December 4th, 2013

Full Cycle Engineering
California Polytechnic State University
1 Grand Avenue
San Luis Obispo, CA 93410

Mr. Harish Bhutani
Owner, Monaero Engineering, Inc.
17011 Industry Pl.
La Mirada, CA 90638

Dear Mr. Bhutani,

FCE is pleased to present the Final Design Report for the Design of a Sustainable Toilet. Attached is an expansion of the Critical Design Report, including detailed descriptions of all of the components of the design, the project management plan, prototype testing, cost analysis, project recommendations, conclusion, and project continuation.

Sincerely,

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Design of a Sustainable Toilet
Final Design Report

Submitted to the faculty of the Mechanical Engineering Department, and digital archive
December 4th, 2013
by:
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Full Cycle Engineering
“Using sanitation to improve quality of life”

California Polytechnic State University
Multidisciplinary Senior Design Project 2013
Collaboration between CE 466/467 and ME 428/429/430
ME Project Advisor: Dr. Mohammad Noori
Project Sponsor: Mr. Harish Bhutani
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1. Abstract

The objective of this project is to design and build a self-sustaining toilet for implementation in rural areas of India, while meeting the design requirements set by the project sponsor, Mr. Harish Bhutani. The toilet will be built out of low cost and readily accessible materials and require little to no water, no electricity, and minimal maintenance. A successful design will ultimately reduce the transmission of disease caused by waterborne pathogens, improve the health and way of life of the rural community members, and be marketable to other impoverished areas of the world lacking adequate sanitation.

Five primary conceptual designs were created and evaluated as part of this report. These designs were presented to the project sponsor and the pit composting system was approved as the final design. The pit composting system consists of four sets of 8-pit systems, for a total of 32 pits, to service a 100 person village. Each pit consists of the brick pit, a concrete lid, a squat pan, a ventilation duct, a composting cover, a urine diversion system, and a privacy shelter. Fifty percent of the urine will be diverted out of the pit into a separate storage container. This container will be emptied onto vegetated land when full. Along with human waste, yard waste and dry additives will be added to the pit to facilitate proper composting. The waste will be composted, pathogen free, and ready for application as fertilizer after one year with proper operation. The total cost of the system will be approximately $10,000.
2. Introduction

As of 2008 there are more than 700 million Indians without access to toilets. Open defecation is common practice in areas without adequate safe sanitation; individuals either don’t wash following defecation or bring a small amount of water with them to wash. Openly defecating near water sources puts community members at a high risk for contracting waterborne diseases. Additionally, defecating without taking sanitary hygiene measures to ensure complete removal of waste from the hands can bring fecal pathogens into kitchen or other living areas, again increasing the risk of contracting disease. Another risk associated with open defecation is the unguaranteed safety of women. They are made more vulnerable during the process and as a result become victims to sexual violence.

Organizations have attempted to implement toilets in low income areas of India that lack adequate sanitation but the technologies have been too complex, incompletely funded by government subsidy, or required more maintenance than villagers were willing to contribute. Communities often transformed unused toilets into storage areas for food. The goal of this project is to construct a toilet suitable for implementation and long-term use in rural India in a publicly accessible area requiring little water, no electricity, and minimal maintenance. The residents of these rural villages have little to no income so the toilet needs to have a simple, economical design that requires no specialized equipment to construct. Materials chosen for the design should be readily available and generic. Per sponsor expectations, the design should not require water. Access to water sources is unreliable, often requiring retrieval and transportation over long distances. Sponsor highlights address the need for the toilet to have monetary benefit to entice entrepreneurial investment in the product for the ultimate benefit of the community. With the expectation that the rural village is not connected to the electrical grid, no energy source will be available to power any parts of the toilet. The toilet design must therefore be either self-sustaining or operated on
mechanical power harvested during use. Finally, at maximum the toilet should require annual maintenance. The toilet design will decrease exposure to harmful pathogens, thus benefiting the lives of many Indians currently living in unsanitary conditions.

The problems of sanitation do not stand in India alone; there are numerous countries around the world dealing with similar sanitation issues. A successful design must be adaptable to different climates, cultures, and societies; and it must be cross-cultural, withstanding global sanitation demands and customs. The final product will be marketable to communities as a way to improve their health, eliminate the need for open defecation, and decrease contamination of community water sources, with an overall goal to improve quality of life and simplify sanitation.
3. Background Research

3.1 Existing Designs

Initial research for this project has been done on efforts already made to solve the problem of global sanitation. Below, the designs of two of the leading organizations working to innovate the toilet are described. A few of the other major designs researched are also briefly stated.

3.1.1 Sulabh International

Several organizations, such as Sulabh International have spearheaded efforts to implement improved sanitation by providing an alternative to open defecation. Sulabh International has successfully implemented a two-pit public toilet system in over 8000 locations. This flush composting toilet design is hygienically and technically appropriate for Indian communities. It has proven to be acceptable by Indian societal standards and cultural traditions. The two-pit system allows one filled pit to decompose, removing the foul smell and greatly reducing the amount of pathogens in the waste, making it safe for handling, while the other is in use. The pits are lined in brick, stone, burnt clay, or cement concrete rings to provide structural support. They are placed a minimum of one meter apart from each other, and a minimum of 3 meters from open wells and shallow hand pumps providing ground water to prevent contamination. The pits are air tight creating the potential for both household and small shop applications. The toilet contains a custom pour flush squatting pan design made of ceramic, fiber glass, PVC, mosaic, or cement concrete. In addition, 1.5 to 2 liters of water is used for flushing, and daily maintenance is required.

![Figure 3-1 Sulabh International two pit, pour-flush, composting toilet](image-url)
3.1.2 Bill and Melinda Gates Foundation

Another organization focused on improving sanitation in India is the Bill and Melinda Gates Foundation. The Water, Sanitation & Hygiene (WSH) program of the Bill and Melinda Gates Foundation awarded grants to researchers all over the world as part of the Reinvent the Toilet Challenge in 2011. The goal of this pursuit was to bring sustainable sanitation solutions to the over 2.5 billion people who don’t have access to safe sanitation[12]. Researchers were awarded accordingly for pursuing innovative techniques to manage human waste safely and sustainably.

The following designs are a few of the results of the Bill and Melinda Gates foundation efforts. Submitted in the 2011 challenge, the California Institute of Technology designed a solar-powered and self-contained system to break down water and human waste, where the excess power generated from the panels is stored for nighttime or low-sunlight operation. The Delft University of Technology in the Netherlands used microwave technology to convert human waste into electricity, while a team in Switzerland created a urine-diverting toilet, flushing with recycled water and transporting human waste and urine to a decentralized processing center. Several other groups explored the uses of biochar from human feces and using it as a heating source. The University of Toronto mechanically dehydrated the solids, sent the urine through a sand filter, and disinfected the urine with ultraviolet light.

3.1.3 Other Designs Researched

In addition to the previously stated sources, FCE studied many other designs in an attempt better understand the breadth and variety of current toilet system designs. One of which is EcoSan. They developed a waterless toilet system which uses a helical screw conveyor and ventilation to dry and reduce the waste to roughly 5 – 10% of its original mass. The dry waste is then processed by composting or various other methods.

Different squatting pan designs for both washing with water and without water have been explored. These pans are waterless systems, and enable urine diversion. Feces are typically relocated for composting, and the urine

![Figure 3-2 EcoSan toilet schematic](image)
is collected for use as plant fertilizer.

France’s Ecosphere Technologies has installed over 330 “Saniverte public dry pit toilets” in France, Switzerland, and Spain. The waterless public toilet design has been adapted depending on high altitude locations, rural or urban areas, and also ski resorts. The system transforms the feces and toilet paper intake into dirt by using a specific earthworm as the compost mechanism: Aesenia Faetida, with proper ventilation to reduce odors. Urine is collected separately and used for agricultural purposes or sold.

3.2 Pitfalls of Existing Designs

Many designs similar to those produced from the 2011 WSH Reinvent the Toilet Challenge failed during the implementation phase due to complexity and necessary maintenance. Cultural dispositions regarding human waste require a design that allows for minimal contact with the waste and low maintenance. Designs involving electricity and gas are too complex to be implemented in the areas these toilets are intended to benefit. Currently, a simpler and more practical design that has the potential to be implemented quickly and on a global scale is necessary to improve the health and living conditions of those lacking adequate sanitation.

3.3 Cultural Considerations

In addition to technical research and experimentation, the design team researched current social norms of the community. Discrimination based on the caste system in India, though legally outlawed, still has evident residual effects in regards to current sanitation practices [7]. In India, human excreta is regarded as the “most hated object” as referenced by Sulabh International, a non-profit social service organization founded to improve sanitation and free scavengers (or waste scavengers).
collectors). People in this hereditary caste are considered subhuman and referred to as “untouchables”. They are forced to maintain and clean toilets and collect human excreta under extremely unsanitary conditions\(^8\). Besides the fact that contact with raw human waste is hygienically unsafe and should be prevented, the design should dignify its users and perpetuate no cultural stigmas against those associated with safe handling of the compost. This design aims to alleviate the burden on scavengers and remove the need for direct contact with any raw human waste.

A toilet design that accommodates both women and men is imperative. Providing women with a dignifying, private place to defecate will aid in preventing the sexual violence that often takes place in an unprotected open-defecation situation. It will also allow them to safely take sanitary measures during menstruation. It is important that the design is equally available to men and women and provides its users with safety and security.

In addition to researching cultural traditions, FCE understands the importance of contacting the village directly, when possible, to discuss how the toilet design can be adapted for their immediate and long-term sanitation needs. Ideally, a representative of the rural village can provide first-hand insight regarding the site-specific design constraints, sanitation desires of the community, and also any designs or techniques to avoid that the village would reject or refuse to use on a long-term basis. Advice regarding cultural relations from Sulabh International, members of Cal Poly’s Engineers Without Borders, and the project sponsor can also help guide the research and design process.
4. Objectives

As of 2008, more than 700 million Indians do not have access to proper sanitation. The majority of the 700 million Indians are forced to use open defecation as their primary method of relieving themselves. The lack of sanitation leads to soil and groundwater contamination by fecal-borne pathogens in the raw waste. This exposure leads to the contraction of ailments such as diarrhea, cholera, hepatitis A, hookworm, and more. Impoverished rural villages need a low cost, low maintenance toilet system that eliminates exposure to fecal pathogens. This system must be culturally acceptable and have the ability to create usable byproducts to encourage continual use of the design. Additionally, the toilet design will meet the seven conditions defined by the World Health Organization (WHO) for a sanitary latrine \(^{[14]}\) (see Appendix E).

4.1 Design Requirements
- Does not use any additional water to transport waste
- Design is fabricated from materials easily accessible in the villages
- Does not require electricity to function
- Requires a minimum duration of a year between maintenances
- Design must be easy to use
- Design should accommodate a 100 person community

4.2 Sanitation Requirements
- Design must prevent soil and groundwater contamination by raw waste
- Design must control odor from the raw waste
- Raw waste cannot be handled directly by anyone
- Design that encourages personal hygiene

4.3 Cultural Requirements
- Eliminates the need for scavengers to evacuate raw waste
- Properly accommodates women, children, and the elderly
- Design must be adaptable to a wide range of climates
- Design must be able to be adapted for worldwide implementation

4.4 Marketing Requirements
- Design must produce a usable byproduct
- Design must be low cost
5. Method of Approach

5.1 Project Outline

Full Cycle Engineering is composed of a multidisciplinary team of engineers from the Civil, Environmental and Mechanical Engineering departments. Though this project is multidisciplinary in nature, the Civil and Environmental Engineering departments require that the project will be completed by June of 2013, requiring all members of FCE to adhere to that deadline. Given this completion date, the following sections are tentative milestones to accomplish during the completion of this project.

5.1.1 Influence of Background Research

The issue of the lack of proper sanitation systems in third world countries is not new; however, an adequate solution hasn’t been found. In order to learn from concepts created and implemented previously, it is important to have a comprehensive understanding of them. Section 3, Background Research, provides examples of several major organizations that have made attempts at sustainable toilet designs to date. Understanding the benefits and pitfalls of these existing designs aid in the process of concept design generation.

5.1.2 Ideation

A comprehensive understanding of the project’s background permits the creation of an informed product definition, defined as a set of criteria that the product will have to achieve. Section 2, Introduction, introduces these criteria and Section 4, Objectives, addresses them in more detail. The problem definition guides the ideation process, and potential solutions to the problem are brainstormed. In this manor, idea generation processes are used to produce unconventional and unique solutions to the problem.

5.1.3 Concept Generation

All of the generated solutions are assessed, and many are either incomplete ideas or do not satisfy the criteria for the project. The solutions that have the potential to meet all of the criteria for the project are developed into preliminary concepts. The preliminary concepts consist of semi-detailed drawings of the proposed system and any key features contained in the system. If necessary, basic calculations are done for each preliminary concept to start defining some of the variables within the system. In addition, a House of Quality (see discussion in Section 6.3.1) and Decision Matrix (see Section 6.3.2) are used as part of the Quality Function Deployment analysis, performed to narrow the possible concepts down to a lead concept.
5.1.4 Lead Design Concept

The lead design concept is presented to the project sponsor for review. It is supported with detailed computer sketches defining all major components of the system. Feasibility analysis partnered with a decision matrix theoretically ensures that the concept will work. As needed, prototypes of parts of the system will be fabricated to ensure the successful function of those individual parts. After applying sponsor feedback and suggestions from the Conceptual Design Review to the lead concept design, and upon sponsor’s final approval, the lead concept officially becomes the project design and a prototyping and testing begins.

