Preliminary Investigation of Required BSCA Amount for Soil Cement Mixtures

Undergraduate Honors Thesis

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ABSTRACT

The recent increase of flooding in the United States and the high expenses related to the damage that these floods have caused to waterway structures suggests a potential interest in rapid setting soil cement to make effective repairs. For this thesis, mix designs of soil only at three different sand-clay proportions were prepared and tested for moisture content and maximum dry density. Due to the early closing of the laboratory and research activities, reliable results were collected from the 70% sand and 30% clay proportions. At those proportions of soil, the optimum moisture content was found to be 8.88% with a maximum dry density of 20.76 kN/m^3. Even though a test using 6 % of belitic calcium sulfoaluminate (BSCA) cement at 70% sand and 30 % clay proportions was performed, the test was unsuccessful because of a significant change in moisture content compared to that previously found. Further testing is required in order to determine the ideal quantity of BSCA cement to be used for different soil-cement mix design proportions. This thesis recommends as the next step the testing of the 70% sand and 30 % clay soil proportions with 5, 7 and 9 percent of BSCA and OPC cement by weight at 7,8,9,10 and 11 percent water content. The comparison between the development of strength will be tested by performing unconfined compressive strength tests. This will allow a comparison of the behavior of the BSCA cement with portland cement, and lead to guidance on proper soil-cement proportioning with BCSA cement.

INTRODUCTION:

Soil cement is defined in ACI 230 as a densely compacted mixture of portland cement, soil/aggregate, other cementitious materials when necessary, and water. [1] Soil cement provides slope protection for dams, liners for structures, dikes, and foundation stabilization. [1] In March of 2020, the National Oceanic and Atmospheric Administration stated that “Nearly every day, dangerous flooding occurs somewhere in the United States and widespread flooding is in the forecast for many states in the months ahead”. [2] The National Centers for Environmental Information has summarized weather and climate disasters that have cost over a billion dollars in the United States (US). [3] When analyzing the events corresponding to flooding that occurred in 2019, three events were listed. One of them corresponding the Mississippi River flooding that extended to midwestern and southern US. The National Weather Service said this was the longest continuous stretch above flood stage since 1927. [4] The flooding caused significant damage to agriculture, roads, bridges, levees, dams. causing a total cost of about $6.2 Billion. [3] The second event was the Arkansas River flooding, which is considered a historic flood that affected the Arkansas River Basin causing damage to homes, agriculture, roads, bridges, and levees for a total estimated cost of $3.0 Billion. [3] The third, Missouri River and north central flooding; these floods inundated millions of acres of agriculture, numerous cities, and towns, and caused widespread damage to roads, bridges, levees, and dams. Total Estimated Costs: $10.7 Billion. [3] The recent increase of flooding has caused damage that has cost over 15 billion dollars. Repairs to levees and other infrastructure along the Platte and Missouri Rivers in 2019 costed around $1 billion. [5] How expensive was the damage in Arkansas in 2019? A Little Rock levee district spent $2 million to cover the cost of repairing the flood damage in this state. [6] Overall, the levee situation has been getting worse year by year, that the American Society of Civil Engineers gave the country’s levee system a D grade in 2017, suggesting $80 billion in investment over 10 years. [7] Therefore, rapidly repairing soil structures could prevent some of the costly flood damage that is becoming a regular event in the US. Thus, the purpose of this thesis is to test sand and clay samples to find optimum moisture and to plan a research strategy to make rapid setting soil cement.

BACKGROUND/LITERATURE REVIEW

BSCA CEMENT

The conservation of energy and the reduction of emissions have become the modern world's current environmental protection themes [8]. Belitic calcium sulfoaluminate cement (BCSA) is a hydraulic, rapid-setting alternative to ordinary portland cement (OPC). [9] The OPC production process is known for its high consumption of energy since this process requires high-temperature sintering for its formation at about 1450°C [8]. Instead, BCSA cement constitutes a more eco-friendly option due to its lower energy and CO2 emissions during production, and its comparable physical performance. [10] Its production requires less lime and it can be produced at about 200 °C lower than the required temperature for OPC cement. Therefore, it reduces energy consumption and carbon dioxide emissions [11]. BCSA produces less than half the carbon dioxide than OPC during production [12]. BCSA cement offers design and construction professionals a quick setting concrete mixture that has an early strength development and does not shrink, reaching 31.026 MPa (4500 psi) compressive strength in about one to two hours. [13] It is a cement capable of achieving the required compressive strength for prestressed concrete construction in less than one-third the time required for conventional concrete. [12] The usual initial setting time is 10 to 20 minutes and even with retardation produces a concrete with strength of 4000psi in 2 to 4 hours. [9] The reduction of porosity and shrinkage are additional benefits of using this material in prestressed concrete applications [12].

Even though the rapid setting property is one of its major advantages, it takes responsibility since it requires knowledge to use it properly.

