THE DENSITY AND REBOUND OF SHREDDED MUNICIPAL SOLID WASTE

by

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STATEMENT OF THESIS APPROVAL

The following faculty members served as the supervisory committee chair and members for the thesis of Travis P. Christensen.
Dates at right indicate the members' approval of the thesis.

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ABSTRACT

The Salt Lake Valley Solid Waste Management Facility (SLVSWMF) in Salt Lake City, Utah, is considering changing how municipal solid waste (MSW) is managed. Specifically, the SLVSWMF is planning to shred all incoming MSW prior to landfilling. Landfilled solid waste at the SLVSWMF is mixed and typical of MSW in the United States, consisting of incompressible and compressible types of waste. Shredding MSW reduces void space and creates a more easily compacted mass.

To test the density and rebound of shredded and nonshredded MSW, a 1 yd^3 steel compactor was constructed, which has the ability to deliver a load of up to 11125 lb/ft^2. Compaction pressure was designed to simulate the in-situ compaction typically achieved at the landfill by use of a mobile compactor. MSW was loaded into the compactor until filled, and incremental loads were applied until11125 lb/ft^2 was reached and was measured using a pressure gauge. Shredded waste was generated using a waste shredder unit, which incorporates low speed, high-torque technology. The mass and volume of compacted waste were also recorded, which allowed for the determination of densities under applied pressure.

The initial average in-place density was 297 $lb/yd^3$for the nonshredded MSW and 592 lb/yd^3 for the shredded MSW. The final average in-place density was determined to be 626 lb/yd^3 for the nonshredded MSW and 1144 lb/yd^3 for the shredded MSW, both of which were calculated after the maximum load had been applied, released, and left to rebound for 24 hours. Rebound of the nonshredded and shredded MSW was similar between the two with an average of 3.1 inches for the nonshredded MSW and 3 inches, respectively, for the shredded MSW.

Overall this research indicates that compaction of shredded MSW creates a more structurally stable mass that is much denser than nonshredded MSW. The average final in-place density of shredded MSW is 65.1% greater than the average final in-place density of nonshredded MSW. The increase in final in-place density of shredded MSW translates directly into a volume savings of 39.4%. Should municipalities decide to shred solid waste, a significant amount of landfill volume will be conserved.

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INTRODUCTION

The amount of municipal solids waste generated annually in the United States as reported by the Environmental Protection Agency is approximately 250 million tons, at a per capita rate of 4.4 pounds/person/day. Each year, 54.2% of the generated waste is discarded, 34.1% is recycled or composted, and 11.7% is combusted for energy recovery (US EPA, 2013). The amount of waste that is landfilled has remained relatively steady since the 1980s when recycling and composting became more popular. Recycling and composting have been increasing since that time (US EPA, 2006). The push for recycling, composting, and combusting for energy recovery is paramount because many landfill facilities across the United States are simply running out of volume. To evaluate future landfill capacities, the municipality needs a general idea of the waste composition, water content of waste, waste density, and per capita generation as these properties vary from region to region. For instance, in states where a deposit is refunded on glass and/or plastic, fewer recyclables are landfilled.

The Salt Lake Valley Solid Waste Management Facility (SLVSWMF) is located west of Salt Lake City, Utah. The facility handles 436,000 U.S. tons of solid waste (2012 data) from Salt Lake County and surrounding areas, and sits on 550 acres of land. Landfilling is typical of operations across the US: MSW is collected from neighborhoods, apartment complexes, and businesses and transported to the Salt Lake Valley Transfer Station. There, MSW is trucked to the landfill where is it dumped on the tipping face. A

60 ton compactor drives over the waste three times before moving onto the next section. The cell is covered nightly with soil.

The Salt Lake Valley is expected to run out of holding capacity by the year 2065. To postpone the closure of the SLVSWMF, the County has implemented curb-side recycling of plastic, paper, and glass, curb-side pick-up of yard waste followed by large-scale composting, and diversion of bulky items, such as refrigerators and carpet pad. In spite of these efforts, bulky and incompressible items continue to be a problem for the landfill operations. Tires, mattresses, wood pallets, office furniture, etc., still make their way to the landfill and take up space.

In order to preserve landfill volume, SLVSWMF staff has become more aggressive and pro-active in handling MSW. Tires are shipped to a recycling facility at a cost to the facility. A bill will be submitted to the Utah Legislature to encourage people to recycle mattresses. The bill would add a small tax to the sales of mattresses, off-setting the recycling program. The program would ship the ~150,000 mattresses processed each year by the SLVSWMF to a recycling facility. Lastly, the director of the SLVSWMF is considering shredding and compacting MSW to increase waste density prior to landfilling. Consequently, the objectives and research questions outlined below led to the inception of this study.

Objectives

1. Quantify the density and 24-hour rebound of nonshredded municipal shredded waste from the Salt Lake County Transfer Station.
2. Quantify the density and 24-hour rebound of shredded municipal shredded waste from the Salt Lake County Transfer Station.

3. Determine an average factor that describes the change in the density and 24-hour rebound of shredded MSW from nonshredded MSW.

Research Questions

1. To what extent does shredding MSW prior to compaction change the density and 24-hour rebound? (Primary Question)

    1a. How many additional years of operation would shredding all incoming waste into the SLVSWMF provide without having to construct additional landfill cells? (Secondary Question – Design Recommendation)

2. At an applied load of 60 tons, the weight of SLVSWMF compactor, how would the density and 24-hour rebound differ from nonshredded to shredded MSW? (Primary Question)

Hypotheses correlating to each numbered research question were developed.

Hypotheses

1. The density of compacted MSW has been shown to range from 501 to 1002 lb/yd^3, compared to 152 to 304 lb/yd^3 for nonshredded MSW (SWANA, 1994). Shredding prior to compacting is expected to increase the density further. An approximate density increase of 30% has been seen from nonshredded MSW to shredded MSW. Twenty four hour rebound results of shredded MSW have not been studied extensively but are hypothesized to have a decrease of 15% from nonshredded MSW.

1a. A 30% percent increase in density translates to a 30% reduction in volume from nonshredded MSW. The landfill is currently expected to reach full capacity by the year 2065, which is approximately 50 years in the future. Assuming that the population growth is the same for both the shredded and nonshredded MSW scenarios and that people continue to produce 4.4 pounds of waste per day, the shredded MSW would add an additional 27 years of use to the SLVSWMF.

2. An applied load of 60 tons which is equally distributed over 4 wheels would result in a load of 15 tons per wheel. Assuming that each wheel has a contact area 7.5 ft^2, then the resulting average applied pressure would be 4000 lb/ft^2. It is hypothesized that this average applied pressure will result in a 30% increase in density assuming a straight line increase in density as the load is applied.

REVIEW OF LITERATURE

In 2011 the United States generated 250 million tons of municipal solid waste which is down 3.2% from 2007. Each year, 54.2% of the generated waste is discarded, 34.1% is recycled or composted, and 11.7% is combusted for energy recovery. Of the 250 million tons of MSW produced annually, the individual components of the MSW, prior to recycling, are broken down to show each component's percentage by weight as seen in Figure 1 (US EPA, 2013).

Over the past several decades the number of operational MSW landfills has decreased while the size of landfill operations has increased considerably. Permitting and construction of new landfill facilities has become more difficult due to additional regulations, lack of suitable sites, upfront costs, and public opposition. Optimization of MSW compaction will extend the life of existing landfills and reduce the need for future landfill construction (Hanson *et al.*, 2010). The placement efficiency at landfills is governed by compaction which controls the short-term density of the MSW. Maximizing MSW placement efficiency reduces the landfill space requirements and has the ability to extend the life of a landfill facility (Ham *et al.*, 1978).

Typical MSW disposal procedures in the United States involve the dumping the loose MSW on the tipping face of a landfill and compacting the MSW in small lifts with a compactor. The compactor will typically pass over the MSW several times to achieve the desired compaction (Leonard *et al.*, 2000). The density of MSW, compacted using the method described above, in landfills has been shown to range from 501 to 1002 lb/yd^3, compared to 151 to 304 lb/yd^3 for nonshredded, non-compacted MSW (SWANA, 1994).

Shredded MSW testing performed in Madison, Wisconsin in 1978 indicated that shredded MSW on average had a density approximately 27% greater than of nonshredded MSW compacted under the same conditions. Leachate production from shredded MSW occurred at a faster rate than nonshredded waste and the shredded MSW did not require a daily cover because vermin were unable to survive on the shredded MSW. The findings also indicated that compacted, shredded MSW produced less odors and was less likely to have the wind blow litter away than the nonshredded MSW (NTIS, 1974). Additional research was performed on the Madison, Wisconsin landfill site and it was found that the volume per unit mass occupied by shredded MSW was as much as 50% below that of nonshredded waste (Chen, 1974).

Minimal research has been performed in the field of shredded MSW in regards to density and 24-hour rebound. There appeared to be a push of research in the 1970s but since then there has not been much activity related to the subject. The lack of current research in the field of shredded MSW density and rebound was one of the main drivers for this project. The following sections will describe the experimental methodology used to quantify the properties of shredded MSW and the results of the testing.

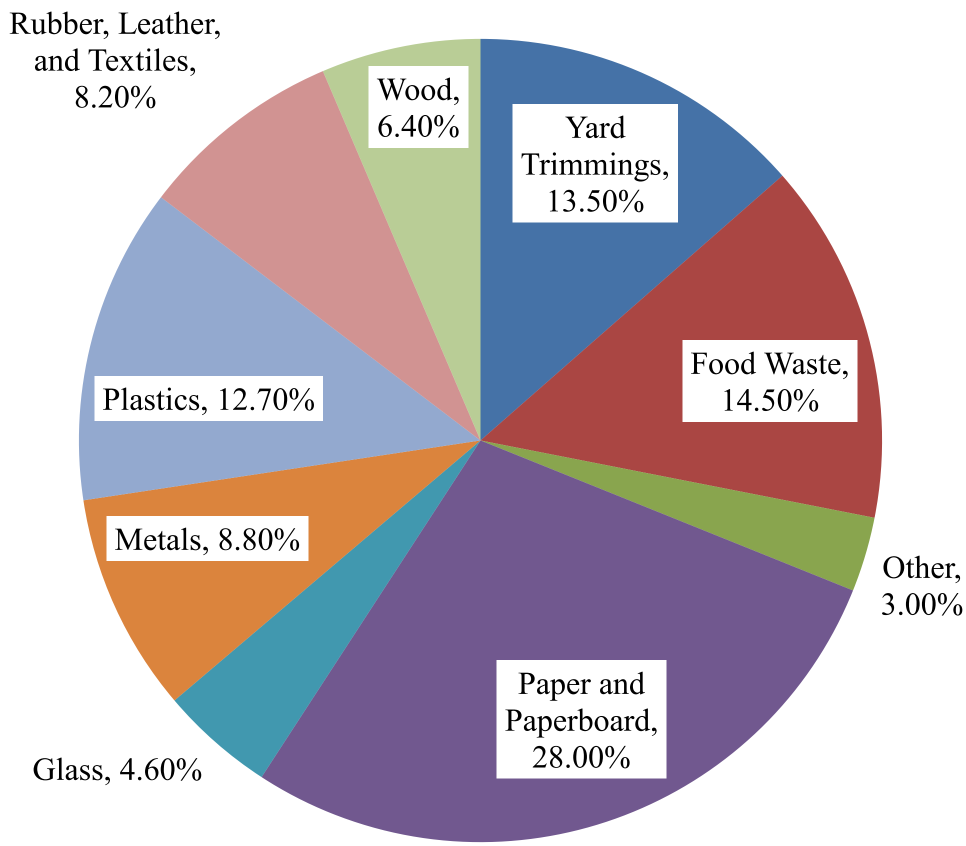

Figure 1. Composition of MSW by Weight Percentage of 250 Million Tons
(Source: Modified from http://epa.gov)

EXPERIMENTAL METHODOLOGY

Testing Apparatus

The testing apparatus consisted of a steel cylinder bolted to a steel plate, a steel lid, a hydraulic ram, and a load cell, as seen in Figure 2. The volume of the steel cylinder was approximately 1 yd^3 and the area of the steel lid was 9.2 ft^2. The hydraulic ram had a stroke of 18 inches and was capable of exerting up to 11125 lb/ft^2 of force. The load cell was manufactured by AMDET and measured the force exerted to whole number accuracy.

MSW Sampling

A fully loaded commercial front-end MSW collection truck dumped the collected load on the transfer station floor; the floor had previously been cleared of MSW from other sources. Bulky items that would not fit into the testing apparatus such as mattresses and large furniture were removed from the MSW pile. The MSW pile was then mixed with a front-end loader to increase the uniformity. A portion of the MSW pile was gathered by the bucket of the front-end loader and brought to the testing apparatus. The MSW was then shoveled by hand into the cylinder of the testing apparatus. The remaining MSW pile was covered using tarps to prevent moisture loss for shredding and testing the following day.

Shredding MSW

The remaining MSW pile was shredded using the Salt Lake County transfer station industrial shredder that shreds material to 4 inches or smaller. The shredder was run for 10 minutes prior to loading the MSW allowing residual material in the shredder to be removed. Once the MSW had been shredded it was mixed using the bucket of a front-end loader.