5.1.5 Design Fabrication and Testing

Once the design is approved, a final analysis will be done to fully define the design, and a final set of drawings will be produced for prototype fabrication. Materials will be purchased at local Home Depot or other construction material warehouse, or if possible collected for free from pre-approved locations. Scaled-down prototypes, partial to-scale prototypes, and a full scale prototype (depending on time, communication, and material constructability) will be fabricated for better understanding of the functionality of the design. Prototype testing will highlight the design elements that will work and the ones that need improvement.

5.2 Equipment and Testing

The goal of the project is to produce a sustainable toilet that is made from readily accessible materials with no need for specialized equipment for installation. This requires that the toilet be constructed from common components that don’t require custom fabrication. The toilet and sanitation system will be produced from materials that can either be made, or modified to suit the project needs. Common materials like brick, concrete, clay, plastic and metal containers, and wood will most likely be used in the design.

The team will have access to equipment to aid in the design, analysis, and fabrication of the project though California Polytechnic State University San Luis Obispo. Computer programs like Engineering Equation Solver, and computer aided design programs such as Solidworks will be used for the analysis and design. To ensure that the toilet system is sustainable and prevents pathogens from getting to groundwater and agricultural sources, biological tests will be performed on soil and water samples, if possible. For these tests the project team will need to either send samples out for testing, or gain access to a biology lab to perform the tests.
6. Design Development

6.1 Ideation and Preliminary Concepts

Guided by the project objectives, FCE brainstormed unique ideas and processes that could be solutions to the sanitation problem. The solutions that have the potential to meet all of the criteria for the project were developed into preliminary concepts. The preliminary concepts consist of semi-detailed drawings of the proposed system and any key features contained in the system. The further developed top concept designs are included in Section 6.2, below.

6.2 Top Concept Designs

Computer aided sketches, system descriptions, and feasibility analyses are provided in this section for the top concept designs. Top concept designs were determined based on their realistic constructability, completeness of system, and adherence to the project objectives. There are five potential design concepts with the fifth featured concept being FCE’s lead concept design.

6.2.1 Thermophilic Composting System

The system setup design can be seen below in Figure 6.1. This system exposes the raw waste to heat, creating an ideal thermophilic composting environment to effectively pasteurize the waste. The added heat will allow thermophilic bacteria to flourish, at temperatures between 130 and 160°F, accelerating the composting process. Each composting pit will have its own heating chamber. Three sides of the heating chamber will be built with brick, and the fourth side will be exposed to the sun and made out of a Plexiglas sheet. The composting pit itself will be made from either brick or metal to allow easy heat transfer into the waste. Additionally, each heating chamber will have a reflective focusing sheet around the composting pit to reflect the heat rays from the sun on to the composting pit surface, which can be seen below in Figure 6.2. The squat toilet at the top will be made of plastic and have a surrounding structure for privacy, which can be seen in Figure 6.3. The user can access the toilet by walking up the hill, because the system is cut into an existing hillside. A urine diversion component will be used to allow control of the amount of urine added to the compost; therefore, controlling the amount of Nitrogen needed for the composting process. The high temperature environment will kill off most of the pathogens, but once the pit is filled, its contents will be transported to a secondary compost location for complete composting to occur over 6 months to a year. Job creation from transporting both partially composted waste and finished compost ready for agricultural application will benefit the community.
Figure 6-1 Thermophilic Composting System design

Figure 6-2 Thermophilic heating chamber

Figure 6-3 Privacy shield for squatting toilet
6.2.2 Anaerobic Digesting System

Anaerobic digestion of waste is possible when the waste is kept under anaerobic (no oxygen) conditions. Facultative anaerobes break down the waste and form biogas, a mixture of methane and carbon, which can be burned and used in heating applications. This system requires an air-tight seal for the pit holding the waste to create anaerobic conditions. The top surface of the pit will be a semipermeable material which allows only gas to pass through. Above this would be a dome shaped top to capture the biogas. A gas release valve would extend from the top of the pit to above ground where the gas could be used. The anaerobic bacteria culture must be seeded or grown under optimal conditions and maintained to ensure the digestion takes place. Sawdust or other carbon rich materials would also need to be added to the pit to increase the C:N ratio and optimize the anaerobic reaction. The resulting bio-slurry at the end of the process is not guaranteed to be pathogen free[^13^], since some pathogens might survive the heat generated in the process, but it can be used as fertilizer. The system design can be seen in Figures 6.4 and 6.5.

[Figure 6-4 Anaerobic Digestion System diagram]

[Figure 6-5 Anaerobic Digestion System design]
6.2.3 Urea Paper Stacking System

This idea incorporates a pre-composting component by means of a specially fabricated urea paper sheet. The urea coated on the paper sheet reacts with feces which raises the pH of the waste enough to kill harmful pathogens \[15\]. Stacks of these sheets will be provided at the toilet to be used once per use, as seen below in Figure 6.6. Urine will be diverted and stored for use as fertilizer. Solid waste will land on the paper sheet, and when the user is finished, they will use a specially designed lid to press down on the paper sheet forcing it into the spring loaded cylindrical container, as seen below in Figure 6.7. When the trash can sized container system is filled the entire container is removed and transported to a secondary composting location. A roller dolly type transportation unit will be crafted to transfer the containers to the secondary composting location. The trash can sized system can handle approximately one month’s waste from one family. The unit would not be for public use but for 4-6 person homes due to its small capacity. Many of these systems would need to be installed for a public facility.

![Figure 6-6 Urea paper sheet](image)

![Figure 6-7 Spring loaded waste container and compacting lid](image)
### 6.2.4 Urea Bag Digestion System

In this system individual waste would be trapped and sealed in urea lined plastic bags. The system design can be seen below in Figures 6.8 and 6.9. Before each use, a new bag will be cut from the roll and be placed over the hole, as seen below in. After being filled, the user would pull a lever that manually seals the bag and drops the bag into the pit below. The bag containing the waste would drop into a pit. The waste inside the bag would react with the urea; raising the pH and sterilizing the waste \(^{[15]}\). The waste would continue to anaerobically digest inside the plastic bag. The plastic bag itself will be biodegradable, and have a decomposition rate slower than the digestion rate of the waste so that the waste will become sterile before the bag decomposes. Once the pit is filled with the bagged waste, the pit could either be buried or the waste could be removed and picked up by a third party and transported to an anaerobic digestion facility for further treatment.

![Figure 6-8 Urea Bag Digestion System design (Isometric View)](image)

![Figure 6-9 (Top View)](image)
6.2.5 Pit Composting System – FCE Lead Concept Design

This system will consist of multiple pits with some are in use while others are full and sealed for composting, as seen below in Figure 6.10. The design will allow the raw feces to compost while the majority of the urine is diverted. The composting process would include adding carbon-rich materials such as shavings of leaves and grasses, food scraps, and sawdust. Diverting a portion of the urine away from the compost pile will help regulate the carbon to nitrogen ratio and moisture content needed for effective composting. Ash can also be added to reduce odors. Additional mixing and aeration will increase the composting time and the death of pathogens in the waste. Urine would be diverted from the toilet to a separate storage container and may be used as fertilizer after a short time. The detailed explanation of this design and concept drawings of the design are located in Section 6.4 Lead Concept Design Description.
6.3 Concept Design Selection Process

The following sections explain how the lead design concept was selected, and the criteria in which the concepts were judged upon.

6.3.1 House of Quality

A house of quality was used as part of the project’s quality function deployment (QFD). QFD was used to transform the customer’s needs, as Mr. Bhutani and the proposed Indian village members, into engineering characteristics for the toilet design. The QFD prioritized each product characteristic while simultaneously setting development targets for the toilet. The house of quality was useful for defining the relationship between the customer’s desires the engineering design requirements of the project.

The house of quality was used as a way to quantify the importance of the constraints the design is looking to fulfill. The five primary concept designs were compared in the house of quality. The results of the house of quality show the relative importance of the quality characteristics. Maintenance difficulty was weighted as the most important, followed by adaptability and water requirement.

The house of quality results were used in weighting the decision matrix when deciding which design was the best to further pursue. The weighting values applied to the decision matrix equally weight the customer’s demands and the engineering requirements to ensure that the best possible design is selected. The House of Quality may be referenced in Appendix D.

6.3.2 Decision Matrix

A decision matrix was used to compare the five primary conceptual designs. Design requirements are listed across the top row of the table. The importance of each was weighted based on their values from the house of quality. The conceptual design systems were then scored from 1 – 10 on their ability to meet each design constraint. Tables and descriptions detailing the scoring of each design constraint may be referenced below Table 1.
### Table 6-1 Decision Matrix

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<td>9</td>
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<td>2</td>
<td>10</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>10</td>
<td>2</td>
<td>30.8</td>
</tr>
<tr>
<td>Urea Plastic Bag</td>
<td>10</td>
<td>4</td>
<td>9</td>
<td>3</td>
<td>2</td>
<td>10</td>
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<td>2</td>
<td>4</td>
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<td>4</td>
<td>33.6</td>
</tr>
</tbody>
</table>

#### 6.3.2.1 Water Requirement (Liters)

<table>
<thead>
<tr>
<th>Value</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt; 8</td>
</tr>
<tr>
<td>2</td>
<td>7 – 8</td>
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<td>6 - 7</td>
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<td>4 - 5</td>
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<tr>
<td>9</td>
<td>0 - 1</td>
</tr>
<tr>
<td>10</td>
<td>No Water</td>
</tr>
</tbody>
</table>

Water requirement was scored based on the amount of water needed to operate the toilet. None of the proposed systems require any water. No water is needed for flushing as all systems are located directly above the storage receptacle, allowing the waste to drop straight down without needing to first pass through piping.

#### 6.3.2.2 Capital Cost (Dollars)

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2</td>
<td>270 - 280</td>
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<td>260 - 270</td>
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<td>240 - 250</td>
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<td>6</td>
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<td>7</td>
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<td>210 - 220</td>
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<td>9</td>
<td>200 - 210</td>
</tr>
<tr>
<td>10</td>
<td>&lt; 200</td>
</tr>
</tbody>
</table>

Capital cost was scored based on the cost of materials required to build the toilet design. Estimates were made on the quantity of materials to construct the exterior building, the toilet itself, and the storage receptacles used. Prices were based on the cost of products in the U.S. in dollars. Additional chemicals or materials required for operation were estimated based on a one month usage. These were further assessed in the recurring costs.
6.3.2.3 Installation Cost (Dollars)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
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<td>&gt; 850</td>
</tr>
<tr>
<td>2</td>
<td>750 - 850</td>
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<tr>
<td>4</td>
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<tr>
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<td>8</td>
<td>150 - 250</td>
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<td>9</td>
<td>50 - 150</td>
</tr>
<tr>
<td>10</td>
<td>&lt; 50</td>
</tr>
</tbody>
</table>

Installation cost was scored based on the cost required to pay someone hourly to build and install the system. Hourly wages were based on the U.S. minimum wage. The amount of man hours required to construct each design were estimated based on the complexity of the system.

6.3.2.4 Maintenance/Recurring Cost (Dollars)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt; 180</td>
</tr>
<tr>
<td>2</td>
<td>160 - 180</td>
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<td>3</td>
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<tr>
<td>4</td>
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<td>8</td>
<td>40 - 60</td>
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<td>9</td>
<td>20 - 40</td>
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<tr>
<td>10</td>
<td>&lt; 20</td>
</tr>
</tbody>
</table>

Maintenance/recurring costs were scored based on a yearly estimate of the cost of materials needed to operate system. Costs were estimated based on one month of usage. The Urea Paper and Plastic Bag systems require materials added each time the system is used, resulting in the highest recurring costs. The composting systems and digester require only saw dust or other yard waste added to the system, resulting in a lower recurring cost.

6.3.2.5 Useable Byproducts (percentage of raw waste converted to useable byproduct)

<p>| | |</p>
<table>
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<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
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<tr>
<td>3</td>
<td>50</td>
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<td>4</td>
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<td>50</td>
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<tr>
<td>9</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
</tr>
</tbody>
</table>

Usable byproducts were scored based on an estimate of the efficiency of the toilet system to convert the raw waste into a useable byproduct. The Pit and Thermophilic composting systems will convert all the waste to useable compost. Digestion systems create biogas which can be burned and used for heating. Digesters also create a bioslurry that can be used as fertilizer, however this bioslurry has a high potential of still containing dangerous pathogens. In typical processes bioslurry is treated again after digestion to ensure sterilization[13]. A specific bacterial culture is needed to facilitate the digestion of waste which can be difficult to create without seeding. The Urea Paper Stacking and Plastic Bag systems would create a safe byproduct but the waste would require further treatment before being used as fertilizer.
### 6.3.2.6 Treatment Time (Months)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt; 9</td>
</tr>
<tr>
<td>2</td>
<td>8 – 9</td>
</tr>
<tr>
<td>3</td>
<td>7 – 8</td>
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<tr>
<td>4</td>
<td>6 – 7</td>
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<tr>
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<td>5 – 6</td>
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<td>8</td>
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<tr>
<td>9</td>
<td>1 – 2</td>
</tr>
<tr>
<td>10</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Treatment time was scored based on the amount of time needed to render the waste sterile. The Pit composting system was estimated to take between 3-6 months with proper composting. Thermophilic composting can render waste entirely sterile if the waste is kept at above 130°F for 15 minutes\(^4\). It is unlikely that the system is capable of consistent thorough heating of the waste to this temperature however, so a 3 month minimum sterilization time is suggested. The digester system has an estimated solids retention time of 8 months. Urea Paper Stacking and Urea Plastic Bag systems would potentially render the waste sterile in about four weeks as the pH is raised.