SOIL CEMENT

Soil cement is a simple, highly compacted mixture of soil, cement, and water. [14] It is an effective and economical construction material for use in water resource applications including streambank protection, slope protection, channel and pond linings, and grade control structures [15]. The major factors affecting the properties and characteristics of soil cement mixtures are the type of soil or aggregate material, the proportion of cement in the mix, the moisture conditions, and the degree of compaction. [14]. The proportions of cement and water, as well as the density at which the mixture should be compacted, are determined by standardized tests. The water in a properly mix of soil cement needs to ensure maximum compaction by lubricating the soil and it also needs to hydrate the cement for it to hardens. [16]

The most favorable group of soils for making soil cement is well graded sandy and granular soils since they require the least amount of cement for adequate hardening. Another good group of soils for making soil cement are sandy materials deficient in fines, that produce a good soil cement, but require slightly more cement than the previously mentioned group. Silty and clayey soils are dependent on the pulverization of the soil [16]. The most practical soils are those that do not contain more than 35 percent of silt and clay and that are easily pulverized. [17] If the soil can be effectively pulverized, then it is be suitable for soil cement.

Well graded soils of gravel, coarse sand, and fine sand with low content of plastic silt or clay will require about 5 percent or less cement by weight while the poorly graded one sized sand would require about 9 percent by weight. When using OPC non-plastic to moderately plastic silty soils require about 10 percent by weight and the plastic clay soils require 13 percent or more. [18]

The normal range of OPC required based on the AASHTO soil group classification is shown in the figure below. [16]

TABLE 1. Normal Range of Cement Requirements for B- and C-Horizon Soils*

AASHTO Soil Group	Cement, percentage by weight of soil	Cement, pounds per cubic foot of compacted soil-cement	Cement, kilograms per cubic metre of compacted soil-cement
A-1-a	3-5	5-7	80-110
A-1-b	5-8	7-8	110-130
A-2-4 A-2-5 A-2-6 A-2-7	5-9	7-9	110-140
A-3	7-11	8-11	130-180
A-4	7-12	8-11	130-180
A-5	8-13	8-11	130-180
A-6	9-15	9-13	140-210
A-7	10-16	9-13	140-210

Figure1. Normal Range of Cement for Soil Groups AASHTO. [16]

SOIL CEMENT FOR WATERWAY APPLICATIONS

Work with soil cement as a slope protection started in the early 1950s in Colorado. The Bureau of Reclamation performed a 10-year durability study which included freeze/ thaw and wet/dry cycles tests on the Bonny Dam. The success of the study led to an exponential growth of the soil cement for slope protection in the 60s and 70s. [19] The application of soil cement has demonstrated to effectively provide protection to water resources. Soil cement has also been used to protect riverbanks or levees in mostly urban areas in the Southwestern United States. [18] For example, during two significant flood events in Tucson, Arizona, in 1978 and 1983 for which the soil cement bank protection prevented millions of dollars in property damage. [15] To effectively resist forces of stormwater of velocities up to 20 ft/sec, the soil cement was designed in stair-step geometry and achieved minimum 7-day compressive strength between 600 and 750 psi. [15]

The most commonly used test to determine optimum moisture content and maximum density is the "standard" Proctor density test described in ASTM D-558 for laboratory test specimens and also for field control testing during construction. [19] The freezing and thawing test procedures for compacted soil cement are described in ASTM D560, and the methods for wet and dry cycle testing are described in ASTM D559. [18] Investigating the durability of the soil cement is major objective and some of the methods that have been helping to analyze the environmental impact on the soil cement include: weight loss, since a specimen of unchanging hardness would result in a uniform rate of weight loss related to the characteristic of the soil; and volume change and moisture gain, but they were found not to be a sensitive measure of deterioration for all soil types. [20] Overall, results of multiple tests indicate that increasing the cement content of a soil cement mixture increases erosion resistance. However, the size of the aggregate in the soil cement has an even greater effect on its erosion resistance. [15]

PROCEDURES

Determining the BSCA cement required for the soil cement design mix was the goal. However, in the first stage of the investigation, standardized tests were performed using design mixes that contained soil only. These tests were run in order to determine the soil’s optimum moisture content and maximum density to get an approximation of the proportions to use when working with design mixes containing BSCA cement. Mixes of different proportions of play sand and red art clay were tested. The Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (ASTM D698) [21] was performed with the deviation that a proctor mold of a volume of 37.2 cubic inches was used instead of the standard mold of 1/30 cubic feet. In order to calculate the number of blows required for the mold to use, the following equality was used. The compaction effort per unit volume equation was used as follows:

$$E = \frac{W - Hammer * H - Drop * \#Blows * \#layers}{V}$$

The number of blows was calculated by substituting the volume of the mold with 37.2 cubic inches and keeping all else the same as in the standard method. The standard test compaction effort, E, equals 12400 lb $* ft/ft^3$.

The samples were prepared the day before the proctor test. For each of the five saturation points as recommended in ASTM D698. A total of 1600 grams of clay and sand were weighed. However, for the design mix containing clay only, 1300 grams were used. The saturation points were targeted with a gap of 1 to 2 percent in between them. The soil was left to cure in the molds covered with a plastic wrap. After 24 hours of preparation, the proctor test was performed. A 5.5 lb hammer was usedwith 16 blows per layer and a total of three layers per test. Note that after having compacted the last layer, the compacted soil extended into the collar. The acceptable excess of soil was then trimmed off using a metallic straight edge. The weight of the proctor apparatus containing the soil was recorded. Once the compacted soil was taken out of the mold, a specimen from its middle part was kept. The moisture content test over this specimen was then performed in accordance to the Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass (ASTM D2216). [22] The can with the soil was then placed into the laboratory oven with a drying temperature of 110°C for 24 hours and then the stabilized weight was recorded. The dry unit weight of the soil was then calculated following the Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens (ASTM D7263). [23] A relationship between the dry unit weight and the water content for the soil was achieved by plotting a compaction curve. Therefore, values of optimum water content and maximum dry unit weight were determined from the compaction curve.