Test Procedure

Salt Lake County Transfer Station

Once the cylinder of the testing apparatus was full of MSW, the steel plate was placed on top of the MSW and displacement measurements from the top of the cylinder to the top of the steel plate were recorded from four marked locations. After 5 minutes had passed, the hydraulic ram applied a pressure of 436 lb/ft^2 to the top of the steel plate which was resting on the MSW. Displacement measurements were taken again from the top of the cylinder to the four marked locations immediately after the pressure was applied and 5 minutes later. This process of applying a pressure and recording the displacement and load cell reading was repeated for 873, 1309, 2400, 3490, 4581, 6762, 8944, and 11125 lb/ft^2 applied pressures. After the final pressure of 11125 lb/ft^2 was applied and the displacement had been recorded, the hydraulic ram was retracted and displacement measurements from the four marked locations were recorded and then recorded again 5 minutes later. The steel plate was then removed and a 0.125 inch thick wood plate was placed on top of the MSW in the cylinder of the testing apparatus and displacement measurements were taken. The purpose of the wood plate was to provide a level hard surface to measure MSW rebound after 24 hours. When compared to the weight of the steel plate the weight of the wood plate was assumed to be negligible.

After 24 hours of rebound, MSW from the test was shoveled in the bucket of a front-end loader and was weighed on a commercial vehicle scale. The waste was then removed from the bucket, and the front-end loader was reweighed. The steel cylinder was reattached to the steel base plate with the connecting bolts.

University of Utah

Testing was also performed at the University of Utah for test numbers 8, 9, and 10, which consisted of solely shredded MSW. The material followed the same selection method as described in the MSW Sampling section. Once the material had been shredded it was placed in large plastic bags which were tied off to prevent loss of moisture. The bags of shredded MSW were transported to the University of Utah and stored for a maximum of 3 days prior to testing.

The testing procedure was the same as the procedure described in Salt Lake County Transfer Station section with one exception. The individual bags of shredded MSW were weighed on a lab scale accurate to one decimal place prior to emptying the contents into the steel cylinder of the testing apparatus. The emptied bag was then weighed and subtracted from the initial weight to determine the weight of the shredded MSW sample.

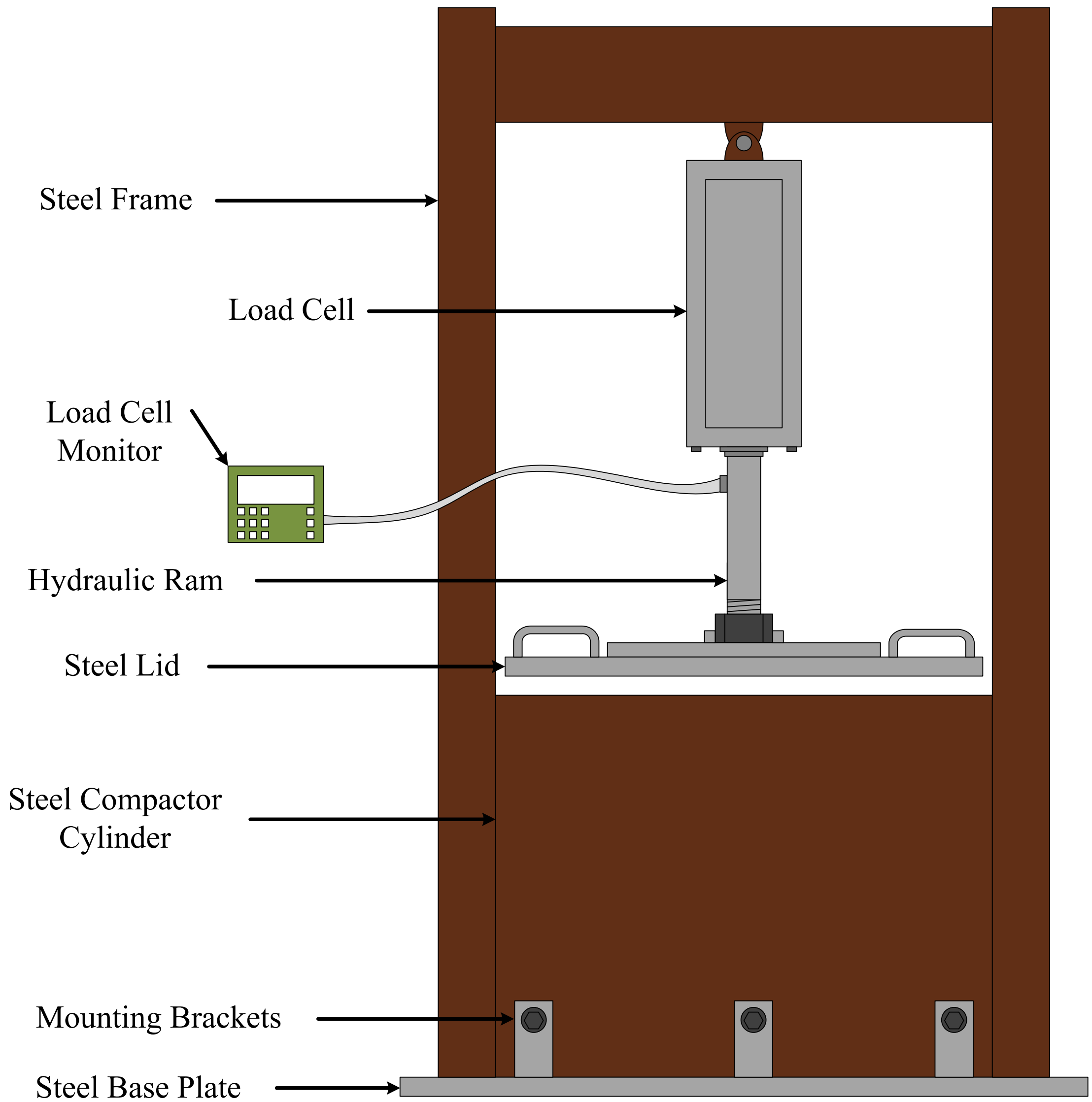

Figure 2. Testing Apparatus Schematic

ANALYSIS

The analysis of the data collected from the testing was stored and processed using Microsoft Excel. An Excel spreadsheet was set up to allow the user input the recorded parameters from each test which included load applied, steel lid displacement, sample weight, and any observations. The inputted data were processed using the equations 1 through 8.

The weight of the sample was calculated by taking the difference of an empty front-end loader and the weight of the same front-end loader with the MSW sample after testing had concluded. While the sample had been compacted the loss of moisture due to evaporation and leaking was assumed to be negligible. The mass of the sample was calculated as

$$M_{Sample} = M_{Sample+Front-End\ Loader} - M_{Empty\ Front-End\ Loader} \tag{1}$$

The steel cylinder has a known area of 9.2 ft^2 and a depth of 3 ft which create a volume of 1 yd^3, which was determined using Equation 2.

$$V = A * D \tag{2}$$

where D [L] is the vertical depth of the steel cylinder was calculated as

$$D = D_T - t_L - D_R \quad (3)$$

where D_T [L] is the total depth of the steel cylinder, t_L [L] is the thickness of the steel lid, and D_R [L] is the distance from the top of the steel cylinder to the steel lid and A [L^2] is the area horizontal area of the steel cylinder which is defined as

$$A = \pi r^2 \quad (4)$$

where π represents pi, which has a value of 3.14 and r [L] is the radius of the steel cylinder.

The density of the sample was calculated as

$$\rho = \frac{M}{V} \quad (5)$$

The applied pressure was calculated as

$$P = \frac{F}{A} \quad (6)$$

where F [M] is the force applied to the MSW and A [L^2] is the horizontal area of the steel lid which was calculated as

$$A = \pi r^2 \quad (7)$$

where π represents pi, which has a value of 3.14 and r [L] is the radius of the steel lid. The in-place density was calculated for the initial, maximum, and final state as well as incrementally after each time the pressure was increased or decreased on the test sample.

Once the density had been calculated the percent increase could be determined as:

$$\%\ difference = \frac{\rho_{non-shredded} - \rho_{shredded}}{\rho_{non-shredded}} \quad (8)$$

The Excel spreadsheet allowed for quick analysis of each of the ten test runs. It was able to quickly determine the in-place density of the test sample from the beginning to the end of the test. The spreadsheet was designed to create several graphics representing the change in density versus the applied pressure and displacement versus density, applied pressure, and applied load. Examples of these plots can be seen in Figures 3, 4, 5, and 6, respectively. These plots were created in both the imperial unit system and the metric system. Reported results will be presented exclusively in the imperial system.