### 6.3.2.7 Capacity (m\(^3\) waste)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt; 0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.5 – 1</td>
</tr>
<tr>
<td>3</td>
<td>1 – 1.5</td>
</tr>
<tr>
<td>4</td>
<td>1.5 – 2</td>
</tr>
<tr>
<td>5</td>
<td>2 – 2.5</td>
</tr>
<tr>
<td>6</td>
<td>2.5 – 3</td>
</tr>
<tr>
<td>7</td>
<td>3.5 – 4</td>
</tr>
<tr>
<td>8</td>
<td>4 – 4.5</td>
</tr>
<tr>
<td>9</td>
<td>4.5 – 5</td>
</tr>
<tr>
<td>10</td>
<td>&gt; 5</td>
</tr>
</tbody>
</table>

The capacity was scored based on the waste storage capacity of one unit of the system. The urea paper stacking system has the least capacity, estimated as 0.12 m\(^3\). The plastic bag system has the second least capacity as each waste is individually stored in a plastic bag, which must then be stored until transportation to further processing. The pit holding the plastic bags is estimated to hold approximately 1 m\(^3\) of waste. A single pit for the Thermophilic and Pit composting systems are being designed to hold about 2 m\(^3\) of waste. The digester system will require an anaerobic pit approximately 6 m\(^3\) in volume.

### 6.3.2.8 Maintenance Difficulty

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>2</td>
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</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Moderate</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
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<tr>
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<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Easy</td>
</tr>
</tbody>
</table>

Difficulty of maintenance is scored subjectively based on the estimated frequency and time required by users to ensure the system is properly functioning. The Pit and Thermophilic composting systems would require additions of sawdust or other yard waste to help composting, frequent mixing, and removal of compost when finished. The digester would require removal of bioslurry. The urea paper system would require stacking pretreated urea paper before each use and removal and disposal of the waste when container when full. The plastic bag system would require putting a new plastic bag in the system before each use, sealing it, and emptying the waste pit either when composted or earlier for post-treatment.
### 6.3.2.9 Lifespan of System (Years)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Lifespan (Years)</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>2</td>
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<td>9</td>
<td>25 – 28</td>
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<tr>
<td>10</td>
<td>&gt; 28</td>
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</tbody>
</table>

Lifespan of system was scored based on the estimated life of the toilet before a complete replacement is needed. The Pit and Thermophilic composting systems both have an estimated life of 20 years. The digester has an estimated life of 17 years as the slightly higher complexity of gas capturing shortens the estimated life span. The urea paper stacking and plastic bag systems have an estimated 12 year life span as they are dependent on supplied materials for operation which may not be constantly available in very rural areas.

### 6.3.2.10 Space Usage (m²)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Space Usage (m²)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2</td>
<td>4.0 – 4.5</td>
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<td>3</td>
<td>3.5 – 4.0</td>
</tr>
<tr>
<td>4</td>
<td>3.0 – 3.5</td>
</tr>
<tr>
<td>5</td>
<td>2.5 – 3.0</td>
</tr>
<tr>
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<td>2.0 – 2.5</td>
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<td>7</td>
<td>1.5 – 2.0</td>
</tr>
<tr>
<td>8</td>
<td>1.0 – 1.5</td>
</tr>
<tr>
<td>9</td>
<td>0.5 – 1.0</td>
</tr>
<tr>
<td>10</td>
<td>&lt; 0.5</td>
</tr>
</tbody>
</table>

Space usage was scored based on the estimated total area usage of the system. The Urea Paper Stacking system would use the least area, estimated at 0.29 m², as it only requires the singular storage bin to stack the waste. When the bin is full it would be hauled away for further treatment. The Plastic Bag system would require the second least amount of space, estimated at 1.0 m². The Pit composting system would use the third least amount of space (2.0 m²), followed by Thermophilic composting (3.0 m²) and the digester (5.0 m²). Thermophilic composting requires more area than the Pit system to accommodate the heating apparatus. The digester requires the largest pit of all the systems as it has the longest solid retention time (SRT) therefore requiring the largest volume and area.

### 6.3.2.11 Adaptability

<table>
<thead>
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<th>Rank</th>
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<tbody>
<tr>
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<td>2</td>
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<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Easy</td>
</tr>
</tbody>
</table>

Adaptability is scored subjectively based on how easily the system may be implemented in various applications with varying waste streams. The Pit system is considered very adaptable as it is the simplest system. The Digester system is the second most adaptable as it requires a slightly larger land area and a fairly more complicated pit with the ability to capture gas. Thermophilic composting is viewed as the next most adaptable as the system relies strongly on sunlight availability which varies significantly based on location and time of year. Plastic bags are seen as the next most adaptable as the treatment time is very low unless processed by a third party. The Plastic Bag system also requires the bags which may not be
available everywhere and chemical treatment if Urea is to be used. Urea Paper Stacking is the least adaptable as it requires chemically treated paper to work and secondary disposal of waste.

After each concept was scored, the values were multiplied by the corresponding weighting factor for the particular design constraint for a final score out of 70. The Pit Composting system received the highest score followed by the Digester and the Thermophilic Composting system. This decision matrix was not the final say in which conceptual design was chosen as the lead concept, but it was used as a tool for quantifying the benefits and flaws of each system.

6.3.3 Drawbacks of Design Concepts

The primary concept designs each excel in certain aspects of treating human waste. The majority of the designs focused on accelerating the pathogen death rate in the waste. Concepts not selected as the lead were most commonly too complex in one aspect such the costs outweighed the benefits. Selecting a system with an adaptable capacity capable of serving a 100 person village was also a major aspect in lead concept selection. The selected composting pit system can cost-effectively be implemented in locations without existing proper sanitation and can also be used to improve sites currently using pit systems.

6.3.3.1 Thermophilic Composting System

When pasteurizing the human waste, specific core temperatures would need to be met and maintained for corresponding time intervals. Verifying these criteria would be hard to accomplish and would require an educated staff to operate and maintain the necessary technological equipment. To improve heat transfer, the tank would be made out of metal. This would need to be manufactured offsite and shipped to the respective villages, resulting in a high cost of the finished product. Furthermore, to improve the solar heating, a polished metal surface would be ideal for reflecting solar rays on the waste pit. An adequate reflecting surface such as a polished metal sheet may not be readily available in rural villages in India. These disadvantages have discouraged further efforts of analyzing this system as a possible solution.

6.3.3.2 Anaerobic Digesting System

A specific microbial population of facultative anaerobes is required in order for anaerobic digestion to take place. This population can be difficult to create without seeding with bioslurry from an already functioning system. The construction of the system would be more complex than composting systems. Material for the semipermeable layer above the solid waste that allows only gas to pass through may not be easily available. The dome shaped roof and gas capturing system would require some advanced expertise to construct. The amount of methane gas produced from this system would be minimal and would require regular maintenance to ensure proper production through the addition
of carbon rich materials. Once the gas is produced, further construction would be required to develop an efficient individual storage method along with a way to regulate its dispersal. Bioslurry is not guaranteed to be pathogen free and may require further processing to sterilize before use. This would result in contact with potential still dangerous waste. These disadvantages have discouraged further efforts of analyzing this system as a possible solution.

### 6.3.3.3 Urea Plastic Bag System

This system would require the manufacturing of the urea lined plastic as well as shipment to each individual village. These villages would be dependent on the timely and sufficient delivery of each order, and would have to resort to prior unsanitary methods if either should be unsatisfied. These disadvantages have discouraged further efforts of analyzing this system as a possible solution.

### 6.3.3.4 Urea Paper Stacking System

This system would require the manufacturing of the urea paper sheets as well as shipment to each individual village. These villages would be dependent on the timely and sufficient delivery of each order, and would have to resolve to prior unsanitary methods if either should be unsatisfied. Low capacity of this system also makes it impractical to service an entire village. These disadvantages have discouraged further efforts of analyzing this system as a possible solution.

### 6.4 Lead Concept Design Description

The Pit Composting System uses pits sealed with concrete lids to contain the raw waste while the pit is in use and during the composting process as seen below in Figure 6.11. The same pit will be used for both the containment and composting of the waste. The system facility will use an alternating method between pits where some will be active and able to use by villagers, and others will be full and in the composting process. The pit will be constructed so that the raw, pathogen infested waste won’t seep into groundwater supplies or into agricultural lands. The pit lid itself will have a cut-out with a squat tray placed over it for the villagers to use. When full, the squat tray will be replaced with a cap to seal off the waste during the composting process. The lid itself could be designed and used to convert existing Sulabh International two-pit systems to waterless pit systems. For the privacy and safety of the users, a mobile shelter is placed over pits that are available for use. The lid will have a urine diversion component that can be routed to a holding tank or back into the pit, depending on necessary moisture content and carbon to nitrogen (C:N) ratio for composting. Carbon rich additives will be mixed in periodically to increase the C:N ratio, along with ash, to cover odors. Aeration for the compost and ventilation for fresh waste odors will be through a crank shaft and bicycle fan mechanism.
6.4.1 **Pit**

The composting pits will be constructed out of concrete, brick, or a combination of the two, designed to best prevent leakage. The design will optimize cost and minimize potential for ground contamination. The pit system will be designed to accommodate the waste stream of a one hundred person village.

6.4.2 **Pit Lid**

The design of the pit lid allows it to be fitted to new pits as well as customized for an existing Sulabh pit. They will be cylindrical in shape and constructed from concrete to produce high strength and a long life. Substitutes to conventional Portland cement will be researched for their availability in rural area. Once in place, the lids will stay stationary over the pit during active use as well as during the composting period. Testing will be done with various mixes, as well as determining the threshold at which reinforcements will be required.
6.4.3 **Squat Pan**

While the pit is in use, the squat pan will be placed on top of the lid where it snaps into place. It will be locked in place during the duration of use but may be removed for cleaning. The squat pan is to be manufactured off-site. It will be made from plastic or other easily cleaned material. The squat pan will consist of two openings, one for urine and one for solids. A splatter shield will provide additional cleanliness. The squat pan is designed to be culturally acceptable and accommodating to both men and women. The squat pan can be referenced in Figure 6.12.

**Figure 6-12 Squat pan on a pit lid**

6.4.4 **Cap**

When the pits are full and in the process of composting a cap will close tightly over the opening in the lid to keep odors out of the immediate public area. The cap will take the place of the squat pan and the shelter during the entirety of the time that the pit is composting. The cap will be in place over empty pits as well. Appropriate signage will notify users whether the pits are composting or empty and ready to be filled.

6.4.5 **Shelter**

Only pits available for use will have privacy shelters. Those pits in the process of composting will not. These shelters will be mobile structures whose presence over a pit will signify to the user that the pit is available for use. Lightweight materials, such as wood, metal, or plastic will be used to construct the portable shelter structure, while a cloth, wood, or other readily available material will be used for side paneling. The shelter structure will be anchored to the ground with a detachable mechanism, so
when the pit is full, the lightweight shelter can be detached and moved to the next empty pit. Pins attached with clips, pegs held in slots with tension, and stakes are all potential mechanisms to anchor the structure legs to the pit Lid.

6.4.6 Urine Diversion

For urine diversion, a simple PVC pipe will be routed from where urine is initially separated to a urine holding tank outside of the pit. This tank will also have a separate PVC pipe connected to the pit, allowing stored urine to be added to the rest of the waste when desired. Controlling of the amount of urine added means the levels of nitrogen can be controlled, yielding better final compost quality. Any excess urine can be easily accessed from the storage tank and used as fertilizer.

6.4.7 Ventilation

In order to produce air flow throughout the system, promoting odor control and aeration for composting, a pipe network in combination with a custom pump will be used. The pump will consist of fins fitted to a bicycle rim and driven by a bicycle chain connected to a crank shaft that is powered by human pedaling, as seen in Figure 6.15.

6.4.8 Composting Process

Composting is able to occur with a proper mixture of water, carbon, nitrogen, and oxygen. With proper ratios, microorganisms are capable of breaking down organic matter into compost, or “humus”. Pathogens in human waste are killed through the heat generated during the composting process and from competition with other microorganisms for available nutrients. Aerobic bacteria create water, carbon dioxide, and
ammonium during the composting process. Ammonium is further converted into nitrates and nitrites which aid in plant growth when the compost is applied as fertilizer.

In the pit composting system, urine will be diverted to prevent the compost from becoming too wet. Moisture contents above 60% can create anaerobic conditions which prohibit the composting process and cause odors. Ideally the moisture content should be kept around 40%. Urine is high in nitrogen, a necessary nutrient in composting, so urine will be added to the compost in appropriate amounts. Material rich in carbon should be added to the compost to maintain an ideal C:N ratio of approximately 20:1 by mass. Carbon rich materials include sawdust, woodchips, leaves, brush, grasses, hay, general green and food waste. If odor occurs, ash can be added to the top of the compost as a natural cover. The time required to fully compost human waste is conservatively estimated as one year but can be reduced to 6 months with proper aeration techniques.
7. Critical Design Description

The top five concept designs were presented to the project sponsors, Mr. Bhutani and Ms. Rami, on March 15th, 2013 for formal review. Upon approval of the lead concept design by the project sponsors, the critical design phase of the project began. The lead concept design was analyzed in depth to determine proper dimensions, required materials, cost, and any foreseeable issues. Improvements were made to the concept design and may be referenced in the final design description below.

7.1 System Description

The pits will be arranged into four groups of eight to facilitate a four month rotating composting cycle. One pit group will be open for use and filled with human waste, yard waste, food waste, and dry additives, until the level of the waste input reaches the indicated level inside the pit (A wooden beam will be added into the construction of the pit to indicate the fill line). When full (after approximately 4 months of use), the open group of eight pits will be closed off with a screen and rain cover, and allowed to sit for one year’s time to compost. When one group of eight pits is closed off to compost, the next group of eight pits is opened for use. The cycle continues in such a manner that by the time

Figure 7-1 One Group of Eight Composting Pits
the first group of pits to be filled has completed one year of composting, they will be emptied and ready for filling once more. A full cycle consists of 16 months: 4 filling, 12 composting, and then it repeats. At the end of the one year, the contents of the pit are expected to be a pathogen-free, nutrient rich soil that may be used in farming applications.