The initial soil mix design contained 70 percent of sand and 30 percent of red art clay; at these proportions the soil was an AASHTO A2 classification. The second mix design was 100% red art clay. The third and last proportion of soil tested was 85 percent sand and 15 percent clay. Even though the three proportions were tested, further tests are necessary for the second and the third mix proportions. A single test with the addition of the BSCA cement was performed. The soil proportions for the previously mentioned test were of 70 percent sand and 30 percent clay since four compaction curves were plotted based on those proportions. In addition, when the soil cement was tested, 6% by total weight of BSCA cement was added to the design mix. A control group was also tested using the same content of soil but with no cement was added.

RESULTS & DISCUSSION

As previously mentioned in this document, saturation points of the design mix containing 70 percent of play sand and 30 percent of red art clay was tested multiple times. Figure 2 shows the compaction curve from the first test performed at that proportion. An initial moisture content of 2% was assumed. However, after the test was performed, it was noticed that the assumption was not correct since the results were showing that the material had an initial moisture content that could have been negligible. The peak of the curve in Figure 2 corresponds to the maximum dry density, where the optimum water content is located, was only based on one saturation point.

The maximum dry density for this test was found to be 21.01 kN/m^3 at 8.5% of moisture content as shown in Table 1.

Table 1. Compaction Curve 1 Sand 70% Clay 30%

Actual w%	W-Mold kg	WMold+Soil kg	γ Moist kN/m^3	γ Dry kN/m^3	γ Moist lbf/m^3	γ Dry lbf/m^3
4.96	3.98	5.27	20.71	19.73	132.11	125.86
6.32	3.98	5.31	21.24	19.98	135.49	127.43
6.64	3.98	5.33	21.67	20.31	138.16	129.55
8.50	3.98	5.40	22.80	21.01	145.42	134.03
9.80	3.98	5.37	22.32	20.33	142.35	129.64

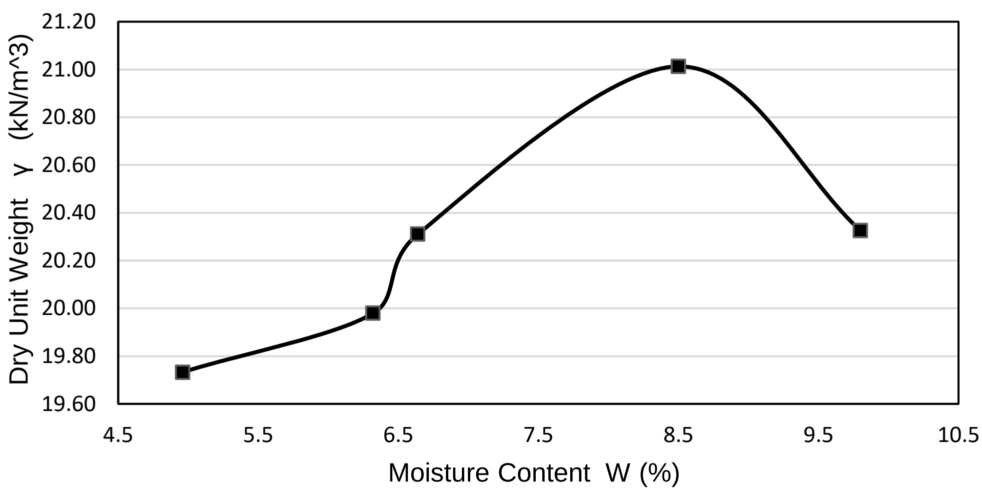

Figure 2. Compaction Curve 1 Sand 70% Clay 30%

In order to find saturations points that could confirm that the maximum dry density and optimum water content found before were correct, the test was performed again for a single saturation point of a target 7.5 moisture content but this time assuming a 0 percent initial moisture content. The actual water content of this sample was found to be of 7.63 percent.

Figure 3 shows a compaction curve which includes saturation points found in the previous compaction but including the saturation point of 7.63 percent of moisture. Results from the compaction 2 did not go as expected. Figure 3 shows a compaction curve that is still reporting the maximum dry unit weight based on one single point. The dry unit weight of the saturation point at 7.63 percent moisture content was of 20.62 kN/m^3, as shown in Table 2, was lower than expected and meaning that more tests using this proportion needed to be performed.

Table 2. Compaction Curve Sand 70% Clay 30% + New Saturation Point

Actual w%	W-Mold kg	WMold+Soil kg	γ Moist kN/m^3	γ Dry kN/m^3	γ Moist lbf/m^3	γ Dry lbf/m^3
6.32	3.98	5.30	21.24	19.97	135.49	127.43
6.64	3.98	5.33	21.66	20.31	138.15	129.55
7.63	3.98	5.36	22.19	20.62	141.53	131.49
8.50	3.98	5.40	22.80	21.02	145.42	134.03
9.80	3.98	5.37	22.32	20.33	142.35	129.64

