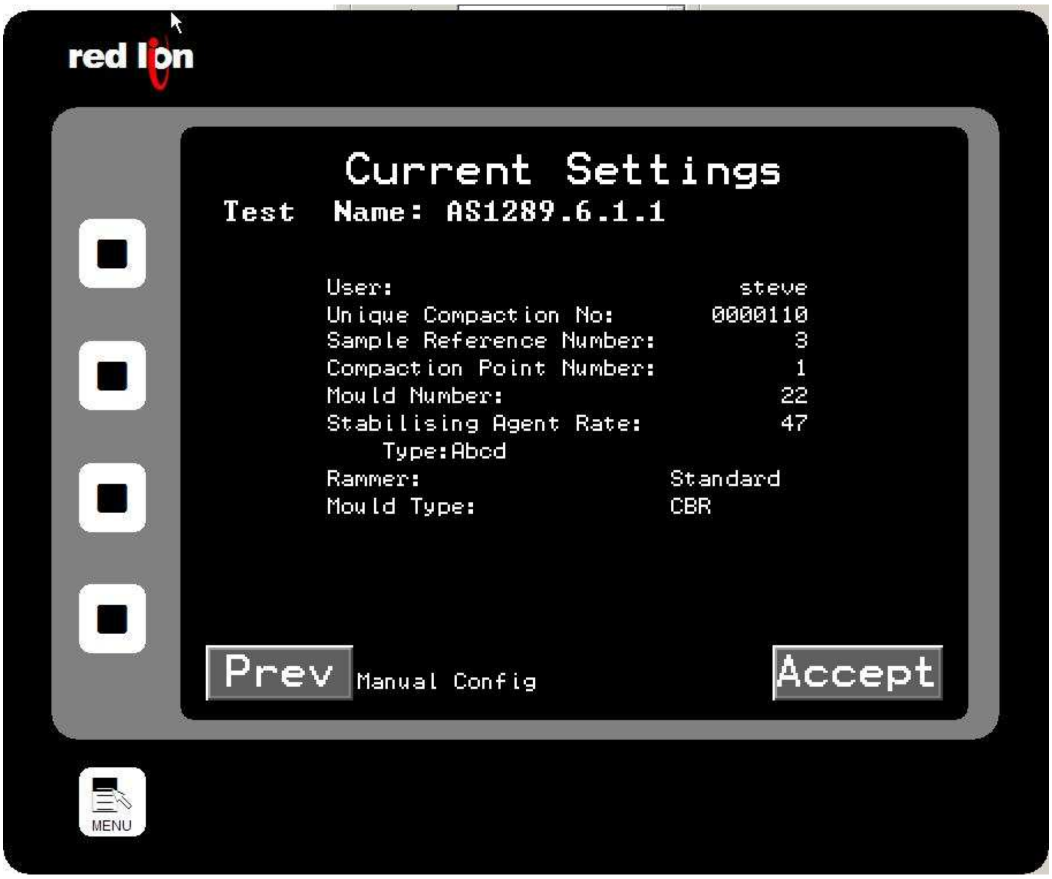
Configuration

Unique Compaction Id: 0000009
Sample Reference Number: 3
Compaction Point Number: 1
Mould Number: 22
Stabilising Agent Rate: 47
Type: Abcd

Test Method Index: 1
Test Name: Q110A
Rammer: Standard
Mould Type: A

Configuration Read From File

Screen 5 – Test Configuration



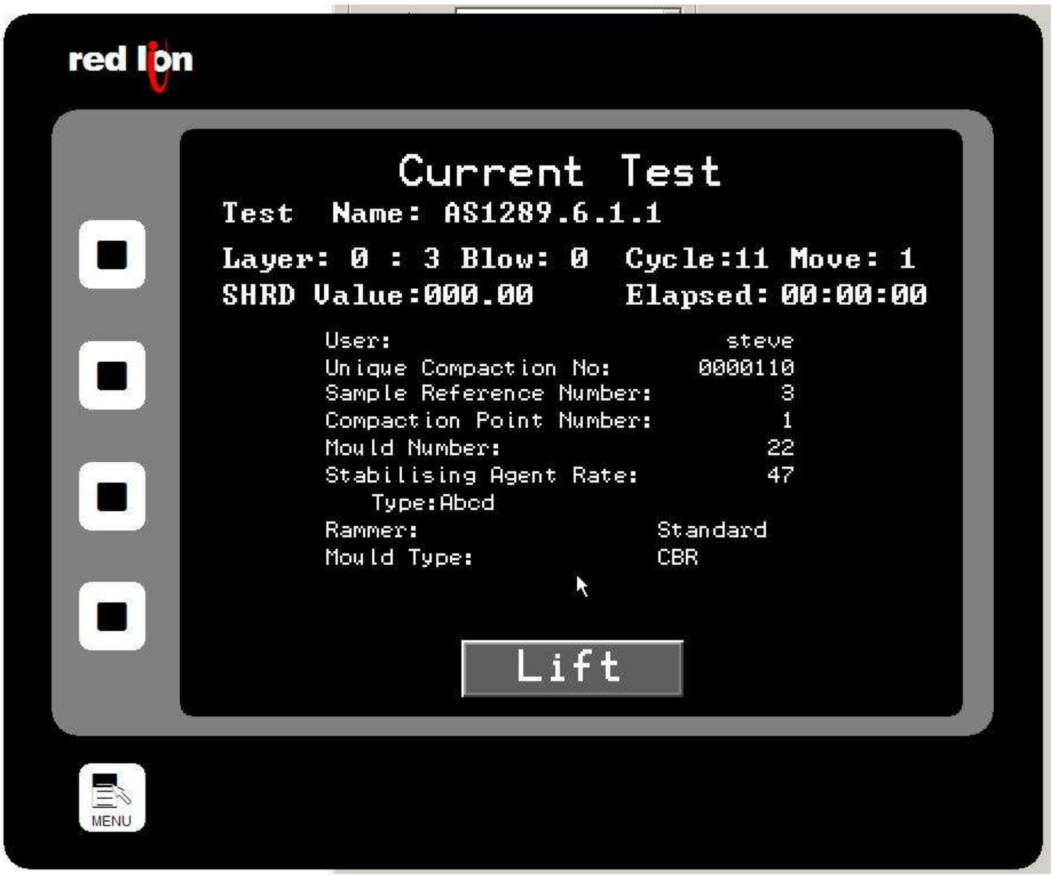
Current Settings

Test Name: AS1289.6.1.1

User: steve
Unique Compaction No: 0000110
Sample Reference Number: 3
Compaction Point Number: 1
Mould Number: 22
Stabilising Agent Rate: 47
Type:Abcd
Rammer: Standard
Mould Type: CBR

Manual Config

Screen 6 – Current Configuration Check



Current Test

Test Name: AS1289.6.1.1

Layer: 0 : 3 Blow: 0 Cycle:11 Move: 1

SHRD Value:000.00 Elapsed: 00:00:00

User: steve

Unique Compaction No: 0000110

Sample Reference Number: 3

Compaction Point Number: 1

Mould Number: 22

Stabilising Agent Rate: 47

Type:Abcd

Rammer: Standard

Mould Type: CBR

Screen 7 – Real time display of cycle data.