The pit composting system will use urine diversion to ensure the moisture content of the compost stays low. Half of the urine will enter the pits directly and half will be diverted to a urine collection container. The urine will be directed by using a Y cut-off valve and alternating weekly between diverting urine to the collection container and back to the pit. The diverted urine will be disposed of away from the pits in a vegetated area, or collected for personal crop use if the user chooses.

7.2  Detailed Description of System Components

7.2.1  Brick Pit

7.2.1.1  Brick Pit Material Selection

Concrete masonry brick will form the pit and provide structural support for the pit lid. This material was selected due to its low cost, availability, low water absorption relative to other types of brick, and overall performance characteristics. No special material fabrication will be necessary because the
design assumes standard concrete brick will be readily available on-location or within a reasonable transportation distance. The brick pit will not require any maintenance. Each time the composted waste is to be removed, a visual inspection will be performed, checking for any structural damage.

7.2.1.2 Brick Pit Dimensions

The pits have been sized to accommodate the total volume of waste per year produced by a 100-person village and the necessary composting additives. In order to maximize the functionality and practicality of the brick pits, several concept changes were made. The cylindrical pit design specified in the lead concept design (Section 6.4) does not permit adjacent pits in a group to be constructed with shared walls. FCE chose a rectangular pit design to permit shared walls and also make better use of interior volume. Pit groups with shared walls require less masonry brick compared to multiple individual pits, minimizing overall masonry brick material costs. The rectangular pit dimensions were designed to maximize volume while minimizing pit depth. A shallower pit depth is desired to decrease any potential injury from falling into an empty pit. For a 32-pit system, the interior dimensions of each pit will be 40” x 40” length by width, and 68” deep.

Figure 7-3 2” x 4” Fill Line Indicator

Composting will take place approximately 1’ below the pit lid. A wooden beam will be included in the masonry brick wall at a depth of 1’ to double as the urine diversion piping support and the physical fill line to observe the fullness of the pit from the center opening. Once all of the pits in an eight-pit group are filled with waste to this approximate wooden beam “fill line”, they will be closed off for composting.
7.2.1.3  **Brick Pit Construction Method**

In order to construct the complete 32-pit system, four large trenches of approximately 30’ long x 4’ wide x 6’ deep will need to be excavated. Eight brick pits with shared walls will be built in each trench. The pits will be grouped together in the sections that will compost together. Common masonry bricklaying practices will be implemented in constructing the pit structure.

7.2.2  **Reinforced Concrete Pit Lid**

![Figure 7-4 Reinforced Concrete Pit Lid](image)

7.2.2.1  **Pit Lid Material Selection**

Reinforced concrete was selected as the pit lid material because it is durable and has a long design life. Necessary mixing materials are: water, Portland cement, fine aggregate (sand), and coarse aggregate (gravel). Concrete as a building material is beneficial for this application because it can be cast into any reasonable desired shape as long as it can be formed. The pit lid will be flat, with one center hole for waste and one cut out at the corner to accommodate the ventilation ducting. Four pairs of No. 3 rebar handles, bent on-site, will be placed along opposite edges of the pit lid to simplify transport. Four long and sturdy sticks can be placed through a pair of handles and eight people can take part in moving the lid once a year for cleaning.
7.2.2.2 Pit Lid Dimensions

The dimensions of the reinforced concrete pit lid were determined based off of the interior length and width dimensions of the pit, 40” x 40”. The other limiting design consideration for the pit lid is the shared wall design of the eight-pit group. With one 4”-wide brick wall division between pits, each lid has a 2” available space on either side to rest on the brick pit structure. The side of the lid parallel to the shared wall will be the longer length, with a small overlap over the bricks on opposite sides, and the side of lid perpendicular to the shared wall will be limited in its length, shorter than the other side. The thickness of the lid is 75 mm or approximately 3”. The lid will have a center hole cut-out for the feces and waste and a cut-out for the ventilation duct in the corner.

The Rectangular Concrete Pit Lid dimensions and volume are listed below:
- General Rectangular Lid: 1.1 m x 1.25 m x 75 mm
- Center Hole Cut-Out: 300 mm x 550 mm x 75 mm
- Ventilation Duct Corner Cut-Out: 225 mm x 200 mm x 75 mm
- Total Lid Volume (less cut-outs): 0.087 cubic meters, or 3.086 cubic feet
- Weight: 463 lbs

7.2.2.3 Pit Lid Design Process: Structural Analysis, Reinforcement, and Mix Design

Several important assumptions, regarding estimated dead and live loads, estimated compressive strength of concrete, and yield strength of steel, were made to complete the structural analysis to determine necessary steel reinforcement.

Conservative assumptions are listed below:
- Live load: one 250 lb person applying half load on each side of the hole
- Compressive strength of concrete, f’c = 1500 psi
- 150 pcf concrete
- Yield strength of steel, fy = 40 ksi

For structural analysis, the lid was analyzed individually in two sections that span the full length in the direction of expected flexure to determine the expected demand load. The section passing the ventilation duct cut-out is thinner (approximately 7.65”), and the section passing the other side of the center hole is wider (approximately 15.65”). The demand distributed loads are a combination of self-weight and the distributed dead loads of tributary contributions from the remaining pit lid concrete not spanning the full length. The distributed dead load contribution from the side of the pit with the 200 mm x 225 mm (approximately 8” x 9”) cut-out for the ventilation duct is accounted for as a dead load spanning the entire length to conservatively simplify calculations. The demand maximum moments were determined using structural analysis (see Appendix I for detailed calculations). Factors
of 1.2 and 1.6 were applied to the maximum moments caused by dead loads and live loads, respectively.

Designing the reinforcement included calculating the minimum area of steel necessary to reinforce the wider of the two lid sections from the above analysis. The minimum required area of steel guides the decision of bar sizes and quantity. For the larger section, one No. 3 bar tied to welded wire reinforcement mesh ⅛” thickness with 6” gaps was chosen to supply the minimum required area of steel for flexural reinforcement. Therefore, the same will also be placed in the smaller section. The area of one No. 3 bar and three 1/8” diameter bars of the mesh were used to calculate the capacity of the section. The maximum factored load demand: $M_u$, in the concrete was found to be 376 lb-ft. The max capacity moment multiplied by strength reduction factor, $\phi$: $M_n\phi$, was found to be 592 lb-ft. Thus, the Ultimate Strength Design equation is satisfied:

\[
\phi M_n > M_u \\
0.9 \times 658 \text{ lbft} > 376 \text{ lbft} \\
592 \text{ lbft} > 396 \text{ lbft} \rightarrow \text{yes, satisfied}
\]

The above equation is satisfied with a live point load of 125 lb applied on each side of the center hole. In order to determine the max allowable live point load, $P_{L,max}$, applied centrally on one side of the pit lid, the following factored load equation was used:

\[
M_u = 1.2(\text{Max moment from dead load}) + 1.6(\text{max moment from live load}) \\
M_u = 1.2M_D + 1.6M_L \\
M_u = 1.2M_D + 1.6\left[\frac{P_{L,max} \times L}{4}\right] \\
592 = 1.2(143) + 1.6\left[\frac{P_{L,max} \times \left(\frac{49.2}{12}\right)}{4}\right] \\
solving: P_{L,max} = 256 \text{ lb}
\]

*See Appendix I for detailed calculations

$P_{L,max}$ is only on one side of the center hole. Therefore, the maximum weight allowable for the lid is about 500 lbs. This number is including many factors and many conservative calculations, but it is the safest assumption. In summary, no more than 2 adults or 3 small children shall stand on the lid at one time.
The summarized specifications for steel reinforcement per lid are listed below:

- 2 No. 3 rebar
- 1 trimmed-to-size welded wire reinforcement mesh sheet: $\frac{1}{8}$” thick with 6” gaps.
- Steel ties to affix the rebar to the mesh

For the concrete mix design, a professional member of Engineers Without Borders allowed the use of an Excel Calculating Spreadsheet that he developed in order to determine volume-based mix designs based on “number of buckets”. The developer of this spreadsheet and others have used it successfully to create volume-based mix designs for developing countries where a common bucket is the most accurate form of measurement available. The bucket method is adaptable to any size bucket, and the user can input certain known givens such as: cement bag weight and desired amount of cement (in bags), percentage of total aggregates that are fine (sand), smaller coarse (smaller gravel), and larger coarse (larger gravel), water to cement ratio, and bucket dimensions. The spreadsheet output includes: marking heights for the measuring buckets, number of buckets of sand, larger gravel, and water for a full batch, and resulting volume of one concrete batch. The batch volume is an output, and the amount of cement is an input, so the necessary amount of cement bags to create the desired batch volume is determined through trial and error. The mix design created for prototyping will be a close representation of what will be made in the field.
Below is a summary of the expected best mix design. Prototyping will help determine actual volumes. The number of 94-lb bags of cement needed as well as the number of Home Depot buckets of sand, aggregate, and water for one 3.3 ft$^3$ batch of concrete is listed below:

- Sand: 2 buckets
- Cement: approximately $\frac{1}{2}$ bags
- Coarse Aggregate: 2 $\frac{1}{2}$ buckets
- Water: $\frac{1}{2}$ bucket

The desired batch volume is per lid, so this number will be multiplied by 32 to get the overall total of concrete needed for construction of a whole system.

### 7.2.2.4 Pit Lid Construction Method

The concrete will be mixed and poured on-site. Formwork will be crafted out of available wood, which will be cut using either a hand or power saw. Ideally a sheet of plywood will be the base of the formwork. If plywood for the base of the formwork isn’t available, a plot of ground can be swept off and covered with plastic. The side formwork wood will be cut to the same height as the lid thickness to allow a long piece of wood to be dragged across the rim of the formwork to evenly level the pour. Formwork for the center hole cut-out and the corner ventilation duct cut-out will be crafted and held in place during the pour either by hand or with wood glue if glue is available. If the pour occurs over ground, the cut-out formwork sections will have to be held in place by hand during the pour.

FCE plans to mix concrete in a wheelbarrow and use a bucket to measure volumes of ingredients. Whatever bucket is available in-country can be specified in the EWB concrete mix design calculator spreadsheet. Pouring the concrete will be done using wheelbarrows and dumping. The reinforcement should be placed after about half of the concrete is poured and leveled. The rebar will be steel-tied to the welded wire reinforcement mesh prior to placement. After reinforcement placement, the remainder of the concrete will be poured and leveled using an even wooden beam. Then the pairs of handles will be placed.

12 hours is the minimum curing time for concrete. That is the absolute minimum time that the concrete must remain in the formwork. To be conservative, FCE will wait 24 hours in order to ensure complete curing. After curing, the formwork should be removed carefully so it can be re-used for subsequent concrete lid pours.

FCE will prototype two lids. A 3.3 ft$^3$ batch of concrete will be necessary per lid. The volume of the concrete pit lid is about 3.1 ft$^3$ but extra concrete is desired to form three testing cylinders at 4” diameter by 8” height (0.06 ft$^3$ each) per batch. Cylinders will be cast from different portions of each
concrete batch made to test for variability in strength within one concrete batch. Compressive strength tests will be executed in the prototyping stages only, in order to estimate the strength performance of the concrete. Variability is expected to be higher in the hand-mixed concrete batch than in a mixer-mixed batch, understandably, so the cylinders will aid in gaging approximately how well the batch is mixed.

Snapshots of the EWB concrete mix design calculator spreadsheet used to calculate bucket quantities can be found in Appendix H.

7.2.3 Squat Pan

![Squat Pan Lid Top Dimensions](image)

**Figure 7-6 Squat Pan Lid Top Dimensions**

![Side View and Dimensions of Squat Pan](image)

**Figure 7-7 Side View and Dimensions of Squat Pan**
7.2.3.1 **Squat Pan Material Selection**

The squat pan will be made out of a generic and readily available plastic. Plastic will be used because it is low cost, easily accessible, and relatively easy to clean. The plastic lab located on Cal Poly’s campus has an excess supply of high-density polyethylene plastic (HDPE) that FCE plans to use to produce the prototype. Pending a successful prototype, this HDPE plastic may be used to produce all of the squat pans needed for a complete system.

7.2.3.2 **Squat Pan Dimensions**

- Outer Area: 600 mm x 350 mm
- Solid waste entry hole area: 250 mm x 200 mm
- Urine Funnel exit diameter: 50mm
- Urine Funnel height: 80mm
- Top Plate Thickness: 5mm
- Guide Rim Depth: 10mm
- Guide Rim Thickness: 5mm

7.2.3.3 **Squat Pan Construction**

The thermoform plastic vacuum mold process will be used for the construction of the prototype squat pan. This method will be performed and tested in the plastics lab on Cal Poly’s campus.

A positive mold for the thermoform plastic vacuum mold will be made out of two main components. The flat top plate of the tray mold, and the positioning ridge will be machined out of MDF particle board. The urine catchment funnel mold will be rapid prototyped to provide the desired design. Each part of the mold will then be glued together, and venting holes will be drilled for the vacuum process. Once thermoformed, the squat pan will then be machined to cut the solid waste hole and urine.
exiting hole. Personal wash water from the user is also expected to enter the pit through the solid waste hole.