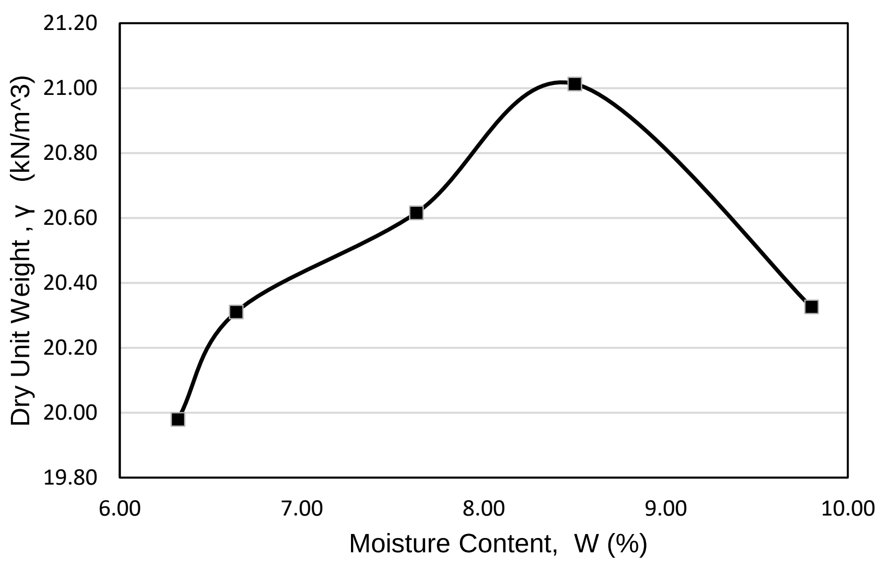

Figure 3. Compaction Curve for 70% Sand, 30% Clay Sample at New Saturation Point

The second proportion of soil used did not include any sand. The design mix contained red art clay only. The saturation points to be tested were decided by a faculty member who has expertise in the field. Figure 4 shows a that the compaction curve from this test was unsuccessful since the dry unit weight of the last three saturation points seemed to be constant for the last three points tested and therefore results are not reliable. See Table 3 to see the dry unit weights reported those points.

Table 3. Compaction Curve Clay 100%

Actual w %	W-mold kg	Wmold+soil kg	γ Moist kN/m^3	γ Dry kN/m^3	γ Moist lbf/m^3	γ Dry lbf/m^3
12.16	3.98	5.13	18.40	16.40	117.36	104.64
13.57	3.98	5.17	19.15	16.87	122.17	107.57
15.45	3.98	5.23	20.10	17.41	128.21	111.06
16.31	3.98	5.25	20.31	17.46	129.55	111.38
18.52	3.98	5.27	20.68	17.45	131.90	111.29

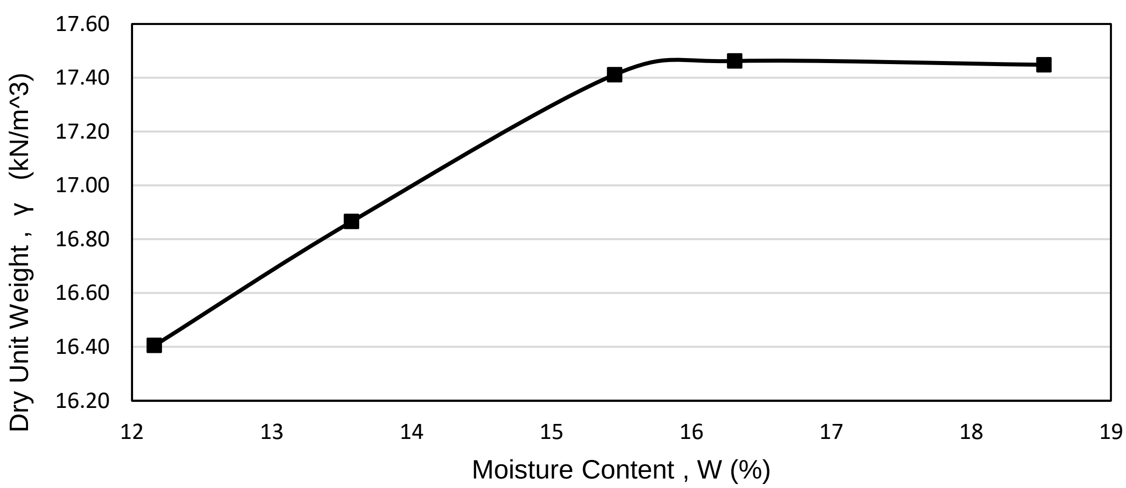

Figure 4. Compaction Curve Clay 100%

The third design mix proportion contained 85 percent of play sand and 15 percent of red art clay. The compaction curve shown in Figure 5 shows that there was some error during the testing. The shape of the curve, Figure 5, showed a lower dry unit weight of 19.52 $kN/m^3$from the 10.30

percent moisture content which theoretically should had reported a higher value of dry density. Table 4 contains the data used to create the curve shown in Figure 5.