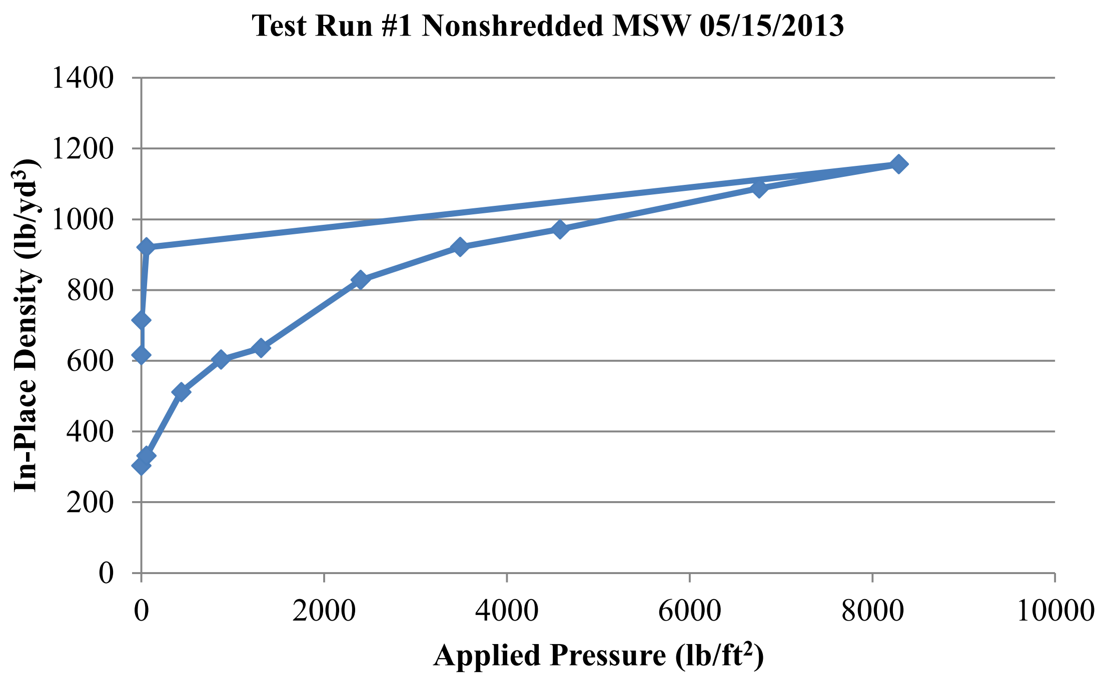

Figure 3. Sample Output - Density versus Applied Pressure

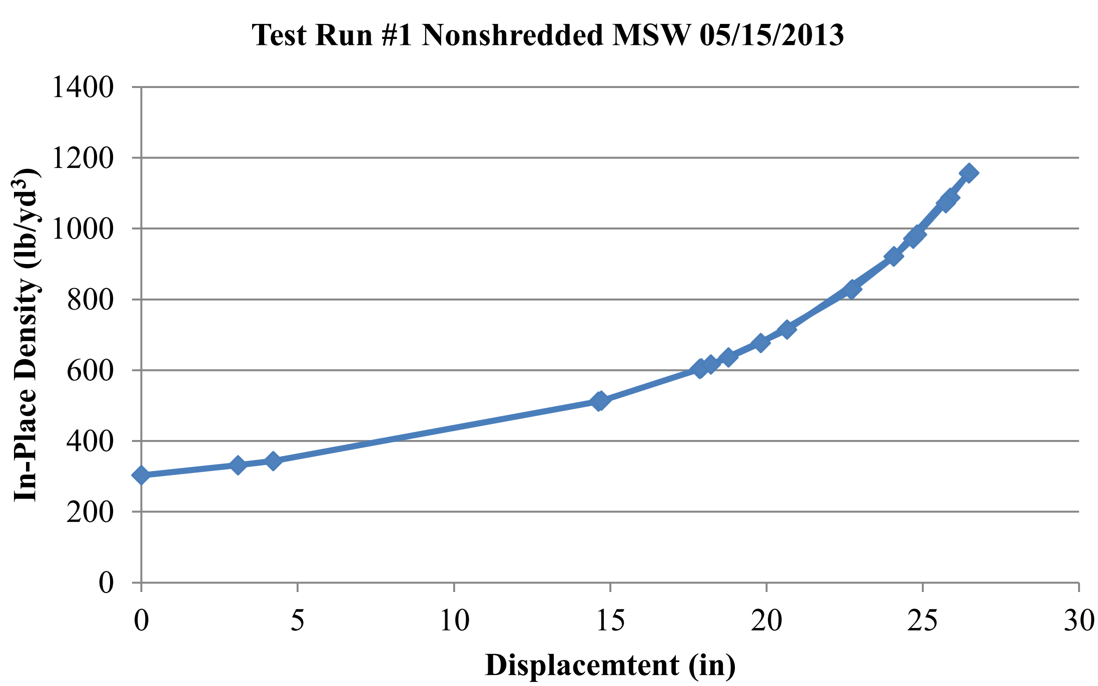

Figure 4. Sample Output - Density versus Displacement

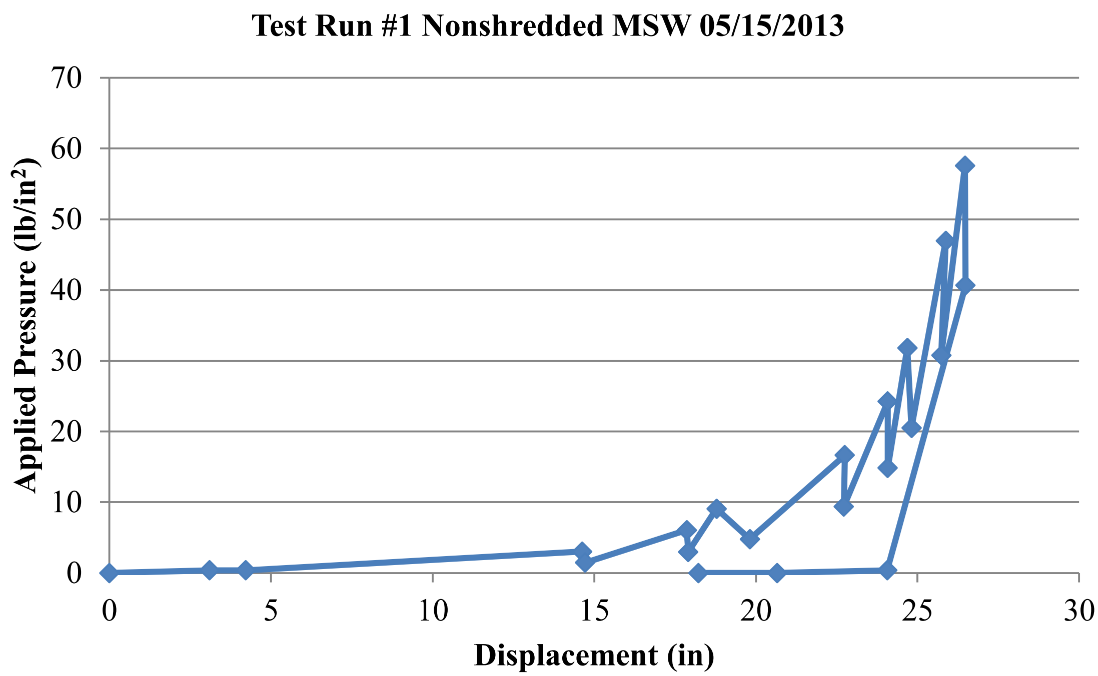

Figure 5. Sample Output - Applied Pressure versus Displacement

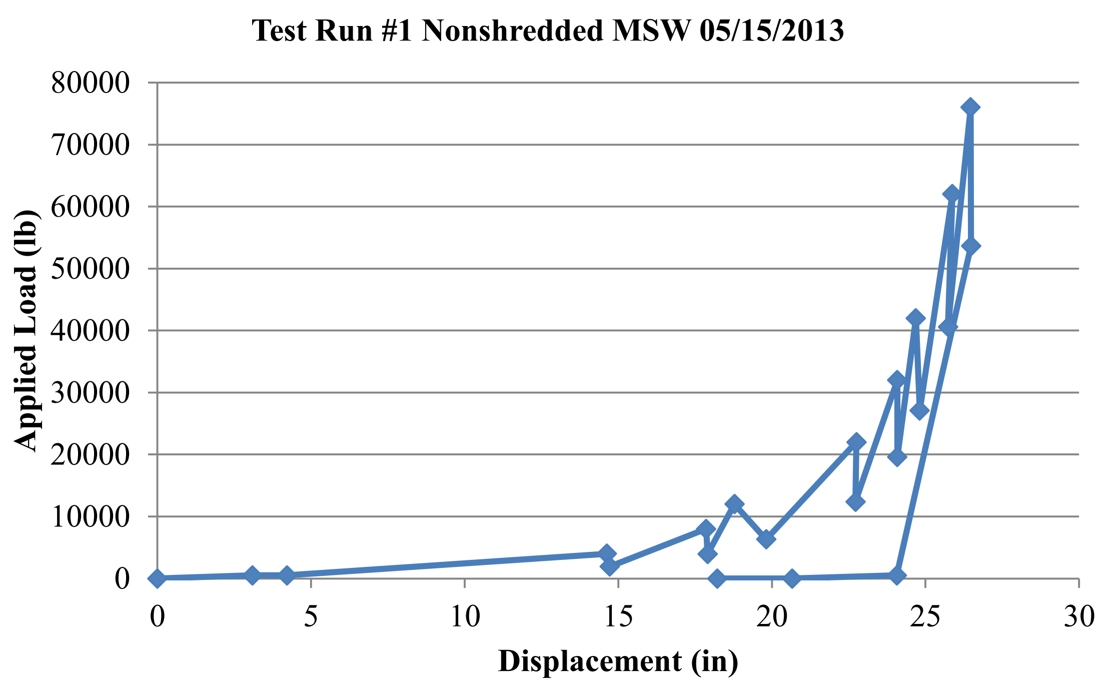

Figure 6. Sample Output - Applied Load versus Displacement

RESULTS

Nonshredded MSW

Three tests were performed at the Salt Lake County Transfer Station to determine the density and rebound of nonshredded MSW. For all three tests the target maximum applied pressure of 11125 lb/ft^2 was unable to be achieved due to the mounting bracket bolts of the testing apparatus which did not allow the steel lid to be compressed past them. Because of this, the greatest applied pressure during these three tests was 8289 lb/ft^2. All three tests were conducted in May 2013 and the results are plotted in Figure 7.

Test 1

The initial in-place density of the nonshredded MSW in the testing apparatus was 303 lb/yd^3. A maximum in-place density of 1156 lb/yd^3 was achieved by applying a final pressure of 8344 lb/ft^2. A final in-place density of 615 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 103% compared to the initial in-place density. The sample experienced a rebound of 2.4 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of 0.89 in^{-1} from 1156 lb/yd^3 to 920 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 114.8 in^{-1} and was recorded from 920 lb/yd^3 to 715 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 98 lb/yd^3 to the final in-place density of 615 lb/yd^3.

Test 3

The initial in-place density of the nonshredded MSW in the testing apparatus was 246 lb/yd^3. A maximum in-place density of 1080 lb/yd^3 was achieved by applying a final pressure of 6762 lb/ft^2. A final in-place density of 526 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 114% compared to the initial in-place density. The sample rebounded 3.3 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of 0.91 in^{-1} from 1080 lb/yd^3 to 880 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 125.2 in^{-1} and was recorded from 880 lb/yd^3 to 656 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 130 lb/yd^3 to the final in-place density of 526 lb/yd^3.

Test 5

The initial in-place density of the nonshredded MSW in the testing apparatus was 340 lb/yd^3. A maximum in-place density of 1377 lb/yd^3 was achieved by applying a final pressure of 6762 lb/ft^2. A final in-place density of 637 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 87% compared to the initial in-place density. The sample rebounded 3.6 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of 1.42 in^{-1} from 1377 lb/yd^3 to 1067 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 156.7 in^{-1} and was recorded from 1067 lb/yd^3 to 785 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 148 lb/yd^3 to the final in-place density of 637 lb/yd^3.

Average Nonshredded MSW

The average initial in-place density was calculated to be 297 lb/yd^3 and the final average in-place density was found to be 593 lb/yd^3 as shown in Table 1. The final average in-place density increased 100% from the initial in-place density. The average rebound of nonshredded MSW was 3.1 inches.

Shredded MSW

Seven tests were conducted to measure the rebound and compaction of shredded MSW. Three tests were performed in conjunction with the three nonshredded MSW tests performed in May 2013, one test was performed in July, and the three final tests were conducted in November. The target maximum applied pressure of 11124 lb/ft^2 was achieved for all but two of the tests due to the mounting bracket bolts of the testing apparatus which did not allow the steel lid to be compressed past them. The results for all seven tests are plotted in Figure 8.

Test 2

The initial in-place density of the shredded MSW in the testing apparatus was 379 lb/yd^3. A maximum in-place density of 1385 lb/yd^3 was achieved by applying a final pressure of 11124 lb/ft^2. A final in-place density of 758 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 100% compared to the initial in-place density. The sample rebounded 3.0 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of 0.76 in^{-1} from 1385 lb/yd^3 to 1116 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 112.8 in^{-1} and was recorded from 1116 lb/yd^3 to 914 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 155 lb/yd^3 to the final in-place density of 758 lb/yd^3.

Test 4

The initial in-place density of the shredded MSW in the testing apparatus was 416 lb/yd^3. A maximum in-place density of 1492 lb/yd^3 was achieved by applying a final pressure of 11124 lb/ft^2. A final in-place density of 782 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 87% compared to the initial in-place density. The sample rebounded 3.2 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of 0.89 in^{-1} from 1492 lb/yd^3 to 1175 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 131.8 in^{-1} and was recorded from 1175 lb/yd^3 to 939 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 157 lb/yd^3 to the final in-place density of 782 lb/yd^3.

Test 6

The initial in-place density of the shredded MSW in the testing apparatus was 738 lb/yd^3. A maximum in-place density of 1876 lb/yd^3 was achieved by applying a final pressure of 11124 lb/ft^2. A final in-place density of 1187 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 61% compared to the initial in-place density. The sample rebounded 3.6 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of 0.84 in^{-1} from 1876 lb/yd^3 to 1576 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 89.4 in^{-1} and was recorded from 1576 lb/yd^3 to 1416 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 228 lb/yd^3 to the final in-place density of 1187 lb/yd^3.

Test 7

The initial in-place density of the shredded MSW in the testing apparatus was 1060 lb/yd^3. A maximum in-place density of 3892 lb/yd^3 was achieved by applying a final pressure of 11124 lb/ft^2. A final in-place density of 2130 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 101% compared to the initial in-place density. The sample rebounded 4.2 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of 3.05 in^{-1} from 3892 lb/yd^3 to 2795 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 370.8 in^{-1} and was recorded from 2795 lb/yd^3 to 2130 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 0 lb/yd^3 to the final in-place density of 2130 lb/yd^3.

Test 8

The initial in-place density of the shredded MSW in the testing apparatus was 558 lb/yd^3. A maximum in-place density of 1836 lb/yd^3 was achieved by applying a final pressure of 8943 lb/ft^2. A final in-place density of 1053 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 89% compared to the initial in-place density. The sample rebounded 2.2 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of 1.14 in^{-1} from 1836 lb/yd^3 to 1509 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 114.3 in^{-1} and was recorded from 1509 lb/yd^3 to 1249 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 150 lb/yd^3 to the final in-place density of 1053 lb/yd^3.

Test 9

The initial in-place density of the shredded MSW in the testing apparatus was 585 lb/yd^3. A maximum in-place density of 1910 lb/yd^3 was achieved by applying a final pressure of 10306 lb/ft^2. A final in-place density of 1161 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 99% compared to the initial in-place density. The compacted sample from this test rebounded 2.0 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of .99 in^{-1} from 1910 lb/yd^3 to 1583 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 154.2 in^{-1} and was recorded from 1583 lb/yd^3 to 1306 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 145 lb/yd^3 to the final in-place density of 1161 lb/yd^3.

Test 10

The initial in-place density of the shredded MSW in the testing apparatus was 405 lb/yd^3. A maximum in-place density of 1535 lb/yd^3 was achieved by applying a final pressure of 11124 lb/ft^2. A final in-place density of 934 lb/yd^3 was recorded 24-hours after the maximum applied pressure had been removed. The final in-place density of the sample increased by 131% compared to the initial in-place density. The compacted sample from this test rebounded 2.8 inches over the 24-hour period when no load was being applied.

When the maximum applied pressure was removed the in-place density changed at a rate of .86 in^{-1} from 1535 lb/yd^3 to 1225 lb/yd^3. When the steel plate was removed from the compacted sample the in-place density changed at a rate of 47.0 in^{-1} and was recorded from 1225 lb/yd^3 to 1141 lb/yd^3. Over the 24-hour period when no load was applied to the compacted sample the in-place density decreased by 207 lb/yd^3 to the final in-place density of 934 lb/yd^3.

Average Shredded MSW

The average initial in-place density was calculated to be 592 lb/yd^3 and the final average in-place density was found to be 1144 lb/yd^3 as shown in Table 2. The final average in-place density increased 93.5% from the initial in-place density. The average rebound of shredded MSW was 3.0 inches.

Comparison of Compaction Test 1 and 2

MSW from the same source was used for the nonshredded MSW test 1 and for the shredded MSW test 2. The MSW was received at the Salt Lake County transfer station on May 15, 2013 from a commercial front-end loading garbage collection truck. Some of the MSW was used in the nonshredded MSW test 1 that day, while the remaining MSW was covered and shredded the following day for use in the shredded MSW test 2.

Shredded MSW test 2 began with a greater initial in-place density of 379 lb/yd^3 than compared to the initial in-place density of the nonshredded MSW test 1 of 303 lb/yd^3; an increase of 25% from shredding alone. The maximum in-place density was 19.8% greater in the shredded MSW test 2, but the nonshredded MSW test 1 had a maximum pressure of 8344 lb/ft^2 applied while test 2 had a maximum pressure of 11124 lb/ft^2 applied. The testing apparatus did not allow for further compaction of the nonshredded MSW. The in-place density of shredded MSW test 2 at an applied pressure of 8344 lb/ft^2, the maximum applied pressure from test 1, was interpolated to be 1288 lb/yd^3 while the nonshredded MSW had an in-place density of 1156 lb/yd^3; an increase of 11.4%. The final in-place density of the shredded MSW test 2 was 758 lb/yd^3 and 615 lb/yd^3 for the nonshredded MSW test 1; an increase of 23.3% as seen in Table 3.