### 7.2.4 Ventilation Duct

#### 7.2.4.1 Ventilation Duct Material Selection

The ventilation duct will be constructed out of galvanized steel and painted black. The objective of the ventilation duct is to heat the air inside of the duct causing it to rise. This will create a negative pressure that will draw air through the pit, aerating the compost and reducing odors. Galvanized steel is used due to its high heat conducting capacity. It will be painted matte black to absorb as much sunlight as possible.

**Figure 7-9 Ventilation System Ducting**
7.2.4.2  Ventilation Duct Dimensions
The ventilation duct will be 8” x 8” x 8’ high. At the base of the duct, two 4”x12” cut outs will be made. This will reduce the restriction of the air flow by increasing the duct entrance area.

7.2.4.3  Ventilation Duct Construction

Figure 7-10 Ventilation Cut-Out the Side of the Pit System

Standard dimensions were used for the ventilation duct so that the material could be purchased from local manufacturers. After construction of the pit and pit lid, the ventilation ducting will be installed. The portion of the ducting shaft below the lid will have the two cut outs for increased airflow. The bottom of the shaft will rest upon the brick pit structure. Additional supports will be made for the shaft above the pit lid to ensure stability. These will be constructed with wood, bricks, and mortar. The scraps from the two cut outs will be used to raise and support a duct cap. This cap will be used prevent rainfall from entering the pit, and will be made of a bent piece of scrap sheet metal that covers the entire duct opening. The duct, raised supports, and the cap will all be assembled together using bolts and screws. Some of the scrap screen material used for the composting cover will be placed at the duct outlet to prevent bugs from entering.
7.2.5 Composting

7.2.5.1 Composting Additive Material

In order to biodegrade the human waste as quickly and efficiently as possible, additives must be used to increase the carbon to nitrogen ratio. In traditional composting, sawdust or other yard waste is used because of their high carbon content. Available additives will vary based on the location the system is implemented. For this report typical values were assumed for the carbon, nitrogen, and moisture content of yard waste.

Maintaining appropriate moisture content is also necessary for proper composting. It was found that additional dry material is needed after additions of human waste and yard waste to reduce the moisture content. Available material will again vary based on location but it is recommended that ash or very dry soil be added. These are both fairly common and ash will also help reduce odors.

7.2.5.2 Composting Additive Quantity

The required quantity of composting additive was calculated based on maintaining an appropriate C/N ratio and moisture content for composting. C/N ratio was determined using the below equation:

\[
R = \frac{Q_u(C_u(100 - M_u)) + Q_f(C_f(100 - M_f)) + Q_{yw}(C_{yw}(100 - M_{yw}))}{Q_u(N_u(100 - M_u)) + Q_f(N_f(100 - M_f)) + Q_{yw}(N_{yw}(100 - M_{yw}))}
\]

Approximately 2 kg/d of yard waste additive was required to maintain a C/N ratio of approximately 20. Moisture content of the compost material was estimated using the following equation:

\[
M. C. = \frac{\Sigma Mass_{wet} - \Sigma Mass_{dry}}{\Sigma Mass_{wet}}
\]

In addition of the yard waste, approximately 25 kg/d of dry soil or ash are required to maintain a moisture content of 50% in the compost mix. These together require approximately 10 m³ of volume for one year of use. Calculations of composting additive materials may be referenced in Appendix F.
7.2.6 Composting Cover

![Figure 7-11 Composting Cover for Ventilation](image)

7.2.6.1 Composting Cover Material Selection

Once a pit is filled and ready for compost the squat pan will be removed and a wooden cover with a screen will be placed over the center hole. This cover will allow air flow but prevent rainfall from entering the pit. Additionally, the screen will prevent insects or animals from entering the composting pit. Composting cover materials will vary based on availability on-site, but the main concerns are preventing insects from entering, keeping excess moisture out, and allowing air flow in.

7.2.6.2 Composting Cover Dimensions

- Screen material area: 600 mm x 350 mm, or large enough to stretch over frame
- Wood frame area: 600 mm x 350 mm with a thickness of 25 mm
- Triangular roof will span the wood frame and will have an approximate height of 150 mm

7.2.6.3 Composting Cover Construction

A recommended design is a rectangular frame constructed out of plywood to fit around the center hole. The screen will be stretched over the frame and attached to it. A cover will be built in a triangular roof design fashion over the screen to prevent rainwater from entering the pit.
7.2.7 Urine Diverter

Figure 7-12 Urine Diversion System and Storage Container

Figure 7-13 Urine Diversion System Top View
7.2.7.1 Urine Diverter Material Selection

The urine diversion container should be a plastic 5 gallon bucket with a lid that will prevent leaking and limit odors. The piping connecting the squat pan to the urine container will be PVC pipe, as it is cheap and fairly common to acquire anywhere. A common plastic Y valve for gardening hoses will be screwed into the PVC to divert the urine either back into the composting pit, or to the diversion container.

7.2.7.2 Urine Diverter Dimensions

On average, a village of 100 people will produce approximately 18 $m^3$ of urine in six months. Diverting 50% of the urine out of the composting pit will require 9 $m^3$ of urine to be handled with the urine diversion container over six months. Required emptying time of the container will vary based on container size. A larger container will fill less quickly and require less frequent emptying. However less frequent emptying is a trade off with ease of emptying as a large container will be heavy and hard to lift when full. A five gallon container is recommended as it will not require a large hole or be too heavy to carry. A full five gallon bucket will weigh approximately 40 lbs and require emptying twice weekly. The full container will be emptied into a nearby garden or vegetated area.

7.2.7.3 Urine Diverter Construction

The urine container will be placed adjacent to the pit. A hole will be dug to place the container in. The top of the container will be below the level of the bottom of the squat pan so the urine can flow by gravity into the container. Piping will be connected to the bottom of the squat pan funnel. This piping will be supported by a 2”x4” board inside the pit to prevent the piping from breaking if stress is applied. Piping will travel through the wall of the pit where it will split into two pipes, one leading to the container and the other leading back into the pit. A valve will change which way the urine is diverted. This valve is to be changed either once per day or once per week.

7.2.8 Privacy Shelter

A privacy shelter will be constructed around each of the pits to provide the user privacy and safety during use. The privacy structure should have at minimum three solid sides and one side to function as entrance and exit. The entrance and exit can be a functioning door or a cloth that can be secured shut. The shelter should be easily movable as it will be removed from full pits when the composting process begins and placed on an empty pit.
8. Project Management Plan

FCE will build a prototype of a single composting pit for analysis. This prototype will be built above ground at a depth of three feet, shallower than the design depth. Construction of the prototype will consist of the following: constructing the concrete pit lid, laying the brick pit structure, positioning the urine diversion pipe fittings and discerning best placement for the corresponding urine collecting container hole, assembling the ventilation system in-place, and executing a thermoform plastic vacuum mold process to form the plastic squat pan.

Prototype construction will allow FCE to evaluate the material selection and construction methods suggested in the report. Design corrections will be made of any flaws discovered during prototyping process. The prototype will not be actively tested with human waste due to potential hazard limitations.

Below are tentative dates for the prototype construction phase of the project. Dates are subject to change based on supervising faculty availability and procurement of necessary materials.

- Prototype construction is scheduled to begin Sunday May 12, 2013. Materials necessary for the concrete lid have been obtained from the Civil Engineering Department. For the pit structure, masonry mortar mix (a cement, lime, and sand mixture) will be obtained from Home Depot. All other materials and tools necessary for the brick pit structure and concrete lid have been obtained. A second construction day is scheduled for Sunday May 19, 2013 to construct a second concrete pit lid and lay the masonry brick for the 3’ deep pit prototype.

- The FCE team is currently working with Professor Vorst and Professor Koch on construction of the plastic squat pan. It will be constructed using a thermoform plastic vacuum mold process. This method will be performed and tested in the plastics lab on Cal Poly’s campus. The deadline for the squat pan construction is May 30, 2013.

- The material for the ventilation system has been fully specified. A search for the most competitive pricing is currently underway. The deadline for the order date of the prototype ventilation material is May 25, 2013.

- The deadline for the ordering of materials for the urine diverting system has been set as May 18, 2013.

- Pending the prompt arrival of all ordered materials, a second construction day has been scheduled for Saturday May 25, 2013. On this day the squat pan, ventilation system, and the urine diverter will be added to the lid and pit structure.
9. Prototype Testing Discussion

Ideally a prototype would be built, used, and composted. The finished compost material would then be analyzed in a lab for the presence of coliform bacteria. Soil samples would be taken around the pit and tested for coliforms to ensure the pit does not leak. These soil samples should be taken and various depths and distances around the pit. Testing of the pit composting system should be done to ensure the composting process will generate a pathogen free waste in the recommend amount of time. Testing should also be done to ensure the pits effectively contain the waste to prevent soil and groundwater contamination.

FCE will prototype a 3’ deep shallow example brick pit, two concrete pit lids, an example plastic squat pan, the compost cover screen, and it will assemble the urine diversion container and piping. These prototypes will allow FCE to locate any design issues that create problems in construction. With the bucket method mix design volumes of ingredients as a guide, prototyping the concrete pit lid also serves as necessary practice for mixing concrete without a standard mixer. Standard ASTM lab procedures to determine the approximate 28-day compressive strength of the prototype concrete casted cylinders will be completed. FCE will have a general idea of the compressive strength that can be expected in the field after performing the ASTM tests on the cylinders in the lab, a procedure unavailable in field. A slump test will be the most standardized process to determine the desired consistency in the field. If a slump cone is not available, general desired consistency of concrete mix should be recognizable.

Attempting to obtain human waste to fill and test the toilet system at Cal Poly presented multiple limitations. It was not possible to test the pit system with actual human waste. The toilet could not be built below ground, as digging required special permitting. Testing the compost after the recommend year compost time could not be done due to the short time span of the project. Lastly, testing the fill time for a 100 person village would not be feasible. The actual time to fill an 8-pit group will be determined after installation (see Section 12: Recommendations).
10. Project Budget

The total budget for this project is $4,500, to be spent on materials for prototyping. Of the total amount, $500 is specifically for transportation, enabling FCE to meet with their sponsor directly if necessary. The majority of funds will go towards materials for the construction of both the concept and functional prototypes. The estimated direct expenses for the project are $2000. The team will use the Mechanical Engineering Machine Shop and Plastics Lab for the fabrication processes, and a small area behind Cal Poly Engineering Building 13 for concrete and masonry construction work. Cal Poly students with required Machine Shop training can use the shop free of charge. All manufacturing will be completed by the FCE team, yielding no outside labor expenses. There will be no monetary compensation for the researching, brainstorming, or the labor performed; therefore, the total personnel costs will be $0. To help minimize the amount of direct expenses, one approach will be to gather materials from scrap piles at Home Depot, or the Cal Poly Machine Shop. In addition, FCE will perform cost comparisons for each purchase made.
11. Cost Summary

Table 11.1 depicts the estimated itemized costs for a single eight-pit group. The costs of the individual materials were based off the prices found in the United States. This estimate must be adjusted once prices for the same materials sold in India can be determined. Table 11.2 outlines other important cost estimations, namely, the total cost for the entire 32-pit system is approximately $10,000. Figure 11.1 graphs the relationship between cost-per-use and system lifetime. This graph was based off of a 100-person village, in which each person uses a pit once a day.

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<td>0.3</td>
</tr>
</tbody>
</table>

Table 11-2 Total Costs: per Pit, per Group, and per System

| Cost per Pit | $ 312.05 |
| Cost per 8 Pit Group | $ 2496.39 |
| Total Cost 32 Pit System | $ 9985.58 |
Figure 11-1 Cost Per Use vs. System Lifetime
12. Recommendations

Before the pit system can be implemented on-location, an effective method for testing must be established. Once successful testing has been performed and the pit system has been implemented, it is strongly recommended that the community appoint a toilet observation committee to oversee the status of the pits and collect monthly data on approximate fullness of pit groups during operation for the first two or three filling cycles. Appendix J contains a suggested field observation sheet to record important dates and approximate fullness.

This committee shall be responsible for:
- Recording the date a pit group is opened up for use
- Making monthly observations of approximate fullness (an average between the eight open pits): Empty, ¼, ½, ¾ full, or full shall be recorded.
- Recording the date a pit group is closed for composting
- Switching the urine diversion valve once a week on Sundays (or an easy to remember day).
- Emptying the urine container into a nearby vegetation area between two and three times per week, depending on fill-up rate.

If it is observed during the first filling cycle that the 8-pit group is filling faster than anticipated, additional pits should be constructed to accommodate the higher waste volume. Each pit group must be allowed a full year to compost and should not be emptied prior. Thus, additional pits must be constructed to account for the new estimated rate of filling.

Selection of system location is important to maximize performance and minimize potential for health issues. Listed below are various factors that should be considered when selecting the site location:
- Pits should be a minimum of 3 meters from any water source.
- Pits should ideally be placed in clay or silty soils with low hydraulic conductivity. This will minimize contaminant spread if leaks occur.
- Pits should be placed adjacent to vegetated areas. This will make emptying of urine diversion containers easier.
- Pits should not be placed in draws or depressions where flooding may occur.

The privacy shelter has not been designed, with the intention that the materials most readily available on-site will be used to construct it. The shelter itself does not have any direct effect on the design of the pit system, so it can be made according to the preferences of the community members. FCE recommends constructing structures to cover only the pit groups in use, that way people can easily determine which pit group is open for use.
13. Conclusion

The Composting pit system provides villagers a safe alternative to open defecation that prevents pathogens from leaching into their groundwater. The communal composting pits with privacy shelters create a safe environment that enables women to use the restroom during the day. When used correctly, the composting pit system is easily sustainable with minimal maintenance required for upkeep. In addition, the pit system can provide the local agricultural community with safe compost to use as fertilizer for their crops.