Table 4. Compaction Curve Sand 85% Clay 15%

Actual w %	W-mold kg	Wmol+soil kg	γ Moist kN/m^3	γ Dry kN/m^3	γ Moist lbf/m^3	γ Dry lbf/m^3
7.71	3.98	5.26	20.58	19.11	131.29	121.89
7.62	3.98	5.27	20.63	19.17	131.59	122.27
8.61	3.98	5.31	21.40	19.71	136.51	125.69
10.30	3.98	5.32	21.53	19.52	137.33	124.51
11.44	3.98	5.35	21.92	19.67	139.79	125.44

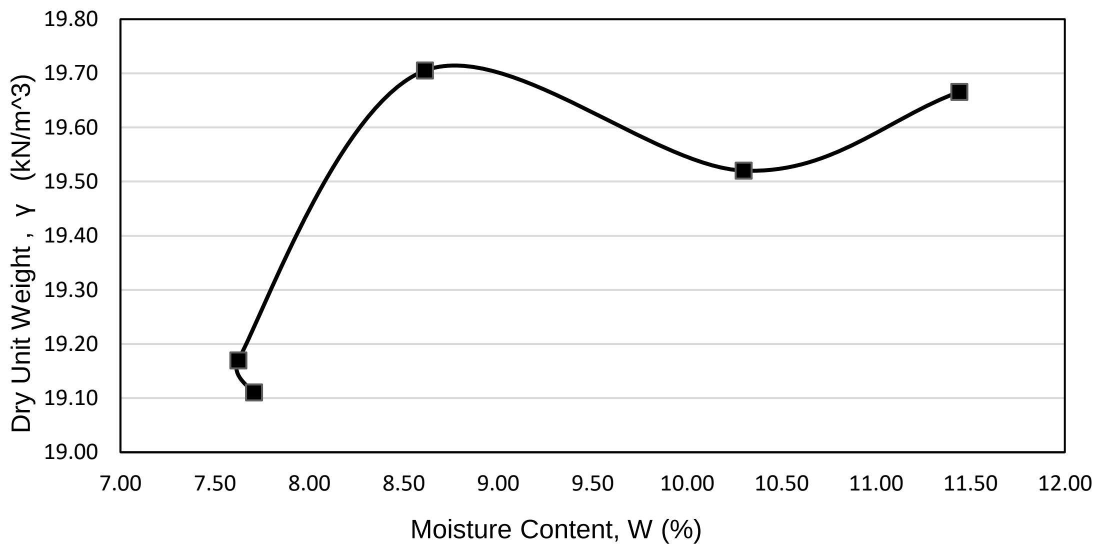

Figure 5. Compaction Curve Sand 85% Clay 15%

After analyzing the factors that could have affected the results. It was taken into consideration that the bag of sand used from all the tests run before was the same. However, for this test proportion a new bag of sand was open, and the initial moisture content of the new sand could had greater than before. The test needs to be performed again in order to get more reliable results.

The results from another compaction of four points of the 70 percent sand and 30 percent clay soil are shown in Figure 6. The maximum dry density according to Figure 6 is of 20.76 kN/m^3 from the point at 8.88% moisture content, this value is highlighted in Table 5. The point showing a moisture content 7.87 % was decided to be tested again since this point, highlighted in red in Table 5, used recompacted soil.

Table 5. Compaction Curve Sand 70% Clay 30%

Actual w %	W-mold kg	Wmol+soil kg	γ Moist kN/m^3	γ Dry kN/m^3	γ Moist lbf/m^3	γ Dry lbf/m^3
6.13	3.98	5.25	20.41	19.23	130.16	122.64
7.87	3.98	5.34	21.76	20.17	138.76	128.64
8.88	3.98	5.39	22.61	20.76	144.19	132.43
10.03	3.98	5.40	22.73	20.66	145.01	131.79

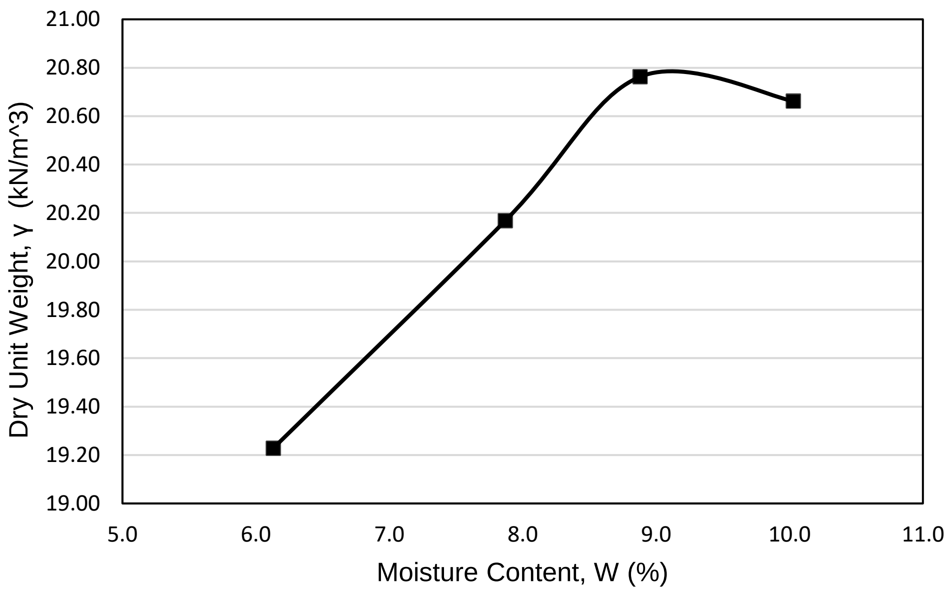

Figure 6. Compaction Curve San 70 % Clay 30%

Another test at the same proportions was performed in order to complete the saturation points from the previous curve in Figure 6. Figure 7 shows a reliable compaction curve with the now confirmed optimum moisture content of 8.88% and a dry unit weight density of 20.76 kN/m^3. The data points and their water content as well as their dry density, are shown in Table 6.