Comparison of Compaction Test 3 and 4

MSW from the same source was used for the nonshredded MSW test 3 and for the shredded MSW test 4. The MSW was received at the Salt Lake County transfer station on May 21, 2013 from a commercial front-end loading garbage collection truck. Some of the MSW was used in the nonshredded MSW test 3 that day, while the remaining MSW was covered and shredded the following day for use in the shredded MSW test 4.

Shredding the MSW produced an initial in-place density of 416 lb/yd^3 for the shredded MSW test 4 and 246 lb/yd^3 for the nonshredded MSW test 3; an increase of 69.2% attributed to shredding. Once again, the nonshredded MSW was unable to achieve the maximum applied pressure of 11124 lb/ft^2, due to the steel lid contacting the mounting bolts. The maximum applied pressure of the nonshredded MSW test 3 was 6762 lb/ft^2 which resulted in an in-place density of 1080 lb/yd^3 and 1492 lb/yd^3 for the shredded MSW; an increase of 38.1%. The final in-place density saw an increase of 48.7% increase from the 526 lb/yd^3 recorded value from the nonshredded to the 782 lb/yd^3 value as seen in Table 4.

Comparison of Compaction Test 5 and 6

MSW from the same source was used for the nonshredded MSW test 5 and for the shredded MSW test 6. The MSW was received at the Salt Lake County transfer station on May 28, 2013 from a commercial front-end loading garbage collection truck. Some of the MSW was used in the nonshredded MSW test 5 that day, while the remaining MSW was covered and shredded the following day for use in the shredded MSW test 6. It should be noted that the MSW used in this testing appeared to be higher in moisture content than other tests.

Shredding the MSW produced an initial in-place density of 738 lb/yd^3 for the shredded MSW test 6 and 340 lb/yd^3 for the nonshredded MSW test 5; an increase of 116.8% attributed to shredding. Once again, the nonshredded MSW was unable to achieve the maximum applied pressure of 11124 lb/ft^2 due to the steel lid contacting the mounting bolts. The maximum applied pressure of the nonshredded MSW test 3 was 6762 lb/ft^2, which resulted in an in-place density of 1377 lb/yd^3 and 1876 lb/yd^3 for the shredded MSW; an increase of 36.2%. The final in-place density saw an increase of 86.2% increase from the 637 lb/yd^3 recorded value from the nonshredded to the 1187 lb/yd^3 for the shredded MSW, as seen in Table 5.

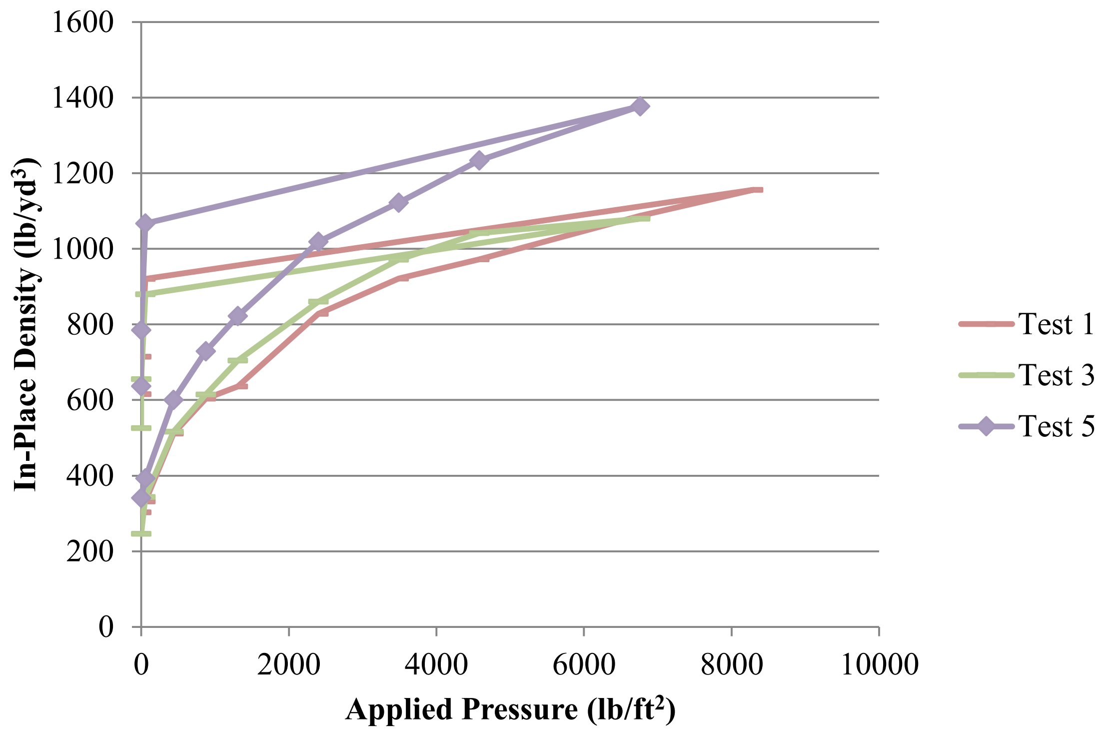

Figure 7. Performance of Nonshredded MSW

Table 1. Summary of Test Results from Nonshredded MSW

Nonshredded MSW Properties	Test 1	Test 3	Test 5	Average
Initial Density (lb/yd^3)	303	246	340	297
Maximum Applied Pressure (lb/ft^2)	8344	6762	6762	7289
Maximum Density (lb/yd^3)	1156	1080	1377	1205
Final Density (lb/yd^3)	615	526	637	593
Density Rate Change when Pressure was Removed (in^{-1})	0.89	0.91	1.42	1.07
Density Rate Change when Steel Plate was Removed (in^{-1})	114.8	125.2	156.7	132.3
Rebound (in)	2.4	3.3	3.6	3.1

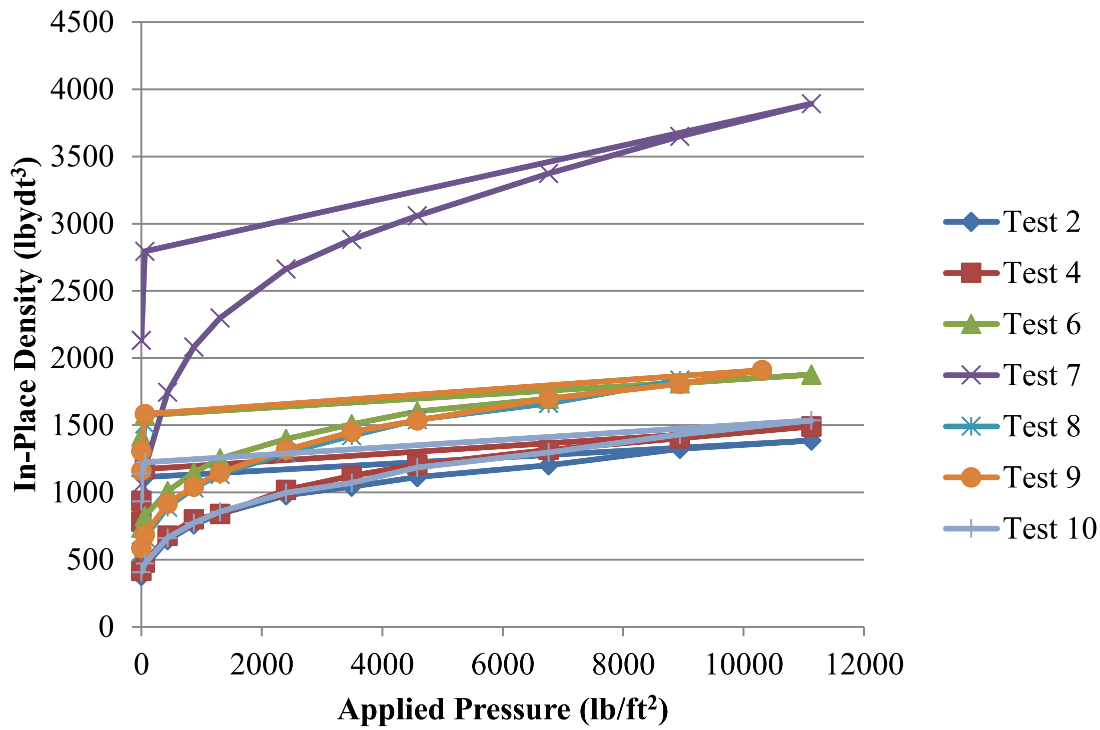

Figure 8. Performance of Shredded MSW

Table 2. Summary of Test Results from Shredded MSW

Shredded MSW Properties	Test 2	Test 4	Test 6	Test 7	Test 8	Test 9	Test 10
Initial Density (lb/yd^3)	379	416	738	1060	558	585	405
Maximum Applied Pressure (lb/ft^2)	11124	11124	11124	11124	8943	10306	11124
Maximum Density (lb/yd^3)	1385	1492	1876	3892	1836	1910	1535
Final Density (lb/yd^3)	758	782	1187	2130	1053	1161	934
Density Rate Change when Pressure was Removed (in^{-1})	0.76	0.89	0.84	3.05	1.14	0.99	0.86
Density Rate Change when Steel Plate was Removed (in^{-1})	112.8	131.8	89.4	370.8	114.3	154.2	47.0
Rebound (in)	3.0	3.2	3.6	4.2	2.2	2.0	2.8

Table 3. Comparison of Nonshredded MSW Test 1 and Shredded MSW Test 2

Mixed MSW Properties	Test 1	Test 2	Percent Change
Initial Density (lb/yd^3)	303	379	25.0%
Maximum Applied Pressure (lb/ft^2)	8344	11124	33.3%
Maximum Density (lb/yd^3)	1156	1385	19.8%
Final Density (lb/yd^3)	615	758	23.3%
Density Rate Change when Pressure was Removed (in^{-1})	0.89	0.76	-14.3%
Density Rate Change when Steel Plate was Removed (in^{-1})	114.8	112.8	-1.8%
Rebound (in)	2.4	3.0	24.2%

Table 4. Comparison of Nonshredded MSW Test 3 and Shredded MSW Test 4

Mixed MSW Properties	Test 3	Test 4	Percent Change
Initial Density (lb/yd^3)	246	416	69.2%
Maximum Applied Pressure (lb/ft^2)	6762	11124	64.5%
Maximum Density (lb/yd^3)	1080	1492	38.1%
Final Density (lb/yd^3)	526	782	48.7%
Density Rate Change when Pressure was Removed (in^{-1})	0.91	0.89	-2.8%
Density Rate Change when Steel Plate was Removed (in^{-1})	125.2	131.8	5.3%
Rebound (in)	3.3	3.2	-3.6%

Table 5. Comparison of Nonshredded MSW Test 5 and Shredded MSW Test 6

Mixed MSW Properties	Test 5	Test 6	Percent Change
Initial Density (lb/yd^3)	340	738	116.8%
Maximum Applied Pressure (lb/ft^2)	6762	11124	64.5%
Maximum Density (lb/yd^3)	1377	1876	36.2%
Final Density (lb/yd^3)	637	1187	86.2%
Density Rate Change when Pressure was Removed (in^{-1})	1.42	0.84	-41.1%
Density Rate Change when Steel Plate was Removed (in^{-1})	156.7	89.4	-42.9%
Rebound (in)	3.6	3.6	0%

DISCUSSION

Compaction

Nonshredded and shredded MSW showed similar properties under compaction despite the physical change to the shredded MSW. The results indicate the variability of incoming MSW to the Salt Lake County transfer station; in-place density was as low as 246 lb/yd^3 for nonshredded MSW and as high as 738 lb/yd^3 for shredded MSW with an outlier of 1060 lb/yd^3. Additionally, the results of both the nonshredded and shredded MSW show that uncompacted waste responds very well initially to compaction and undergoes large increases of density with relatively small increases in applied pressure. However, as the applied pressure increases the effect on the in-place density becomes less and at the maximum applied pressure of 11124 lb/ft^2 the change in density becomes almost negligible.

Another similarity between the nonshredded and shredded MSW was the rate at which density changed when the applied pressure was removed. The nonshredded MSW density decreased at an average rate of 1.07 in^{-1} and 1.22 in^{-1} for the shredded MSW. When shredded MSW test 7, which is an outlier and is discussed later in the section, is removed from the results, then the average rate of change for the shredded MSW is 0.91 in^{-1}. This rate is significant because it describes how the compacted MSW reacts when there is no pressure being applied. While the average density rates differ between nonshredded and shredded MSW by 16.7%, they do react similarly when the load is released even though there were varying maximum pressures applied to different MSW tests.

Shredded MSW experienced a greater initial in-place density than the nonshredded MSW because of the shredding. Three batches of MSW were tested with two tests per batch, one nonshredded and one shredded, which are test 1 and 2, 3 and 4, and 5 and 6, respectively. A greater in-place density was recorded in the shredded MSW for all three batches ranging from an increase as low as 25.0% up to an increase as great as 116.8%. When the MSW was compacted and given 24-hours to rebound the final in-place density increased as little as 23.3% and as much as 86.2%. These results show the variability within the MSW and how compaction of shredded MSW can greatly increase the in-place final density.