This design of a sustainable toilet system for India is the first iteration of a series of anticipated senior design projects. The subsequent design projects will be used to further develop, analyze, and test this design before its final goal of implementation in a village in India. Our team will be traveling to India in February of 2014 to gather more information about the culture, available materials, and direct needs of the villagers to better define the project specifications for future design teams.

13.1 Project Continuation

The following is a list of goals that future design teams should aim to accomplish to continue improving this design:

A retaining wall analysis needs to be performed on the wall of the concrete brick pits. This analysis is needed to ensure that the pit walls will have the strength needed to support the weight of the soil acting on the sides of wall at depth. The retaining wall analysis should be performed with the guidance of and approval of a licensed civil engineer to ensure the safety of the design.

An apparatus needs to be designed and fabricated that will allow for the necessary pathogen and seepage testing to prove that this design prevents leaching into open groundwater sources. This testing will need to abide by California and India laws. Testing hasn't been performed because California state law currently prohibits any potentially hazardous materials to be stored underground without proper containment.

An analysis can be performed to optimize and confirm that the forced air convection caused by the vent improves the aeration composting process. 

A more detailed cost analysis should be done based off the cost of materials in India. This information will be available once the team travels to India.
14. Team Roles

In order to ensure project success, specific roles and responsibilities have been delegated to each team member. Joe Benyon will be in charge of ordering and bookkeeping materials, as well as overseeing all basic and detailed drawings. Kyle Moore will be responsible for the fabrication, concept generation, and selection processes. Meghan will be the main source of contact between the FCE team and sponsor, as well as cataloging all resources used. Tommy Lauderdale will oversee all of the design testing and document editing. In addition, all members will contribute to all tasks, noting that the leads will ultimately be responsible for completion.
15. Works Cited


Appendix A – Team Resumes

Meghan Pranger, E.I.T.
(503) 318-4444 • mpranger@calpoly.edu • 1614 Santa Rosa St #7, San Luis Obispo, CA 93401

Work Experience

San Luis Obispo Public Works Department
Civil Engineering Intern August 2012 - June 2013
• Working part-time during the school year assisting city design engineers and project managers with: asphalt inspections and subsequent data entry in microPAVER, observing active projects in the field, completing plan checks for varying projects.
• For example: reviewing the 50% bike path plans for the pending Higuera to Taft construction project

San Luis Obispo Water Reclamation Facility
Volunteer Operations Intern March - June 2012
• Assisted operators with daily rounds, checked equipment, gathered samples for testing

Concrete Design Project
Spring Quarter 2012
• Group collaboration on a Reinforced Concrete Building Floor Design

Geotechnical Engineering Labs
Spring Quarter 2011
• Particle Size Analysis, Soil Classification, Soil Compaction, Atterberg Limits, Hydrometer Test, Permeability

“Memorial Coliseum Adaptive Reuse Proposal Analysis and Recommendation” Spring Quarter 2010
• Completed a formal (30 page) analysis of pre-existing project proposals, with partner

Education

California Polytechnic State University, San Luis Obispo
Candidate for Bachelor of Science in Civil Engineering Graduation Date: June 2013
GPA: 3.1
Class Level: 5th year

Munich University of Applied Sciences, Germany – Study Abroad September 2010- February 2011

Relevant Civil Engineering Coursework:
• Hydraulic Systems Engineering & Lab, Geological Engineering, Water Resources Eng. & Lab,
Geotechnical Eng. & Lab, Environmental Eng., Eng. Surveying & lab, Sustainable Product Eng., Civil
Eng. Materials Lab, Technical Writing for Engineers

Computer Skills

AutoCAD, WaterCAD, microPAVER, novice MATLAB, proficient Microsoft Word/Excel/PowerPoint
Thomas Lauderdale  
(831) 325-3568  •  tmlauder@calpoly.edu  •  871 Buchon St., San Luis Obispo, CA 93401

Work Experience

Environmental Scientist Intern  
Tetra Tech, San Diego  
September 2012 - December 2013

- Assisted in data processing for multiple projects in the San Diego region. Gained experience in GIS modeling and processing water quality and flow data for use in calibrating watershed models.
- Built a water quality database using Microsoft Access for use on future projects.

Engineer Intern  
Engineering & Environmental Compliance Division  
Department of Plans & Public Works  
City of Monterey, CA  
June 2010 - August 2010

- Conducted samplings, researched and prepared Phosphate Source Identification and Impact Analysis study for City of Monterey.
- Developed methodology for sampling runoff based on City storm water drain system, conducted samplings, mapped sampling results using GIS software, and analyzed results.

Geotechnical Engineering Labs  
Winter Quarter 2012

- Particle Size Analysis, Soil Classification, Soil Compaction, Atterberg Limits, Hydrometer Test, Permeability

Education

California Polytechnic State University, San Luis Obispo  
Graduation Date: December 2013

- Candidate for Bachelor of Science in Environmental Engineering  
  GPA: 3.4  
  Class Level: 5th year

Relevant Environmental Engineering Coursework:


Computer Skills

AutoCAD, GIS, Microsoft Word/Excel/PowerPoint/Access
Work Experience

Aera Energy LLC., Bakersfield, CA
Facilities Engineer Intern                                      Summer 2012

- Mapped the current electrical material procurement process. Applied lean principles to eliminate inefficiencies, and implemented an improved process and method for continuous improvement
- Wrote the on-board guide for new-hires and transfer employees

Aera Energy LLC., Bakersfield, CA
Production Engineer Intern                                      Summer 2011

- Project lead for Six Sigma Heavy Oil Inflow Enhancement Project: Investigated alternative chemical stimulation techniques for heavy oil producers. Collected and tested recovered solid obstructions from heavy oil wells

Power Ascender Design

- Complete design and analysis of power ascender capable of climbing a fixed cable. Included selecting and designing of the systems shaft, bearing, gear, and housing design.

Fluid Mechanics Lab

- Verified drag and lift theories through experiments
- Analyzed laminar and turbulent pipe flow

Engineering Solid Modeling

- Created fully annotated, detailed part and assembly drawings that included global dimensioning tolerances

Education

California Polytechnic State University, San Luis Obispo
Candidate for Bachelor of Science in Mechanical Engineering     Graduation Date: December 2013
GPA: 3.80
Class Level: 4th year

Relevant Mechanical Engineering Coursework:


Computer Skills

AutoCAD, Microsoft Office, DDS: Solid Works, Mathworks: Matlab, C++ Programming
Kyle A. Moore
(916) 502-4482  •  kymoore@calpoly.edu  •  339 Jaycee Drive, San Luis Obispo, CA 93405

Work Experience

California Polytechnic University
Mechanical Engineering Tutor  Spring Quarter 2012
- Tutored Engineering students in the subject of Thermodynamics.

Gyroscopic Workout Device  Spring Quarter 2012
- Group collaboration on inventing a workout device using gyroscopic motion

Power Ascender Design  Spring Quarter 2012
- Complete design and analysis of power ascender able to climb a fix cable. Included Shaft, bearing, gear, and housing design, selection, and analysis

Fluid Mechanics Labs  Spring Quarter 2012
- Verified drag and lift theories through several experiments
- Analyzed laminar and turbulent pipe flow

Engineering Drafting Lab  Winter Quarter 2011
- Studied CAD and current design modeling processes

Education

California Polytechnic State University, San Luis Obispo
Candidate for Bachelor of Science in Mechanical Engineering  Graduation Date: December 2013
GPA: 3.8  
Class Level: 4th year

Relevant Mechanical Engineering Coursework:

Computer Skills

AutoCAD, MATLAB, EES, Solidworks, proficient Microsoft Word/Excel/PowerPoint
Appendix B – Personal Experience

Below are personal statements of experience from each member of Full Cycle Engineering.

Meghan Pranger, E.I.T.

At the San Luis Obispo Water Reclamation Facility I shadowed operators during daily rounds, monitoring wastewater treatment processes. This experience at the facility highlighted that modern water treatment technology requires frugal allocation of money and resources; I also learned first-hand the importance of personal hygiene when handling either the sludge or wastewater. Careful allocation of resources and knowledge of personal hygiene will be necessary considerations motivating the design of a sustainable toilet. As volunteer staff for the Fresno Urban Internship, I lived on $35/day, immersed in a setting resembling urban poverty, thus enabling me to better connect with the people in the community who I worked with on a daily basis. Our volunteer team discussed the importance of finding what non-material resources exist in a community, such as education, skill set, previous experiences, etc., in order to assess our complete collection of resources. As part of an eight-person, multi-ethnic staff team, I lead weekly discussion groups, headed up apartment meetings, mediated conflicts, helped determine a flexible budget, kept a schedule, and pastorally cared for the 30 student interns on the project. These leadership skills will help organize our FCE team and ensure timely and effective progress.

Tommy Lauderdale

I have completed over four years of Environmental Engineering related course work at Cal Poly San Luis Obispo and gained project experience through two separate internships. I have taken classes in Water and Wastewater Treatment Engineering, Biological Wastewater Treatment Process Engineering, Water Quality Measurements, Solid Waste Management, Environmental Health and Safety, Water Resources Engineering, and Geotechnical Engineering. These classes have given me the background understanding necessary to design a toilet that can improve the health and sanitation of impoverished areas of India. I understand the potential for ground water contamination from sewage infiltration through soil and am knowledgeable in the testing required to ensure our final product will prevent this. I believe my knowledge and experience can help the team design a safe and sanitary solution to the present issues.

Joe Benyon

Last summer I worked for Aera Energy, an oil and gas producing company. I was tasked with improving the electrical material procurement process for new development projects. Before I could attempt to make any improvements I had to fully understand the company’s current processes, how the employees felt about them, and what employees considered viable improvements to the current process. After doing this I was able to implement a new procurement process that addressed the employee’s suggestions and concerns as well as shortened lead times between the ordering of the electrical materials to their delivery on the job site. This provided a process that is beneficial in a cost-effective, business standpoint as well as a practical standpoint for the employees ordering and installing the materials. The techniques I learned
will be helpful in producing a low-cost, sustainable toilet for developing countries because I have had experience in making sure the physical requirements of a project are met as well as the underlying socio-cultural needs.

Kyle Moore
Through the Mechanical Engineering curriculum I have been tasked with numerous group projects, each having their own goals to be achieved and obstacles to overcome. From these assignments I have been able to refine my teamwork performance as well as learn how to discover my role in a respective group to promote overall project quality. These skills will surely prove beneficial when working on a multi-disciplinary project such as the sustainable toilet. Certain tasks will need to be delegated based off academic background; consequently there will be times to lead and times to support. I feel confident that my schooling thus far will make me an effective member of this team, able to transition into its respective dynamic and produce a successful final product.
Appendix C – Professional References

The following three individuals have knowledge of our team’s qualifications to perform the requested services. Parties associated with this project may contact any or all of the professional references listed below.

Reference 1:

<table>
<thead>
<tr>
<th>Name</th>
<th>Terry Watson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position or Title</td>
<td>Senior Facilities Engineer</td>
</tr>
<tr>
<td>Firm or Agency</td>
<td>Aera Energy, LLC.</td>
</tr>
<tr>
<td>Street Address</td>
<td>10000 Ming Ave</td>
</tr>
<tr>
<td>City, State &amp; Zip</td>
<td>Bakersfield, CA 93311</td>
</tr>
<tr>
<td>Telephone</td>
<td>(661) 978-8719</td>
</tr>
<tr>
<td>Email</td>
<td><a href="mailto:TCWatson@aeraenergy.com">TCWatson@aeraenergy.com</a></td>
</tr>
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Reference 2:

<table>
<thead>
<tr>
<th>Name</th>
<th>Dan Van Beveren</th>
</tr>
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<tbody>
<tr>
<td>Position or Title</td>
<td>Senior Civil Engineer</td>
</tr>
<tr>
<td>Firm or Agency</td>
<td>City of San Luis Obispo Public Works</td>
</tr>
<tr>
<td>Street Address</td>
<td>919 Palm Street</td>
</tr>
<tr>
<td>City, State &amp; Zip</td>
<td>San Luis Obispo, CA 93401</td>
</tr>
<tr>
<td>Telephone</td>
<td>(805) 783-7715</td>
</tr>
<tr>
<td>Email</td>
<td><a href="mailto:dvanbeveren@slocity.org">dvanbeveren@slocity.org</a></td>
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Reference 3:

<table>
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<tr>
<th>Name</th>
<th>Clint Boschen</th>
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<tbody>
<tr>
<td>Position or Title</td>
<td>Environmental Scientist Water Resources</td>
</tr>
<tr>
<td>Firm or Agency</td>
<td>Tetra Tech</td>
</tr>
<tr>
<td>Street Address</td>
<td>9555 Balboa Ave., Suite 215</td>
</tr>
<tr>
<td>City, State &amp; Zip</td>
<td>San Diego, CA 92123</td>
</tr>
<tr>
<td>Telephone</td>
<td>(858) 268-5746</td>
</tr>
<tr>
<td>Email</td>
<td><a href="mailto:Clint.Boschen@tetratech.com">Clint.Boschen@tetratech.com</a></td>
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## Appendix D – House of Quality

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<td>0</td>
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### Quality Characteristics

- **Rational:** Easy to build, easy to maintain.
- **Economical:** Low cost, low maintenance.
- **Environment:** Low impact on the environment.
- **Reliability:** High reliability, low failure rate.
- **Aesthetics:** Good design, pleasing appearance.
- **Life Cycle:** Long lifespan, low replacement cost.
- **Functionality:** Meets user requirements, performs as intended.