Table 6. Compaction Curve Sand 70% Clay 30 %

Actual w %	W-mold kg	Wmol+soil kg	γ Moist kN/m^3	γ Dry kN/m^3	γ Moist lbf/m^3	γ Dry lbf/m^3
6.14	3.98	5.25	20.41	19.23	130.16	122.64
6.69	3.98	5.30	21.16	19.83	134.97	126.51
7.92	3.98	5.36	22.2	20.58	141.63	131.24
8.88	3.98	5.39	22.61	20.76	144.19	132.43
10.03	3.98	5.40	22.73	20.66	145.01	131.79
12.42	3.98	5.38	22.4	19.92	142.86	127.08

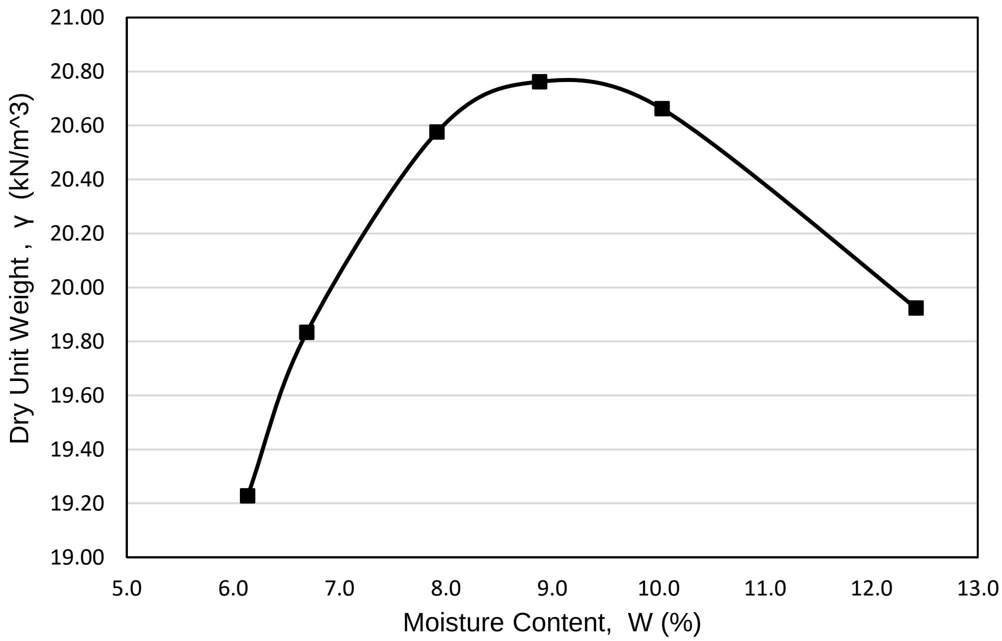

Figure 7. Compaction Sand 70% Clay 30%

The first trial using cement was run. Three target saturation points were tested: 7%, 8% and 9% of water content since the optimum was found to be of 8.88% but considering it would be drier because of the addition of the BSCA cement. Two design mixes were prepared, one with 70% sand and 30% proportions correspondent to the control group, and the second one with the same soil proportion of 70% sand and 30% clay but also containing 6 % of BSCA cement. One important factor to consider is that the soil for this test was dried in the oven for 24 hours before its compaction to improve repeatability.

The results of the control group, Figure 8, show a significant decrease in water content compared the optimum water content found from the last test using the same proportions of soil as shown in Figure 7. The optimum moisture content of the control group was of 7.46 percent and its dry density of 21.16 kN/m^3 also shown in Table 7. One of the factors that could explain this discrepancy of the lower optimum water content is that the soil was placed in the oven before its compaction because the new bag of sand was thought to be wet.

Table 7. Compaction Curve Control Group Sand 70% Clay 30 %

Cement %	Target w%	Actual w %	W-mold kg	W mold+ soil kg	γ Moist kN/m^3	γ Dry kN/m^3	γ Moist lbf/m^3	γ Dry lbf/m^3
0	7%	6.28	3.98	5.37	22.32	21.00	142.35	133.93
0	8%	7.46	3.98	5.40	22.73	21.16	145.01	134.94
0	9%	8.63	3.98	5.40	22.85	21.03	145.73	134.15