Even though the tests 1 and 2, 3 and 4, and 5 and 6 had MSW from the same source and batch, the samples tested were not identical and the material variability of the MSW is hypothesized to contribute to the difference in the recorded data. While efforts were taken to increase the homogeneity of the batch using a front-end loader to mix the MSW, MSW by nature is heterogeneous. Additionally, moisture and organic content vary annually and based upon location could have impacted the test results. The tests conducted are a small sample of MSW received at the Salt Lake County transfer station. They show that shredding and compacting the MSW can increase the average final in-place density by 52.7%.

Four more tests were conducted to further quantify the densities of shredded MSW; tests 7, 8, 9, and 10 and the results from these tests can be found in Table 2. Three of the tests were conducted from the same batch of shredded MSW; tests 8, 9, and 10.

These tests once again demonstrate the variability present in MSW, the initial in-place density ranges from 405 lb/yd^3 to 585 lb/yd^3 and the final in-place density ranges from 934 lb/yd^3 to 1161lb/yd^3. The average in-place initial and final densities of tests 8, 9, and 10 were calculated to be 516 lb/yd^3 and 1050 lb/yd^3, respectively.

The combined average initial in-place density of the shredded MSW was calculated to be 592 lb/yd^3 and 1144 lb/yd^3 for the final in-place density from all seven of the shredded MSW tests. Shredded MSW test 7 contains densities which are 44% to 129% greater than the highest densities recorded from the other test and was believed to be an outlier. To test this, the interquartile range, a type of descriptive statistics, was determined for all of the shredded MSW tests for the in-place initial, maximum, and final density. The interquartile range for the initial density was found to be 184 lb/yd^3 which indicated that an outlier would exist at any value above 860 lb/yd^3. The interquartile range for the maximum density was found to be 418 lb/yd^3 which indicated that an outlier would exist at any value above 2536 lb/yd^3. The interquartile range for the final in-place density was found to be 405 lb/yd^3 which indicated that an outlier would exist at any value above 1793 lb/yd^3. All of the densities were greater than the minimum value for the outlier as shown in Figure 9.

When test 7 is removed from the shredded MSW density averages the initial in-place density drops to 514 lb/yd^3 and the final in-place density decreases to 979 lb/yd^3. The result is shredded, compacted MSW that has a final in-place density that is 65.1% greater than compacted MSW as shown in Table 6. This translates directly into a volume savings of 39.4% based upon the average values.

Rebound

The 24-hour rebound results of nonshredded and shredded MSW were not as conclusive as the results from the compaction study. The results showed that rebound could vary greatly from nonshredded to shredded MSW; a range of values from 0% with a difference of up to 24.2% was observed during testing. However, shredded MSW did not always have the greater rebound. In one recorded instance the rebound of shredded MSW was greater than that of nonshredded MSW but in two other test comparisons shredded MSW had less than or the same rebound as the nonshredded.

The average 24-hour rebound of nonshredded MSW calculated from the three tests was determined to be 3.1 inches while the average24-hour rebound for the shredded MSW was determined to be 3.0 inches. These average values are within 2.5% of one another which is statistically insignificant. When shredded MSW test 7, the outlying value, is removed from the average, the adjusted average 24-hour rebound of shredded MSW is 2.8 inches. This is 11.0% less than the nonshredded MSW but should be used with caution because test results from different sources and collection dates are being compared and averaged. Test 1and 2, 3 and 4, and 5 and 6 may have more credible data concerning the rebound because the material being tested had a greater probability of being similar between the tests because it came from the same source. Based upon the makeup of the MSW, rebound can vary significantly. For instance, MSW that has a high rubber or foam content will rebound greatly, whereas MSW that has a high metal or paper content will not experience much rebound over a 24-hour period.

Overall, clear trends were unable to be established for the 24-hour rebound of shredded MSW. Additional testing is required to determine how the 24-hour rebound of shredded MSW compares to nonshredded MSW and whether or not that rebound would decrease the potential 39.4% landfill volume savings reported here.

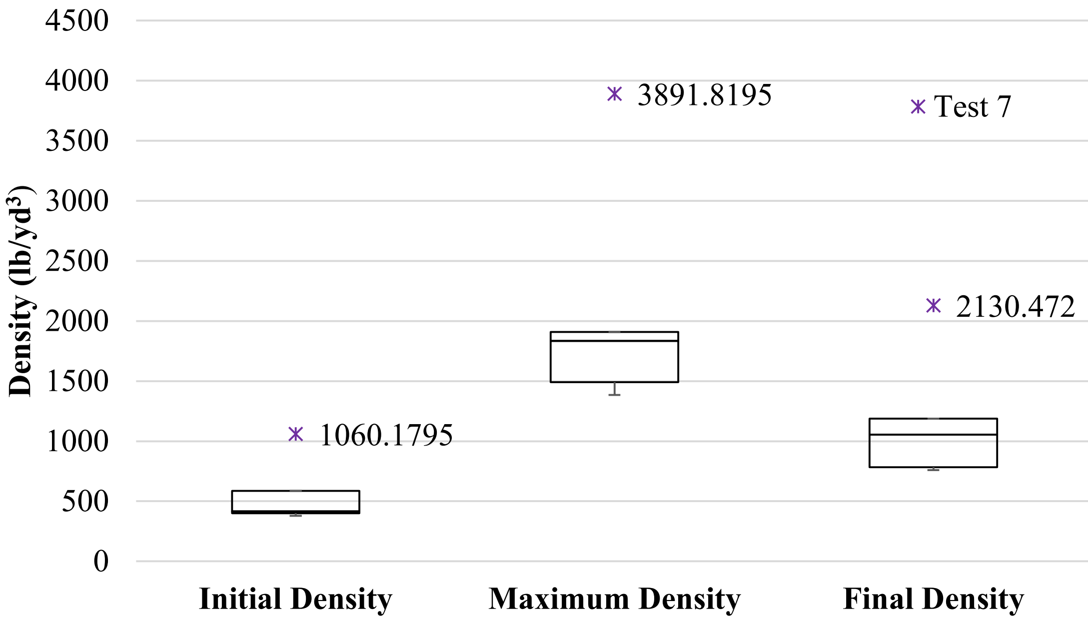

Figure 9: Box Plot of Shredded MSW Values and Test 7 Outlier

Table 6: Average MSW Densities (Excluding Shredded MSW Test 7 Outlier)

Mixed MSW Properties	Average Nonshredded MSW	Average Shredded MSW	Percent Increase
Initial Density (lb/yd^3)	297	514	73.3%
Maximum Density (lb/yd^3)	1205	1672	38.7%
Final Density (lb/yd^3)	593	979	65.1%

CONCLUSIONS

The compaction and rebound of shredded municipal solid waste received at the Salt Lake County transfer station have been presented in this thesis. Details of the experimental methodology were covered and analysis results were reported as to how the shredded MSW performed in comparison to nonshredded MSW.

Shredded MSW has been found to have an increased density when compared to nonshredded MSW in both initial and final in-place densities. Shredded MSW is a viable option to extend the life of landfill cells operated by the SLVSWMF.

Analysis Results

Overall, shredded MSW demonstrated a substantial improvement in the initial and final in-place density when compared to nonshredded MSW. For the compaction tests which came from the same MSW batch, the initial in-place density increased from 25.0% to 116.8% and the final in-place density increased from 23.3% up to 86.2%. On average, the shredded MSW increased in density by nearly 65% which could result in a potential landfill space savings of almost 40%.

The results of the rebound of shredded MSW were not nearly as conclusive as the compaction results were. From this study, the rebound of shredded MSW was found to be 2.5% greater to 11% less than the rebound of nonshredded MSW. However, the data are noisy and additional research is recommended for this property of shredded MSW.

This project has been successful in quantifying the compaction of shredded MSW. In addition to fulfilling this task, the project also contributes to research being performed in conjunction with Salt Lake County, Kleinfelder Inc., and Utah State University to study and better understand many properties of shredded MSW such as compaction, leachate production, degradation, and biogas production in laboratory and field settings and has the potential for additional research opportunities with the University of Utah in the future.

Benefits to the Solid Waste Disposal Industry

The solid waste disposal industry stands to benefit greatly from the findings outlined in this research. In particular, the increase in density of shredded MSW of 65% from nonshredded MSW, which would result in a nearly 40% volume reduction has the potential to change the way MSW is managed and disposed of. A 40% percent volume reduction would offset the development of new landfill cells by 50 or more years depending on the population growth factor that is used; having the potential to save the industry large sums of money in development costs. For instance, based upon the current growth projections for the Salt Lake County, the SLVSWMF could continue to operate for another 70 years without having to construct additional landfill cells. This is assuming that all incoming waste is shredded prior to compaction and that all shredded MSW has a volume reduction of at least 40% from the nonshredded MSW.

While a reduction of this magnitude would be significant in the industry, more research must be conducted. The research needed is outlined in the section below.

Future Research Needs

Continuation of this research is very important in understanding if shredding all incoming municipal solid waste into a landfill facility would have a positive volume, leachate, off-gas, and economic benefit. There is the also the option for additional study and research with the work that was performed for this study. Continuing to further quantify the density and rebound of shredded MSW would give more credibility to the research already conducted and would provide more research opportunities. Future research needs include:

1. What would the cost associated with shredding all incoming MSW include? How much additional equipment would need to be purchased and what would be the reliability of the new equipment? The needs for this research are as follows: Contacting equipment suppliers to find the average cost and reliability of shredding equipment. Working with the SLVSWMF to determine the annual volume of incoming MSW and how the incoming volume will change as the service area and population increases. Research should also be conducted from other cities which have recently constructed new landfill cells in order to determine a typical development and construction costs. With this information, the cost of shredding all incoming MSW could be compared against the cost of developing a new landfill cell and the SLVSWMF could decide what would be a better use of their funding and available resources.
2. How does shredding incoming MSW change the waste's properties such as leachate production and gas production? The needs for this research are as follows: Perform lab and field scale tests to quantify the changes in leachate

production and properties compared to nonshredded MSW. Lab and field scale tests should also be conducted to determine the quantity and quality of gas production, specifically methane production, compared to nonshredded MSW. Leachate and gas production are two items closely regulated and monitored by the EPA for active and closed landfill sites. Depending on the results of this research, monitoring times and frequency could either be increased or decreased for shredded waste landfills which could potential save owners money.

3. How does shredding all incoming waste affect the volume savings reported in this research? How does the in-place density of shredded MSW determined in this report compare to shredded MSW that is being compacted at the SLVSWMF? The needs for this research are as follows: Perform field testing at the SLVSWMF to determine the actual in-place density after the shredded MSW has been compacted. Using an auger drill bit would allow the compacted MSW to be removed from a lift and weighed, the hole created by the auger would have a known volume and the in-place density could be determined. This research is important because it would produce realistic final in-place densities that could be encountered in the field. It would be interesting to look at how the additional weight of MSW in each lift (due to the higher density) affects the lifts below it. The additional weight could cause additional compaction of the material below it as time goes on and as more lifts are added.
4. How does the 24-hour rebound differ between shredded and nonshredded MSW? The needs for this research are as follows: Additional testing of shredded and nonshredded MSW should be conducted to determine if there is a difference

between the 24-hour rebound. The nonshredded and shredded test samples should be as similar as possible in terms of percentages of types of waste to have an accurate comparison. This is crucial for the determining the feasibility of shredded MSW on a large scale. If it is determined that the rebound of shredded MSW is substantially greater than nonshredded MSW then the volume savings that come from shredded the MSW may be lost when the material rebounds. It should also be considered that MSW on the tipping face of the landfill only has an opportunity to rebound for a period of 24-hours 1 day a week, which is Sunday when the landfill is closed. Every other day of the week the landfill is closed at nights so the MSW only has approximately 12-hours to rebound. It may be useful to also look at 12-hour rebound based upon this fact.

5. How does the compaction and rebound differ between different components of MSW such as paper, plastic, and organic content? What is the optimum water content for each of the individual components needed to achieve the maximum final in-place density? The needs for this research are as follows: Sorting MSW by individual components and testing them on a smaller scale than what was performed for this research. MSW could be shredded using a heavy duty paper shredder. The moisture content could also be varied to determine the optimum moisture content to produce the highest in-place density. Understanding how each component of shredded MSW affects the overall density of shredded MSW is very important. The research may show that certain items do not compact well or contribute greatly to rebound. These types of results could be an incentive for a landfill to perform presorting prior to compacting the MSW to remove the types

of material that reduce the final in-place density or increase the rebound and dispose of these in an alternate manner.

APPENDIX A

ADDITIONAL DATA PLOTS

Additional data plots are included as Figure 10 to 23.