### Competitive Analysis

- **Competitor A:** Strong in reliability, low in cost.
- **Competitor B:** Strong in aesthetics, weak in reliability.
- **Competitor C:** Strong in life cycle, weak in cost.

### Recommendation

- **Recommendation:** Develop a system that balances reliability and cost, with a focus on ease of maintenance and environmental impact.

---

*Full Cycle Engineering*
Appendix E – World Health Organization Guidelines

- The surface soil should not be contaminated
- There should be no contamination of ground water that may enter springs or wells.
- There should be no contamination of surface water.
- Excreta should not be accessible to flies or animals.
- There should be no handling of fresh excreta; or when this is indispensable, it should be kept to a strict minimum.
- There should be freedom from odors or unsightly conditions.
Appendix F – Composting Calculations

Composting Calculation Parameters

<table>
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<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
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<tbody>
<tr>
<td>Mass of feces</td>
<td>Q_f</td>
<td>105</td>
<td>g/ppd</td>
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<tr>
<td>Mass of yard waste</td>
<td>Q_yw</td>
<td>20</td>
<td>g/ppd</td>
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<tr>
<td>% C in urine</td>
<td>C_u</td>
<td>0.55</td>
<td>%</td>
</tr>
<tr>
<td>% C in feces</td>
<td>C_f</td>
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<td>%</td>
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<td>% C in yardwaste</td>
<td>C_yw</td>
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<td>%</td>
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<tr>
<td>% N in urine</td>
<td>N_u</td>
<td>0.92</td>
<td>%</td>
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<tr>
<td>% N in feces</td>
<td>N_f</td>
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<td>%</td>
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<td>% N in yardwaste</td>
<td>N_yw</td>
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<tr>
<td>Moisture content urine</td>
<td>M_u</td>
<td>95</td>
<td>%</td>
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<tr>
<td>Moisture content yard waste</td>
<td>M_f</td>
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<td>%</td>
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<td>Moisture content feces</td>
<td>M_yw</td>
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<td>%</td>
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<td>Mass of Soil/Ash</td>
<td>Q_s</td>
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<td>g/ppd</td>
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<tr>
<td>Soil/Ash Moisture Content</td>
<td>M_s</td>
<td>5</td>
<td>%</td>
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C/N Ratio and Moisture Content for various percents urine diversion

<table>
<thead>
<tr>
<th>% Urine Diversion</th>
<th>Q_u (g/ppd)</th>
<th>C/N Ratio</th>
<th>Moisture Content</th>
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<tbody>
<tr>
<td>0%</td>
<td>1000</td>
<td>15.0</td>
<td>69%</td>
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<tr>
<td>10%</td>
<td>900</td>
<td>15.9</td>
<td>66%</td>
</tr>
<tr>
<td>20%</td>
<td>800</td>
<td>17.0</td>
<td>63%</td>
</tr>
<tr>
<td>30%</td>
<td>700</td>
<td>18.1</td>
<td>59%</td>
</tr>
<tr>
<td>40%</td>
<td>600</td>
<td>19.5</td>
<td>54%</td>
</tr>
<tr>
<td>50%</td>
<td>500</td>
<td>21.0</td>
<td>47%</td>
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<td>60%</td>
<td>400</td>
<td>22.9</td>
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<td>70%</td>
<td>300</td>
<td>25.1</td>
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<td>80%</td>
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<tr>
<td>90%</td>
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<tr>
<td>100%</td>
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<td>35.6</td>
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6 month production for 100 person village

<table>
<thead>
<tr>
<th>Substance</th>
<th>kg/6 months</th>
<th>m³/6 months</th>
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<tbody>
<tr>
<td>Urine</td>
<td>9125</td>
<td>9.125</td>
</tr>
<tr>
<td>Feces</td>
<td>1916</td>
<td>1.92</td>
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<tr>
<td>Yard waste</td>
<td>365</td>
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<td>Soil/Ash</td>
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<tr>
<td>Total</td>
<td>15969</td>
<td>16.0</td>
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</tbody>
</table>
Appendix G – Pit Group Composting Cycle

Notes:
- One block on the Horizontal Axis represents one month.
- One block on the Vertical Axis represents 1 group of 8 pits (Pit groups A, B, C, D).
- One Cycle serves a 100-person community for 16 months worth of incoming waste.
- Composting Process takes 1 year.
- The design parameter for the system is 1 year's worth of waste for 100 people.

- 4 Pit Groups for 32 Total Pits in the System.
- When Pit Group A fills up, A is closed for composting, and B is opened.
- When Pit Group B fills up, A is 1/3 composted, B is closed for composting, and C is opened.
- When Pit Group D fills up, A is finished composting and cleaned out, B is 2/3 composted, C is 1/3 composted, and D is closed for composting.

Special Note:
- Pits should always be filled to max capacity before being closed for composting.
- If pits fill SLOWER than 4 months, when a pit group completes one year composting time, they are to be cleaned out and left empty and closed until needed.
# Appendix H – Concrete Mix Design: Bucket Method

## Method to Convert a Simple Concrete Mix Design (W/C Ratio Only, No Admixtures) for Batching in the Field Using a Measuring Bucket Only.

### 1. Desired Mix Design Parameters

<table>
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<th>Component</th>
<th>English Data Entry in Yellow Cells</th>
<th>Optional Metric Data in Orange, with</th>
<th>Conversions in Lt. Blue</th>
<th>Specific</th>
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<td>Cement Type:</td>
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</tr>
<tr>
<td>Wt. per Sack, lbs</td>
<td></td>
<td>94</td>
<td>94</td>
<td>--</td>
</tr>
<tr>
<td>Wt. per Sack, kg</td>
<td>Cement Wt. Conv. to lbs.</td>
<td>0</td>
<td>0</td>
<td>3.15</td>
</tr>
<tr>
<td>Cement Content, sacks per cubic yard</td>
<td>*Re-enter converted cement</td>
<td>10</td>
<td>10</td>
<td>--</td>
</tr>
<tr>
<td>Design Water Content, gallons per cubic yard</td>
<td>weight from kg. to lbs. above right</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Design Water/Cement Ratio, gallons per sack</td>
<td>5.78</td>
<td>1</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>Design Water/Cement Ratio, lb./lb.</td>
<td>0.51</td>
<td>0</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>Fine Aggregate, Washed Sand, Percent of Total Agg. Volume</td>
<td>45.0</td>
<td>2.84</td>
<td>2.84</td>
<td>0</td>
</tr>
<tr>
<td>Coarse Aggregate, 9/8&quot; to No. 4&quot; maximum size, Percent of Total Agg. Volume</td>
<td>55.0</td>
<td>2.55</td>
<td>2.55</td>
<td>0</td>
</tr>
<tr>
<td>Coarse Aggregate, 1&quot; to 1.5&quot;* maximum size, Percent of Total Agg. Volume</td>
<td>0.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Air Content, 1.5% non-entrained</td>
<td>1.5</td>
<td>--</td>
<td>--</td>
<td>0</td>
</tr>
</tbody>
</table>

### 2. Mix Design for Any Quantity of Concrete, Using a Measuring Bucket Only

<table>
<thead>
<tr>
<th>Material</th>
<th>Proportion</th>
<th>Specific Units</th>
<th>Absolute Volume, cu. ft.</th>
<th>% of Total Volume</th>
<th>Weight, lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Agg., Sand</td>
<td>45.0</td>
<td>%</td>
<td>2.64</td>
<td>9.44</td>
<td>34.9</td>
</tr>
<tr>
<td>Coarse Agg., 9/8&quot; to No. 4&quot;</td>
<td>55.0</td>
<td>%</td>
<td>2.55</td>
<td>11.53</td>
<td>42.7</td>
</tr>
<tr>
<td>Coarse Agg., 1&quot; to 1.5&quot;*</td>
<td>0.0</td>
<td>%</td>
<td>2.57</td>
<td>0.00</td>
<td>0.0</td>
</tr>
<tr>
<td>Water</td>
<td>26.0</td>
<td>gal.</td>
<td>1</td>
<td>3.48</td>
<td>12.9</td>
</tr>
<tr>
<td>Cement</td>
<td>4.50</td>
<td>sacks</td>
<td>3.15</td>
<td>2.15</td>
<td>8.0</td>
</tr>
<tr>
<td>Entrapped Air</td>
<td>1.5</td>
<td>%</td>
<td>--</td>
<td>0.41</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**TOTALS**: 27.00 100.00 4,029

Plastic Unit Wt. pcf: 149.2

Absolute Volume of Aggregate, cu. ft.: 20.97

---

## 2. Mix Design for Any Quantity of Concrete, Using a Measuring Bucket Only

### Step 1: Enter dimensions of measuring bucket

<table>
<thead>
<tr>
<th>Data Entry</th>
<th>Conversions</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Diameter, in.</td>
<td>11.00</td>
<td>5.50</td>
</tr>
<tr>
<td>Bottom Diameter, in.</td>
<td>10.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Height, in.</td>
<td>14.50</td>
<td></td>
</tr>
<tr>
<td>Top Diameter, mm.</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Bottom Diameter, mm.</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Height, mm.</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

### Step 3: Mark measurement lines from bottom of bucket, for approximate % of total volume

<table>
<thead>
<tr>
<th>%</th>
<th>inches</th>
<th>mm</th>
<th>%</th>
<th>inches</th>
<th>mm</th>
<th>%</th>
<th>inches</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>0.75</td>
<td>18</td>
<td>40%</td>
<td>5.80</td>
<td>147</td>
<td>75%</td>
<td>10.88</td>
<td>276</td>
</tr>
<tr>
<td>10%</td>
<td>1.55</td>
<td>40</td>
<td>45%</td>
<td>6.53</td>
<td>184</td>
<td>80%</td>
<td>11.60</td>
<td>295</td>
</tr>
<tr>
<td>15%</td>
<td>2.18</td>
<td>55</td>
<td>50%</td>
<td>7.25</td>
<td>215</td>
<td>85%</td>
<td>13.33</td>
<td>313</td>
</tr>
<tr>
<td>20%</td>
<td>2.90</td>
<td>74</td>
<td>55%</td>
<td>7.98</td>
<td>203</td>
<td>90%</td>
<td>13.05</td>
<td>331</td>
</tr>
<tr>
<td>25%</td>
<td>3.63</td>
<td>92</td>
<td>60%</td>
<td>8.70</td>
<td>221</td>
<td>95%</td>
<td>13.78</td>
<td>350</td>
</tr>
<tr>
<td>30%</td>
<td>4.35</td>
<td>110</td>
<td>65%</td>
<td>9.43</td>
<td>239</td>
<td>100%</td>
<td>14.50</td>
<td>368</td>
</tr>
<tr>
<td>35%</td>
<td>5.08</td>
<td>129</td>
<td>70%</td>
<td>10.15</td>
<td>258</td>
<td>100%</td>
<td>14.50</td>
<td>368</td>
</tr>
</tbody>
</table>

### Step 3: Design for how many sacks** of cement per batch?

**0.55**

<table>
<thead>
<tr>
<th>Material</th>
<th>Proportion</th>
<th>Specific Units</th>
<th>Absolute Volume, cu. ft.</th>
<th>Number of Buckets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Agg., Sand</td>
<td>45.0</td>
<td>%</td>
<td>2.64</td>
<td>1.153</td>
</tr>
<tr>
<td>Coarse Agg., 9/8&quot; to No. 4&quot;</td>
<td>55.0</td>
<td>%</td>
<td>2.55</td>
<td>1.410</td>
</tr>
<tr>
<td>Coarse Agg., 1&quot; to 1.5&quot;*</td>
<td>0.0</td>
<td>%</td>
<td>2.57</td>
<td>0.000</td>
</tr>
<tr>
<td>Water</td>
<td>26.0</td>
<td>gal.</td>
<td>1</td>
<td>0.425</td>
</tr>
<tr>
<td>Cement</td>
<td>4.5</td>
<td>sacks</td>
<td>3.15</td>
<td>0.263</td>
</tr>
<tr>
<td>Entrapped Air</td>
<td>1.5</td>
<td>%</td>
<td>--</td>
<td>0.050</td>
</tr>
</tbody>
</table>

**TOTALS**: 3,300

---

**--**: English Standard or SI unit weight of sacks of cement will not matter, as long as proper weight conversion is entered in Step 1**.

Spreadsheet Developed 10/16/12 by Fred J. Potthast, PE, GE (Calif.) - v. 1.4
Appendix I – Reinforced Concrete Calculations

The following hand calculations explain the analysis method used to analyze the concrete pit lid.

Given/Assumptions
- Assume $f'c = 1500$ psi
- Assume live load from one 250 lb person + 2 for this ½ of the lid
- Assume Green TRB dead loads will carry to purple span
- Assume the purple span (spans whole length) acts as a simply supported beam at its ends
- Assume 150 pcf concrete
- Choose thickness, $h = 3''$, per ACI minimum, one-way slab, simply supported, thickness = $l/80$ (Table 9.5.1(a))
- $49.2''/80 = 0.615''$; choose 3'' thickness
- Assume yield strength of steel, $f_y = 440$ ksi

Determining Loads

Live Load & Acting in center, ½ of 250 lb person = 125 lb.