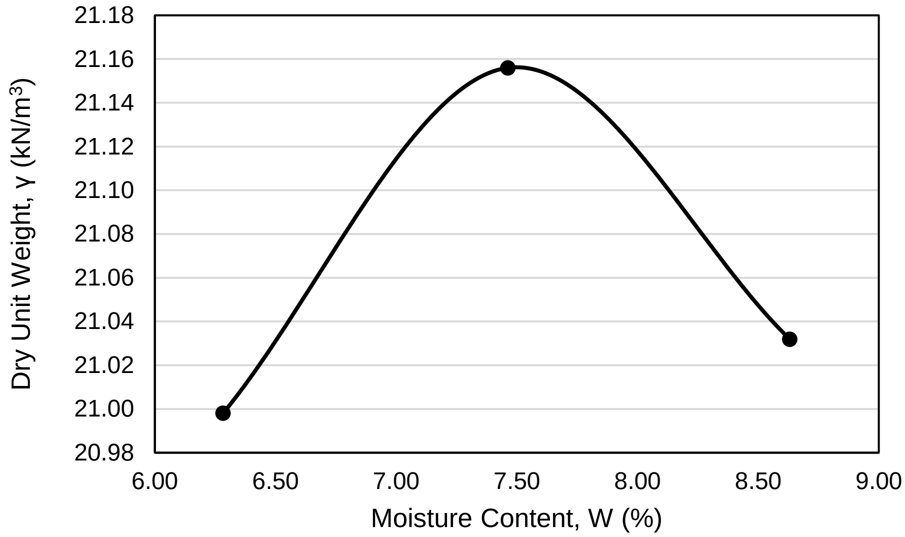

Figure 8. Compaction Curve Control Group Sand 70% Clay 30 %

One of the major challenges faced during the testing of the mixture with the BSCA cement was getting the cylinder off the proctor mold. After the compaction of the BSCA soil cement, considering this is a rapid setting cement, it was difficult to evenly flatten the top. Also, removing the sample from the mold without damaging the cylinder was challenging. This was the first test performed using cement. Some other factors could have affected to the results. The unconfined compressive strength was not adequately calibrated and the cylinder containing cement for the target moisture content of 7% was tested three times for its compressive strength, the load kept increasing and then stopped and the same cylinder was then decided to be tested again. Before a cylinder was tested, the cylinder was let to stand for an hour in order to develop its strength. In order to have a cylinder tested on time, the proctor test was run by one person while the other performed the unconfined compressive strength. However, after the problem with the compression apparatus, the next cylinder was standing out of the mold longer than expected and this could have caused a loss in moisture content. The test was unsuccessful since as shown in Figure 9, the compaction curve reflects unreliable results. The data of these saturation points with cement are shown in Table 8.

Table 8. Compaction Curve Control Group 70% Sand, 30% Clay + 6% BSCA Cement

Cement %	Target w%	Actual w %	W-mold kg	W mold+ soil kg	γ Moist kN/m³	γ Dry kN/m³	γ Moist lbf/m³	γ Dry lbf/m³
6	7%	3.96	3.98	5.31	21.34	20.53	136.10	130.92
6	8%	6.73	3.98	5.34	21.82	20.44	139.17	130.39
6	9%	5.91	3.98	5.06	17.29	16.33	110.29	104.14

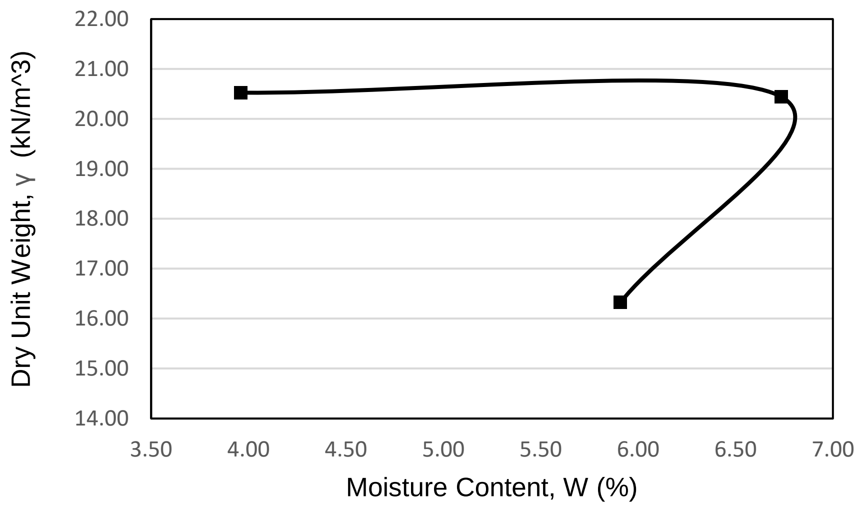

Figure 9. Compaction Curve Control Group 70% Sand, 30% Clay, 6% BSCA Cement

The proportions of 70 % play sand and 30% art red art clay correspond to the AASHTO A2 soil classification. When working with OPC cement, the recommended content of cement for this group classification was of 5% to 9% of OPC by weight of soil, see Figure 1. [16] These recommended percentages of cement can be used as the starting range of proportions of cement for the further study when using BSCA instead of OPC in order to compare their behavior. Therefore, cement percentages of 5, 7 and 9 by weight of soil should be tested. It is known that soil cement, as well as other soil mixtures, should be compacted at their optimum water content for them to achieve their maximum dry unit weight. After having performed four tests using the 70% and 30% proportions, the optimum moisture content reported was of 8.88% for the last test on the soil. Optimum water content would provide enough water for the soil cement to hydrate and start the process of hardening, but too much water content would decrease the strength of the soil cement. Therefore, the water contents recommended to be tested are 7, 8, 9, 10 and 11 percent since that range would include the optimum water content found. The comparison can be made by preparing two batches of the 70% sand and 30% clay proportions of soil and adding the same percentage of OPC and BSCA to each one and testing them at the same water content Performing the unconfined compressive strength of the cylinders from the BSCA and OPC cylinders should provide enough data to determine how each of them perform.

The following table is suggested in order to keep record of the testing results, the cells are expected to be filled with results from the Unconfined Compressive Strength.