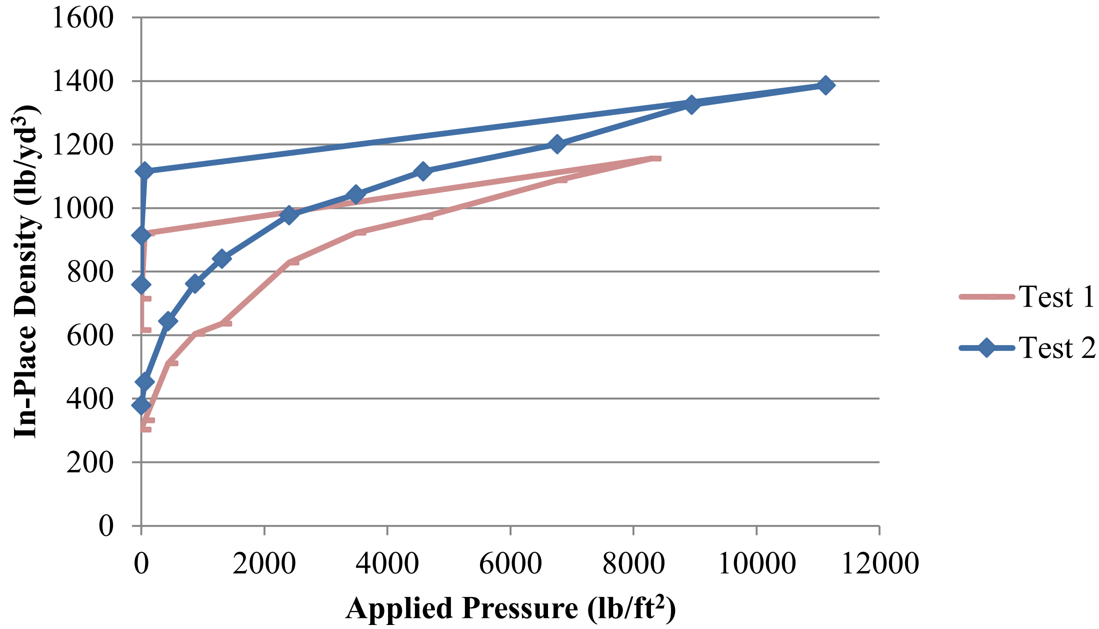

Figure 10. In-Place Density vs. Applied Pressure - Test 1 and 2

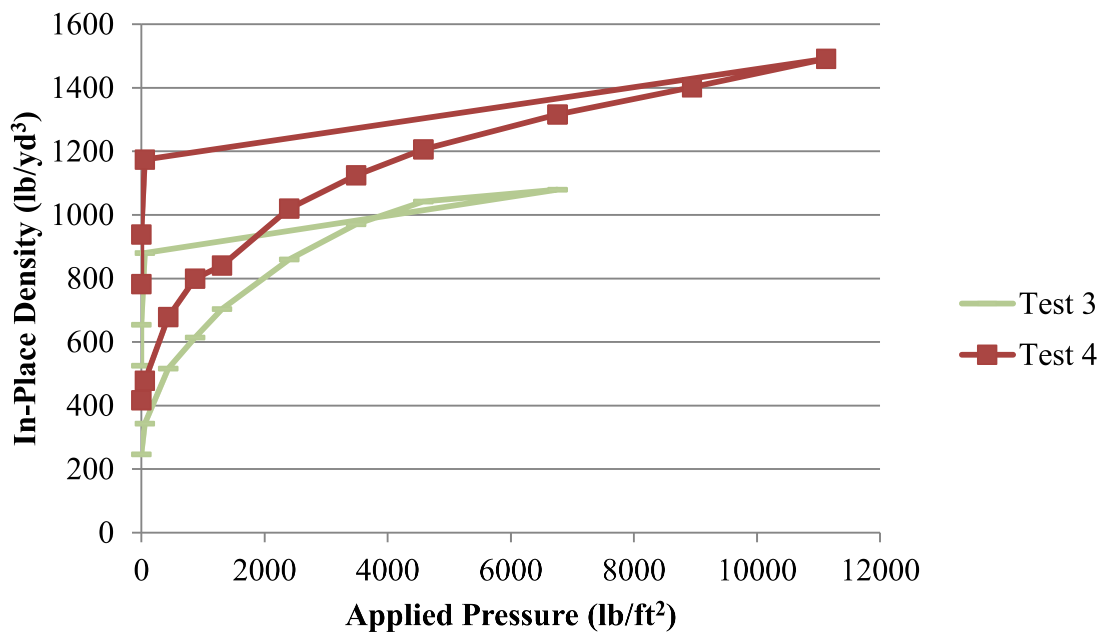

Figure 11. In-Place Density vs. Applied Pressure Test 3 and 4

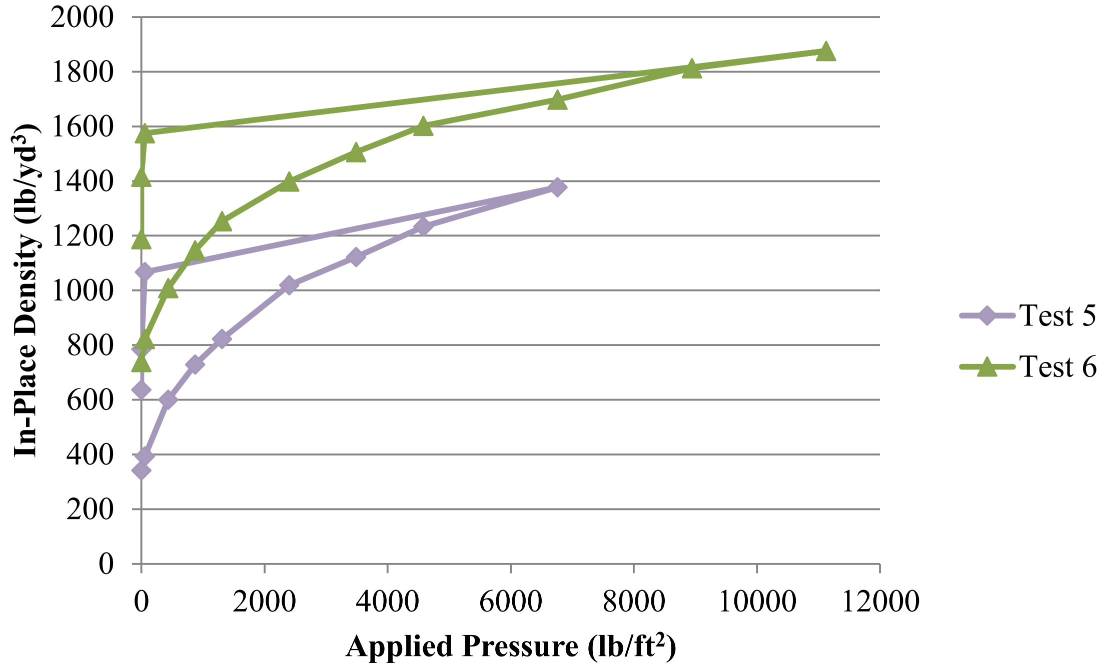

Figure 12. In-Place Density vs. Applied Pressure - Test 5 and 6

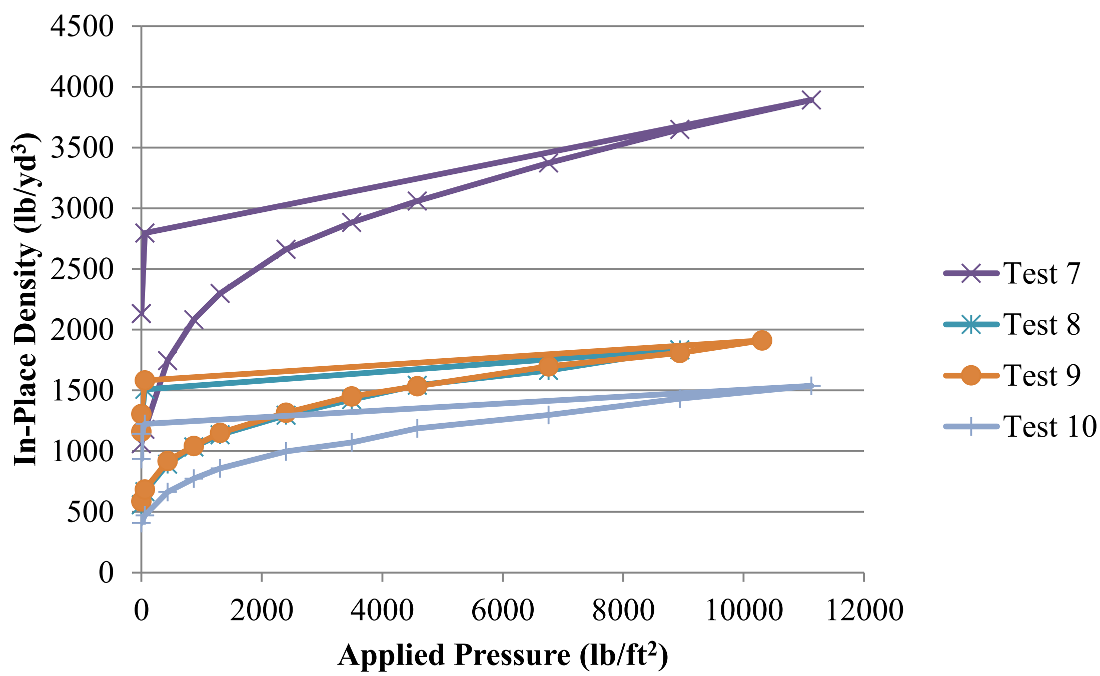

Figure 13. In-Place Density vs. Applied Pressure - Test 7, 8, 9, and 10

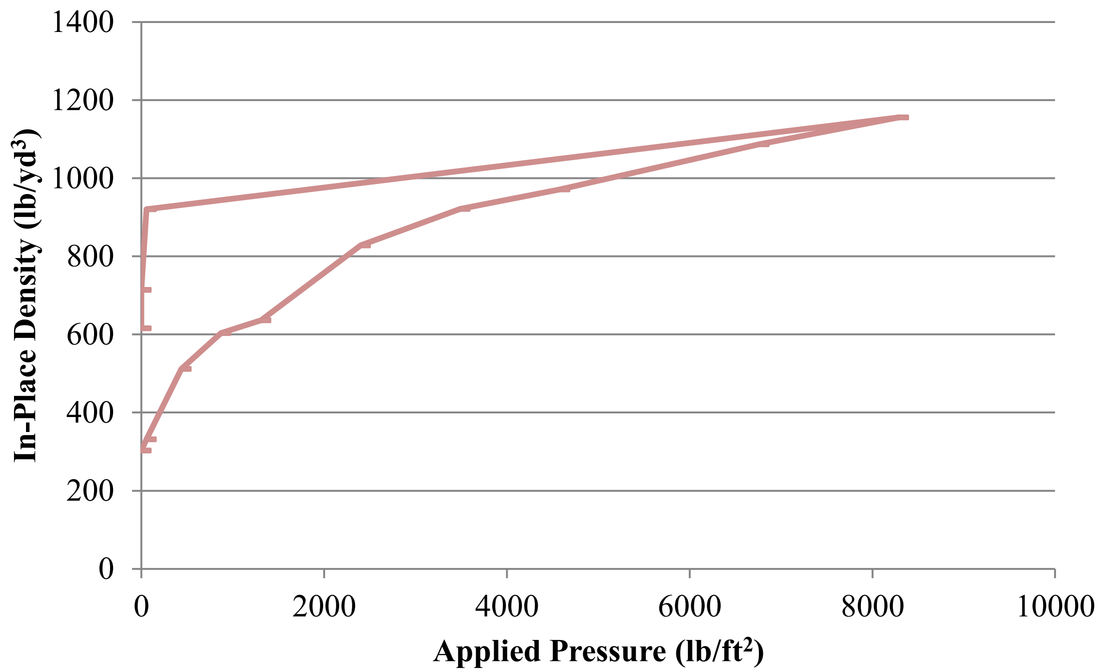

Figure 14. Nonshredded MSW Test 1 - Density vs. Applied Pressure

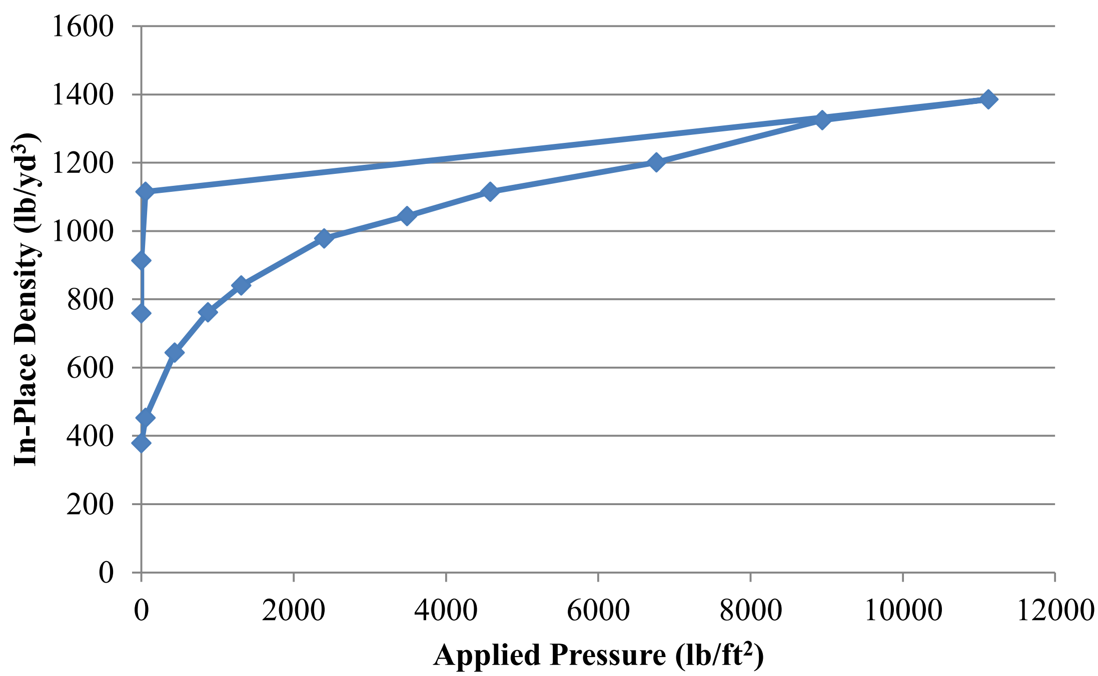

Figure 15. Shredded MSW Test 2 - Density vs. Applied Pressure

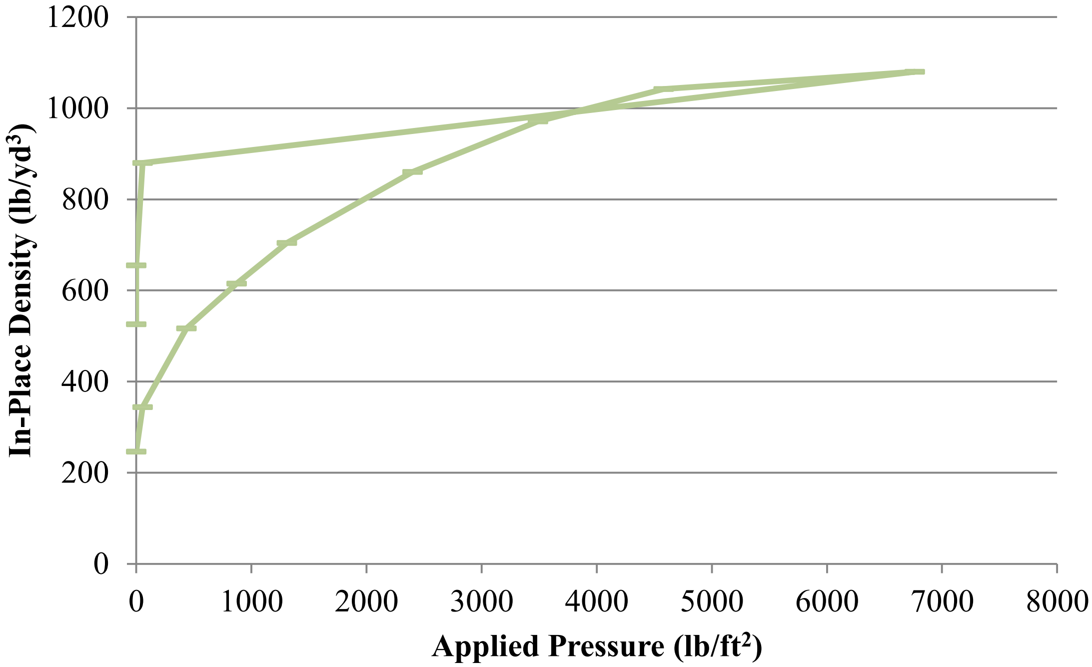

Figure 16. Nonshredded MSW Test 3 - Density vs. Applied Pressure

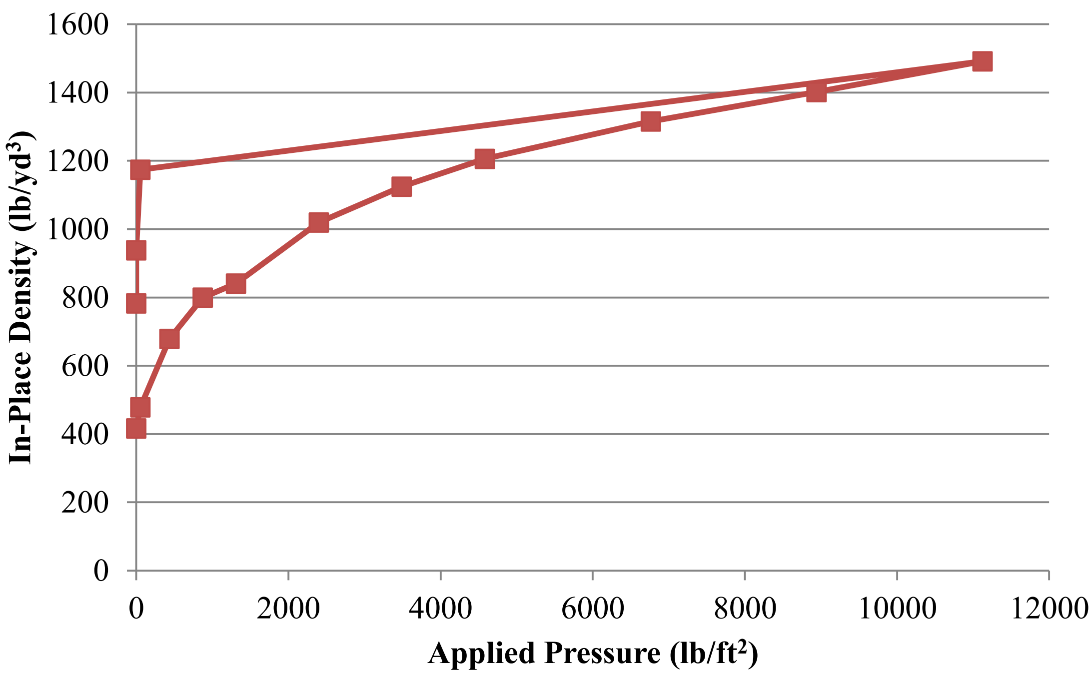

Figure 17. Shredded MSW Test 4 - Density vs. Applied Pressure

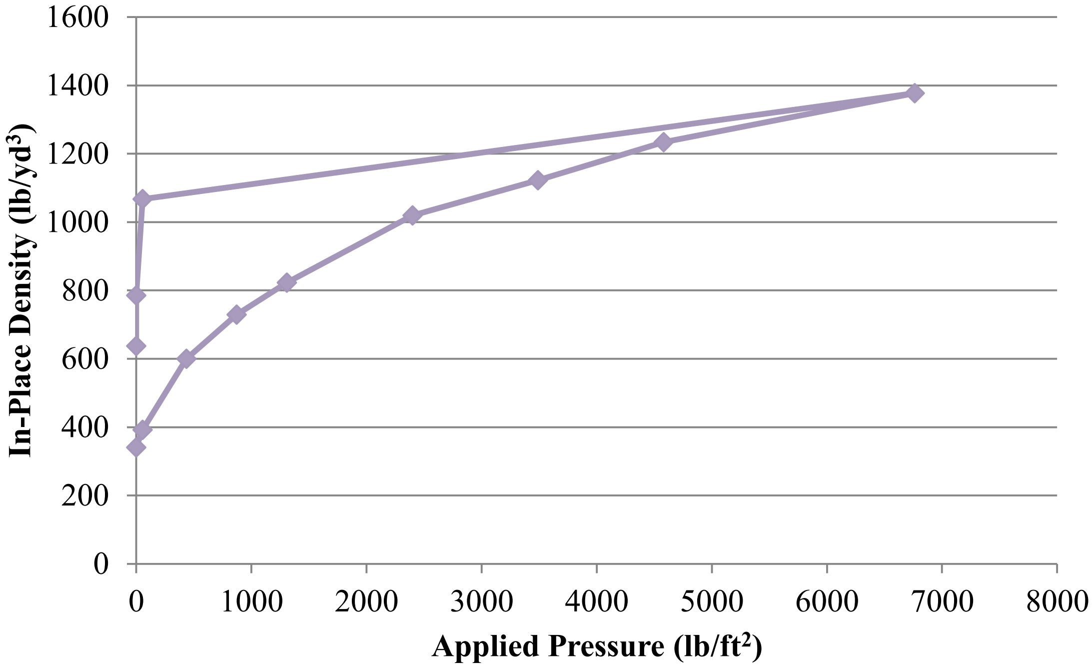

Figure 18. Nonshredded MSW Test 5 - Density vs. Applied Pressure

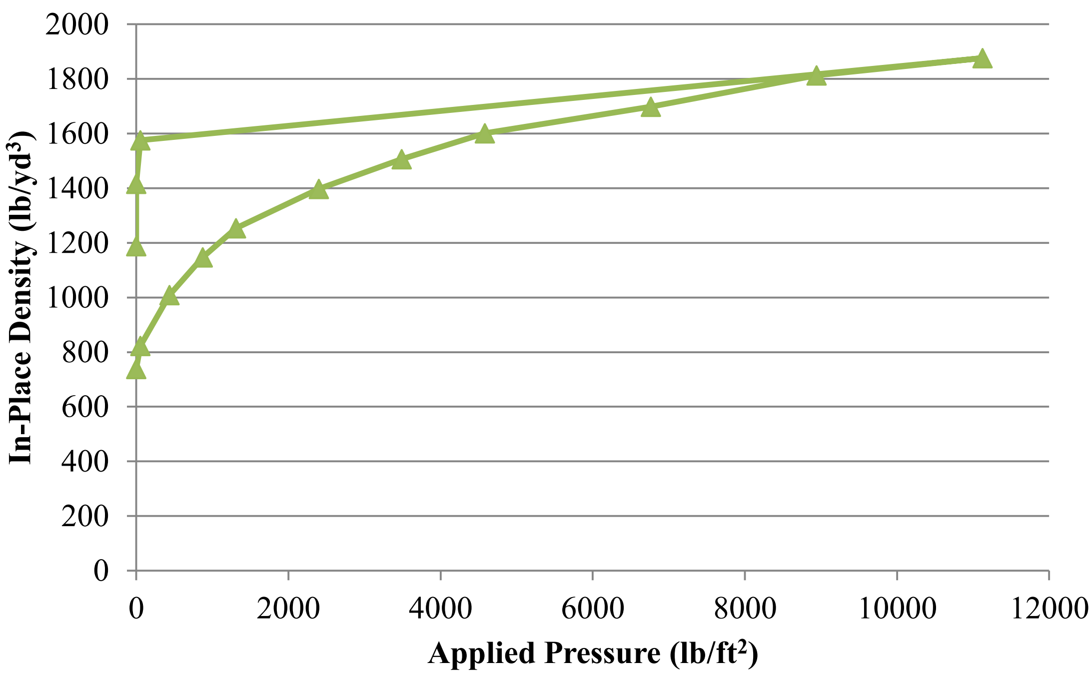

Figure 19. Shredded MSW Test 6 - Density vs. Applied Pressure

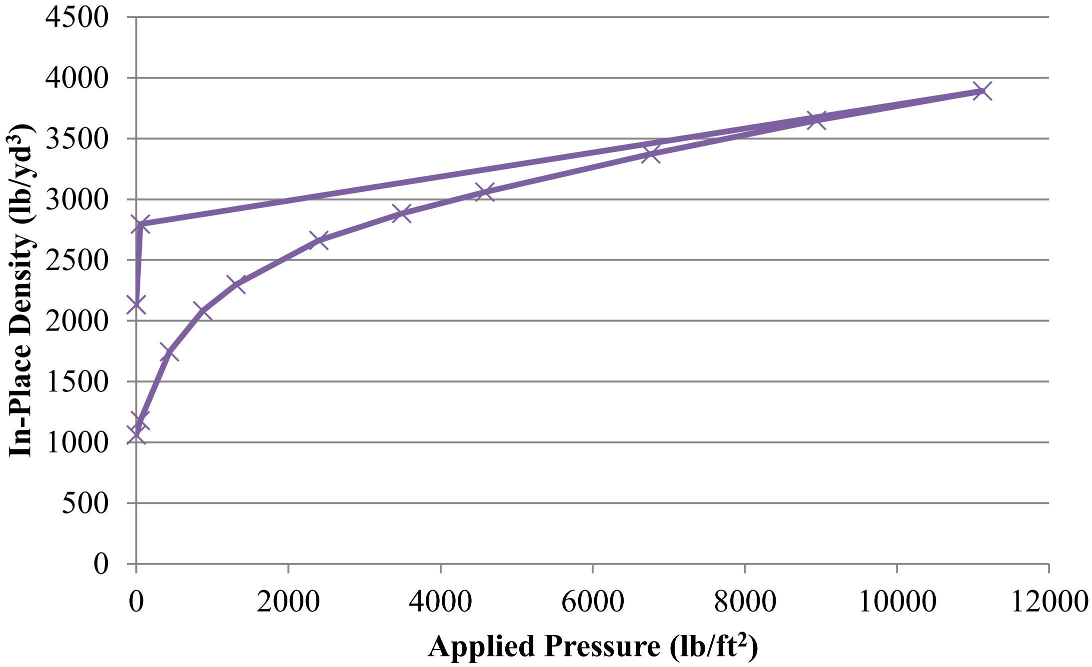

Figure 20. Shredded MSW Test 7 - Density vs. Applied Pressure

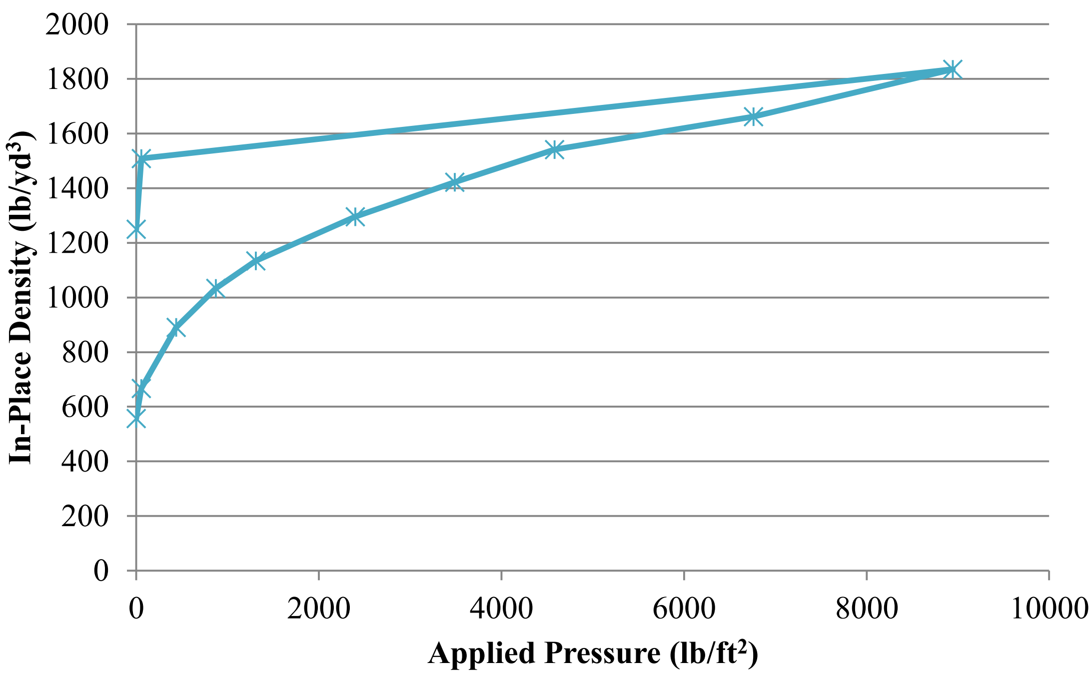

Figure 21. Shredded MSW Test 8 - Density vs. Applied Pressure

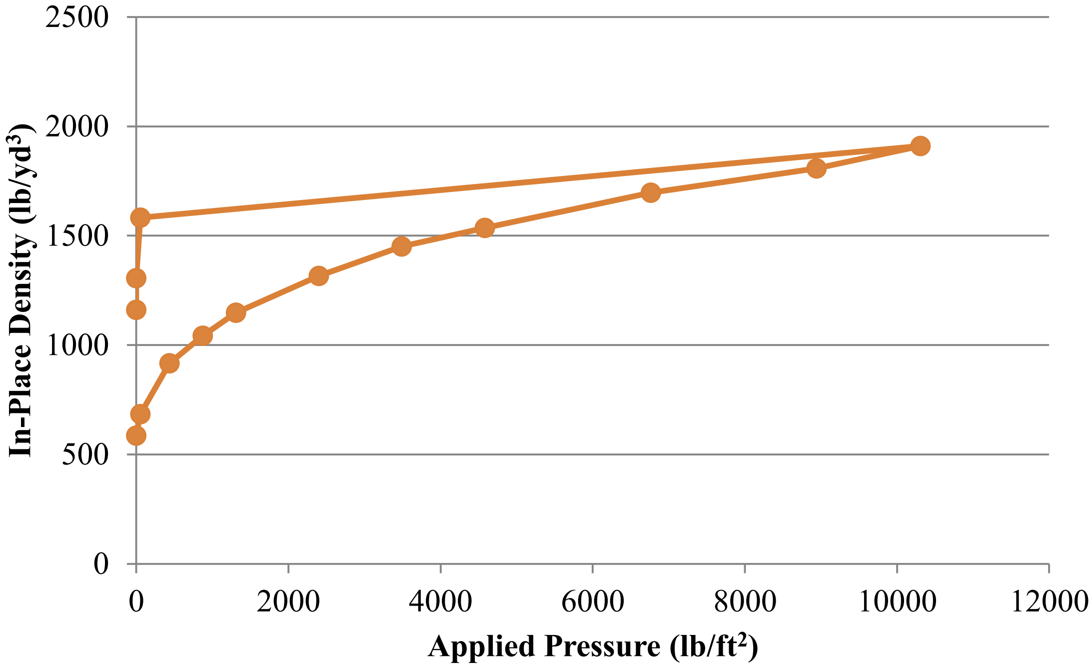

Figure 22. Shredded MSW Test 9 - Density vs. Applied Pressure

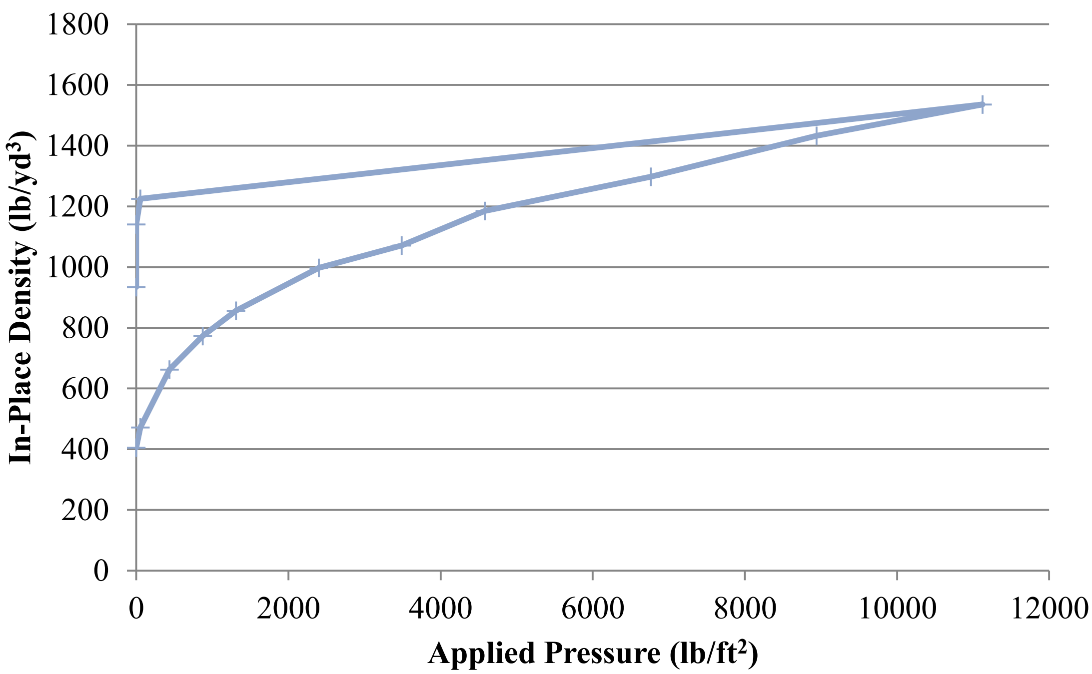

Figure 23. Shredded MSW Test 10 - Density vs. Applied Pressure

APPENDIX B

MSW MOISTURE CONTENT

Nonshredded MSW Moisture Content

The moisture content of the nonshredded MSW from test 1 was determined on May 15, 2013. Three 1 gallon buckets were filled with the nonshredded MSW at the Salt Lake County transfer station and then sealed. The samples were taken to the University of Utah, spread out on sheets of foil, weighed, and placed in an oven at a constant 109 °C for 24-hours. At the end of the 24-hour period the three samples were removed from the oven and weighed to determine the moisture loss. The moisture content results are found in Table 7. The average moisture content for the nonshredded MSW from test 1 was determined to be 43.8%.

Shredded MSW Moisture Content

The moisture content of the shredded MSW from test 2 was determined on May 16, 2013. The same procedure for determining the moisture content for the nonshredded MSW was used. Three 1 gallon buckets were filled with the nonshredded MSW at the Salt Lake County transfer station and then sealed. The samples were taken to the University of Utah, spread out on sheets of foil, weighed, and placed in an oven at 109 °C at the start of the testing and after 24-hours the temperature had dropped to 103.5 °C. At the end of the 24-hour period the three samples were removed from the oven and weighed to determine the moisture loss. The moisture content results are found in Table 8. The average moisture content for the shredded MSW from test 2 was determined to be 30.0%.