Dead Loads:
- Distributed: $W_{d} = \frac{[2 \times (3/8) 	imes (6/12)]}{150 \text{ pcf}} = 37.5 \text{ lb/ft}$
- $W_{d} = \frac{[2 \times (3/8) \times (6/12)]}{150 \text{ pcf}} = 37.5 \text{ lb/ft}$, vertically

For purple span:
- TRB dead loads (A) & (B)
- Self wt. of span
- Live point load ~ person using latrine
Resulting Loading Schematic

\[ W_{SW} = \left( \frac{3}{12} \times \frac{7}{6.5} \right) 150 \text{pcf} = 23.7 \approx 24 \text{ lb/ft} \]

\[ 13 \text{ lb/ft} = W_{DL} \text{ (A)} \]

\[ 19 \text{ lb/ft} = W_{DL} \text{ (A)} \]

\[ 24 \text{ lb/ft} = W_{SW} \]

\[ w_{fl} (A) = 19 \text{ lb/ft} \]

\[ 125 \text{ lb} \]

\[ 13 \text{ lb/ft} = W_{DL} \text{ (A)} \]

\[ 19 \text{ lb/ft} = W_{DL} \text{ (A)} \]

Reaction Forces (symmetrical):

\[ F_y = \frac{19}{2} (13.6 \times \frac{2}{12}) + \frac{(13 + 24 \text{ lb/ft}) (14.2 \times \frac{2}{12})}{2} + \frac{125}{2} \]

\[ = 43.0 \text{ lb} + \frac{151.7}{2} + \frac{125}{2} \]

\[ = 319.77 \Rightarrow 319.77 / 2 = 159.88 \approx 160 \]

\[ R_A = R_B = 160 \text{ lb} \]

Shear Diagram

\[ R_A = +160 \]

\[ 56 \times 13.6 \times \frac{2}{12} = 63.5 \text{ lb} \] down 63.5 over 13.6

\[ 37 \times 11/12 = 34 \text{ lb} \] down 34 over next 11"

Point Load, down 125 lb

\[ 37 \times 11/12 = 34 \text{ lb} \] down 34 over next 11"

\[ 76 \times 13.6 \times \frac{2}{12} = 63.5 \text{ lb} \] down 63.5 over next 13.6"

\[ R_B = +160 \]

\[ M_{ax} = 115.35 \]

\[ (160 + 76.5) \times 13.6 \times \frac{2}{12} = 115.35 \text{ lb-ft} \]

\[ (76.5 + 62.5) \times 11/12 = 72.875 \text{ lb-ft} \] (Add to previous)

\[ 2 \text{ lbs} \]

\[ 8 \text{ lbs} \]

\[ 15 \text{ lbs} \]

\[ 30 \text{ lbs} \]

\[ 45 \text{ lbs} \]

\[ 60 \text{ lbs} \]

\[ 75 \text{ lbs} \]

\[ 90 \text{ lbs} \]

\[ 105 \text{ lbs} \]

\[ 120 \text{ lbs} \]

\[ 135 \text{ lbs} \]

\[ 150 \text{ lbs} \]

\[ 165 \text{ lbs} \]

\[ 180 \text{ lbs} \]

\[ 195 \text{ lbs} \]

\[ 210 \text{ lbs} \]

\[ 225 \text{ lbs} \]

\[ 240 \text{ lbs} \]

\[ 255 \text{ lbs} \]

\[ 270 \text{ lbs} \]

\[ 285 \text{ lbs} \]

\[ 300 \text{ lbs} \]

\[ 315 \text{ lbs} \]

\[ 330 \text{ lbs} \]

\[ 345 \text{ lbs} \]

\[ 360 \text{ lbs} \]

\[ 375 \text{ lbs} \]

\[ 390 \text{ lbs} \]

\[ 405 \text{ lbs} \]

\[ 420 \text{ lbs} \]

\[ 435 \text{ lbs} \]

\[ 450 \text{ lbs} \]

\[ 465 \text{ lbs} \]

\[ 480 \text{ lbs} \]

\[ 495 \text{ lbs} \]

\[ 510 \text{ lbs} \]

\[ 525 \text{ lbs} \]

\[ 540 \text{ lbs} \]

\[ 555 \text{ lbs} \]

\[ 570 \text{ lbs} \]

\[ 585 \text{ lbs} \]

\[ 600 \text{ lbs} \]

\[ 615 \text{ lbs} \]

\[ 630 \text{ lbs} \]

\[ 645 \text{ lbs} \]

\[ 660 \text{ lbs} \]

\[ 675 \text{ lbs} \]

\[ 690 \text{ lbs} \]

\[ 705 \text{ lbs} \]

\[ 720 \text{ lbs} \]

\[ 735 \text{ lbs} \]

\[ 750 \text{ lbs} \]

\[ 765 \text{ lbs} \]

\[ 780 \text{ lbs} \]

\[ 795 \text{ lbs} \]

\[ 810 \text{ lbs} \]

\[ 825 \text{ lbs} \]

\[ 840 \text{ lbs} \]

\[ 855 \text{ lbs} \]

\[ 870 \text{ lbs} \]

\[ 885 \text{ lbs} \]

\[ 900 \text{ lbs} \]

\[ 915 \text{ lbs} \]

\[ 930 \text{ lbs} \]

\[ 945 \text{ lbs} \]

\[ 960 \text{ lbs} \]

\[ 975 \text{ lbs} \]

\[ 990 \text{ lbs} \]

\[ 1005 \text{ lbs} \]

\[ 1020 \text{ lbs} \]

\[ 1035 \text{ lbs} \]

\[ 1050 \text{ lbs} \]

\[ 1065 \text{ lbs} \]

\[ 1080 \text{ lbs} \]

\[ 1095 \text{ lbs} \]

\[ 1110 \text{ lbs} \]

\[ 1125 \text{ lbs} \]

\[ 1140 \text{ lbs} \]

\[ 1155 \text{ lbs} \]

\[ 1170 \text{ lbs} \]

\[ 1185 \text{ lbs} \]

\[ 1200 \text{ lbs} \]

\[ 1215 \text{ lbs} \]

\[ 1230 \text{ lbs} \]

\[ 1245 \text{ lbs} \]

\[ 1260 \text{ lbs} \]

\[ 1275 \text{ lbs} \]

\[ 1290 \text{ lbs} \]

\[ 1305 \text{ lbs} \]

\[ 1320 \text{ lbs} \]

\[ 1335 \text{ lbs} \]

\[ 1350 \text{ lbs} \]

\[ 1365 \text{ lbs} \]

\[ 1380 \text{ lbs} \]

\[ 1395 \text{ lbs} \]

\[ 1410 \text{ lbs} \]

\[ 1425 \text{ lbs} \]

\[ 1440 \text{ lbs} \]

\[ 1455 \text{ lbs} \]

\[ 1470 \text{ lbs} \]

\[ 1485 \text{ lbs} \]

\[ 1500 \text{ lbs} \]

\[ 1515 \text{ lbs} \]

\[ 1530 \text{ lbs} \]

\[ 1545 \text{ lbs} \]

\[ 1560 \text{ lbs} \]

\[ 1575 \text{ lbs} \]

\[ 1590 \text{ lbs} \]

\[ 1605 \text{ lbs} \]

\[ 1620 \text{ lbs} \]

\[ 1635 \text{ lbs} \]

\[ 1650 \text{ lbs} \]

\[ 1665 \text{ lbs} \]

\[ 1680 \text{ lbs} \]

\[ 1700 \text{ lbs} \]
**MAX MOMENT FOR PURPLE SPAN**

From moment diagram, max moment occurs at center.

*Analyze Individual Loadings*

- Point load: 
  \[ P = 125 \]
  \[ M_{\text{max}} \text{ at center} = \frac{PL}{4} = \]
  \[ 125 \left( \frac{49.2}{12} \right) = \frac{128}{4} \text{ lb-ft} \]

- Distributed dead load & self wt:
  \[ M_{\text{max}} \text{ at center} = \frac{WL^2}{8} \]
  \[ = \frac{37}{10} \text{ ft} \left( 49.2 \frac{3}{12} \right)^2 = 74.7 \approx 75 \text{ lb-ft} \]

- Small dead load \( W_{DL} \) → Find Rxns
  \[ R_A = R_B = 21.53 \text{ (symmetry)} \]

- Shear
  \[ 21.53 \]
  \[ 13.1 \frac{3}{8} = 16.8 \]

- Moment
  \[ 12.2 \]

**MAX MOMENT FOR PURPLE SPAN**

Max Moment due to live load, \( M_L = 128 \text{ lb-ft} \)

Max moment due to dead load, \( M_D = \text{sum moments due to dead loads.} \rightarrow M_D = 78 \text{ lb-ft} + 16.2 \text{ lb-ft} = 94.2 \text{ lb-ft} \)

\[ M_0 = 90.2 \text{ lb-ft} \]

**FACTORED DEMAND, \( M_u \)**

\[ M_u = 1.2 M_D + 1.6 M_L \]

\[ = 1.2 (94.2) + 1.6 (128) \]

\[ M_u = 313 \text{ lb-ft} \]
Determine minimum area of steel required: \( A_{\text{min}} \) for the blue span. (Larger cross sec. will need more steel than the purple section)

\[
A_{\text{min}} = 3 \sqrt{f_y' b d}
\]

- \( b \): width of section
- \( d \): dist. to centroid of #3 rebar (centrally placed rebar)
- \( h \): height of thickness of section

\[
\frac{f_y'}{f' c} = \frac{30000}{1500} = 20
\]

\[
A_{\text{min}} = 0.096 \text{ in}^2
\]

Steel reinforcement to consider:

- #3 rebar: \( A_b = 0.11 \text{ in}^2 \)
- \( d_b = 0.375 \text{ in} \)

Welded wire reinforcement mesh with:

- \( 6\frac{1}{4} \) in. spacing
- \( d_b = \frac{1}{8} \text{ in} \)
- \( A_b = \pi d_b^2 = 0.012 \text{ in}^2 \)

Reinforced cross sec.: 

\[
M_n = A_s f_y (d - a/2) = 0.146 (40)(1.5 - 0.625/2) = 7.90 \text{ kip in}
\]

\[
7.90 \text{ kip in} \times \frac{1000 \text{ lb}}{1 \text{ kip}} \times \frac{1 \text{ ft}}{12 \text{ in}} = 658 \text{ lb ft}
\]
MAX MOMENT FOR BLUE SPAN

Determining Loads

- Live Loads = same as purple span = $P_L = 125 \text{ lb}$
- $W_{sl} = 19 \text{ lb/ft per side}$
- $W_{sw} = \text{self wt. distributed load}$

$$W_{sw} = (3'' \times 15.65''/2) \times 150 \text{ pcf} = 48.9 \approx 49 \text{ lb/ft}$$

Max Moments for both live and dead at center

- $M_L = \text{same as purple section}$
  $$M_L = 128 \text{ kip-ft}$$
- $M_D = \frac{W_{sl}^2}{8} \approx 143 \text{ kip-ft}$
  $$M_D = 143 \text{ kip-ft}$$

Factorized Demand Moment, $Mu = 1.2(M_D) + 1.6(M_L)$

$$Mu = 1.2(143) + 1.6(128)$$

$$Mu = 376 \text{ kip-ft}$$

Design Capacity, $Mn > Mu/\phi$

$$\phi \ Mn > Mu.$$ 

$$0.9(1250) > 376$$

$$592 > 376$$

- The larger demand from the blue span

- Capacity > Demand

Full Cycle Engineering
Check strain

If $\varepsilon_s > 0.005$, then steel yields, and member is tension controlled.

\[
f_c = 1500 \text{ psi} \quad \Rightarrow \beta = 0.85 \\
a = 0.293 \text{ in} \\
C = \frac{a}{\beta} = \frac{0.293}{0.85} = 0.345 \\
\varepsilon_s = \frac{0.005}{0.345}(1.5 - 0.345) = 0.100 > 0.005
\]

→ safe to assume $\phi = 0.9 \times (\phi \text{Mn} \geq \text{Mu})$

With one #3, and mesh, what is the max. $P_L$ that can be applied safely?

\[
\text{Mu} > 1.2(\text{Mb}) + 1.6(\text{ML}) \\
592 > 1.2(143) + 1.6\left(\frac{P_L(E)}{4}\right)
\]

\[
420.4 = 1.6\left(\frac{99.2}{12}\right)P_L_{\text{max}} \\
420.4 = 1.64P_L_{\text{max}} \\
P_L_{\text{max}} = 250 \text{ lb} \rightarrow \text{one side of lid}
\]

No more than 500 lbs on lid at a time, live load.
## Pit Group Observation Sheet for One Cycle

<table>
<thead>
<tr>
<th>8-Pit Group</th>
<th>Description of Event</th>
<th>Date Observed</th>
<th>Circle Approximate Fullness Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Opening</td>
<td></td>
<td>Empty</td>
</tr>
<tr>
<td></td>
<td>End Month 1</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 2</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 3</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 4</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>Closing</td>
<td></td>
<td>Full</td>
</tr>
<tr>
<td>B</td>
<td>Opening</td>
<td></td>
<td>Empty</td>
</tr>
<tr>
<td></td>
<td>End Month 1</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 2</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 3</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 4</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>Closing</td>
<td></td>
<td>Full</td>
</tr>
<tr>
<td>C</td>
<td>Opening</td>
<td></td>
<td>Empty</td>
</tr>
<tr>
<td></td>
<td>End Month 1</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 2</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 3</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 4</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>Closing</td>
<td></td>
<td>Full</td>
</tr>
<tr>
<td>D</td>
<td>Opening</td>
<td></td>
<td>Empty</td>
</tr>
<tr>
<td></td>
<td>End Month 1</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 2</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 3</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>End Month 4</td>
<td></td>
<td>Empty--------1/4--1/2--3/4--Full</td>
</tr>
<tr>
<td></td>
<td>Closing</td>
<td></td>
<td>Full</td>
</tr>
</tbody>
</table>

**Notes:**
- **Opening** = Date that the 8-pit group is open for use to start being filled
- **Closing** = Date that the 8-pit group is filled to capacity and closed off for composting
- **End Month 1** = date of observation made at the end of month 1
- Closing date for one group is the opening date for the subsequent pit group