Comparison of Nonshredded and Shredded Moisture Contents

The average moisture content of nonshredded MSW test 1 was determined to be 43.8% while the average moisture content of shredded MSW test 2, which came from the same sample of waste as test 1, was found to be 30.0%; a decrease of 31.3%. The lower moisture content of the shredded MSW may have contributed to the increased in-place density recorded during test 2. Interestingly, the smell of the shredded MSW was much less potent during the 24-hour incubation period in the oven than the nonshredded MSW which had a higher moisture content. The effect of moisture content cannot be applied to the compaction and rebound tests because it was not carried throughout all of the tests.

Table 7. Nonshredded MSW Test 1 Moisture Content

Mixed MSW Properties	Sample 1	Sample 2	Sample 3
Weight of Foil (g)	6.8	6.1	6.2
Weight of MSW and Foil (g)	485.5	535.5	612.0
Weight of MSW and Foil After 24-Hours (g)	268.4	328.4	328.3
Moisture Content	45.3%	39.1%	46.8%

Table 8. Shredded MSW Test 2 Moisture Content

Mixed MSW Properties	Sample 1	Sample 2	Sample 3
Weight of Foil (g)	7.4	7.2	7.1
Weight of MSW and Foil (g)	109.1	284.8	183.4
Weight of MSW and Foil After 24-Hours (g)	84.2	192.8	126.0
Moisture Content	24.5%	33.1%	32.6%

APPENDIX C

NONCONVENTIONAL MSW TESTING

Nonconventional MSW Testing

Bulky items such as chairs, mattresses, and tires which typically have trouble compacting were set aside to be tested on May 23, 2013. The material set aside for testing is described in Table 9.

The testing was nonconventional because the testing apparatus was filled with material and compacted until the hydraulic ram had reached full stroke (18 inches). Once full stoke had been achieved the steel lid was removed and additional material was added. This process continued until the hydraulic ram was able to exert a pressure of 11124 lb/ft^2 on the sample. Table 10 shows the material that was in the testing apparatus and the pressure which was achieved, the successive rows are additional material that was added and the new pressure which could be applied at full stroke of the hydraulic ram.

Once the MSW had reached 11124 lb/ft^2 the pressure was removed and the depth of compacted MSW was recorded. The weight of the MSW in the testing apparatus was then weighed. With these values the final in-place density was calculated as seen in Table 11.

Once the testing had been completed, all of the material listed in Table 9, including the material that had been compacted listed in Table 10, was shredded in the Salt Lake County transfer station shredder. The shredded MSW was then loaded into the testing apparatus and compacted; when a pressure of 1143 lb/ft^2 had been applied, the hydraulic ram reached its maximum stroke. The steel lid was then removed and additional shredded MSW was placed in the testing apparatus and an applied pressure of 11124 lb/ft^2 was achieved. The pressure was removed and the depth of compacted shredded MSW was recorded. The testing apparatus was then emptied of the shredded

MSW and it was weighed on the Salt Lake County transfer station scale. The final in-place density of the shredded was then calculated, as shown in Table 11.

The results of this test were inconclusive due to testing method. It was apparent from a visual inspection that the shredded bulk MSW took up significantly less volume than the nonshredded bulk MSW; however, the results do not indicate this. The results indicate that nonshredded MSW will be marginally denser than the shredded MSW. Intuitively this does not make sense because the nonshredded bulk MSW creates large air voids, whereas the shredded bulk MSW tends to fill in the large air voids. Additional testing is required for bulky MSW to determine the volume reduction and rebound as a result of shredding the MSW prior to compaction.

Table 9. Bulky MSW Set Aside for Testing

Quantity	MSW Description	Quantity	MSW Description
1	Twin Mattress	1	13’x8’ Carpet
4	15” Car Tire	3	15” Truck Tire
1	11’x11’ Carpet	1	11’x3’ Carpet
1	11’x4’ Carpet	1	55 Gallon Drum (Plastic)
4	Plastic Children Toys (Wagon, 2xPowerwheel, Sled)	6	Wood Chair with Foam Padding
1	Bamboo Chair	1	Wood Folding Chair
2	Low Back Office Chair (Fabric)	2	High Back Office Chair (Fabric)
1	Vacuum Cleaner	1	Hardshell Plastic Suitcase
3	Reclining Chair (Fabric)	1	Fabric Seat Cushion
1	Indoor Exercise Trampoline	3	3’x3’ Wood Pallet
2	Wood End Table	5	2’x2’x1’ Styrofoam Blocks
3	3 Gallon Bucket (Plastic)	2	5 Gallon Bucket (Plastic)
1	1 Gallon Bucket (Plastic)	4	Car Bumper (Plastic)
1	2’x4’ Wood Table Top	1	15” Car Rim with Tire

Table 10. Nonshredded Nonconventional MSW

Pressure @ Max Stroke	MSW Description	MSW Description
763 lb/ft^2	1-55 Gallon Drum (Plastic) 2-15” Car Tires 1-11’x3’ Carpet 2-2’x2’ Wood Table Tops	1-Folding Chair (Wood) 1-Recliner Chair Back (Fabric) 1-2’x3’ Wood Pallet
2018 lb/ft^2	1-Plastic Hard Shell Suitcase	
2618 lb/ft^2	1-Short Chair Back (Fabric) 1-2 Gallon Bucket (Plastic)	3-3 Gallon Bucket (Plastic)
3817 lb/ft^2	1-2’x2’x1’ Styrofoam Block 1-Car Bumper (Plastic)	1-Wood Chair 1-Indoor Exercise Trampoline
6326 lb/ft^2	4-Table Legs (Wood)	1-Low Back Office Chair (Fabric)
11124 lb/ft^2	1-Table Top (Wood)	1-Seat Cushion (Fabric)

Table 11. Comparison of Nonshredded and Shredded Bulky MSW

Mixed MSW Properties	Nonshredded Bulk MSW	Shredded Bulk MSW
Mass (lb)	299	299
Depth of Compacted MSW (in)	23.2	23.6
Final In-Place Density (lb/yd^3)	1639	1618

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