Table 9. Suggested Table for Results Recording

Curing Time	Time BSCA or OPC	Water Content W%				
		7%	8%	9%	10%	11%
BSCA or OPC Content by weight %	5%					
	7%					
	9%					
		Unconfined Compressive Strength MPa				

CONCLUSION

Having a rapid-setting soil-cement mix design is useful because it helps to minimize costs of damage to levees and other water structures that are affected by the increase of flooding during these years. BSCA cement could be economically feasible despite its higher up-front cost due to the increased construction time. Furthermore, BSCA cement is more environmentally friendly. In order to find the ideal proportion of BSCA to use in a soil mix design, a comparison between its behavior and the behavior of OPC has to be made. Water contents at which soil cement should be tested are based on the optimum water content found for the same proportions of soil without cement. The optimum water content provides the maximum dry density. A comparison between BSCA and OPC should start by testing the recommended range of cement percentage of OPC for the respective soil classification, at the range of moisture contents that includes the optimum water content of the prepared soil. The unconfined compressive strength should be performed to check the development of strength of thee BSCA cylinders compared to the OPC cylinders. By finding a relation between the percentage of cement to the strength between both BSCA and OPC, then, for a given strength, the amount of BSCA cement to be used could be determined.

APPENDIX

Table 10. Measurements from Laboratory, Sand 70% Clay 30%

DESIGN MIX PROPORTIONS • **Sand** → 70 % • **Clay** → 30 %					
Target Moisture Content of 7 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1.12	kg	Weight of Sand	1.12	kg
W Clay	0.48	kg	Weight of Clay	0.48	kg
W Water	112	g	Weight of Container	86.35	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	129.48	g
W Mold + Soil	5.265	kg	Weight of Container and dry soil	127.44	g
Target Moisture Content of 8 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1.12	kg	Weight of Sand	1.12	kg
W Clay	0.48	kg	Weight of Clay	0.48	kg
W Water	128	g	Weight of Container	87.48	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	150.00	g
W Mold + Soil	5.303	kg	Weight of Container and dry soil	146.05	g
Target Moisture Content of 9%					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1.12	kg	Weight of Sand	1.12	kg
W Clay	0.48	kg	Weight of Clay	0.48	kg
W Water	144	g	Weight of Container	86.88	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	167.10	g
W Mold + Soil	5.329	kg	Weight of Container and dry soil	161.77	g
Target Moisture Content of 11 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1.12	kg	Weight of Sand	1.12	kg

W Clay	0.48	kg	Weight of Clay	0.48	kg
W Water	176	g	Weight of Container	86.50	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	135.78	g
W Mold + Soil	5.396	kg	Weight of Container and dry soil	131.61	g
Target Moisture Content of 13 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1.12	kg	Weight of Sand	1.12	kg
W Clay	0.48	kg	Weight of Clay	0.48	kg
W Water	208	g	Weight of Container	87.71	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	128.62	g
W Mold + Soil	5.373	kg	Weight of Container and dry soil	124.61	g

Table 11. Measurements from Laboratory, Clay 100%

DESIGN MIX PROPORTIONS • **Sand** → 0 % • **Clay** → 100 %					
Target Moisture Content of 10 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.3	kg	Total weight of soil	1.3	kg
W Sand	0	kg	Weight of Sand	0	kg
W Clay	1.3	kg	Weight of Clay	1.3	kg
W Water	130	g	Weight of Container	87	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	133.29	g
W Mold + Soil	5.126	kg	Weight of Container and dry soil	128.27	g
Target Moisture Content of 12 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.3	kg	Total weight of soil	1.3	kg
W Sand	0	kg	Weight of Sand	0	kg
W Clay	1.3	kg	Weight of Clay	1.3	kg
W Water	156	g	Weight of Container	87.55	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	143.7	g
W Mold + Soil	5.173	kg	Weight of Container and dry soil	136.99	g
Target Moisture Content of 14 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.3	kg	Total weight of soil	1.3	kg
W Sand	0	kg	Weight of Sand	0	kg
W Clay	1.3	kg	Weight of Clay	1.3	kg
W Water	182	g	Weight of Container	86.77	g
W Mold No Collar	3.978	kg	Weight of Container and Wet soil	149.84	g
W Mold + Soil	5.232	kg	Weight of Container and dry soil	141.4	g
Target Moisture Content of 16 %					
Proctor Compaction			Moisture Test		
W Total Soil	1.3	kg	Total weight of soil	1.3	kg
W Sand	0	kg	Weight of Sand	0	kg
W Clay	1.3	kg	Weight of Clay	1.3	kg
W Water	208	g	Weight of Container	86.52	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	157.83	g

W Mold + Soil	5.245	kg	Weight of Container and dry soil	147.83	g

Target Moisture Content of 18 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.3	kg	Total weight of soil	1.3	kg
W Sand	0	kg	Weight of Sand	0	kg
W Clay	1.3	kg	Weight of Clay	1.3	kg
W Water	234	g	Weight of Container	86.64	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	161.90	g
W Mold + Soil	5.268	kg	Weight of Container and dry soil	150.14	g

Table 12. Measurements from Laboratory, Sand 85% Clay 30%

DESIGN MIX PROPORTIONS • **Sand** →85 % • **Clay** → 15 %					
Target Moisture Content of 7 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.5	kg	Total weight of soil	1.5	kg
W Sand	1275	kg	Weight of Sand	1275	kg
W Clay	225	kg	Weight of Clay	225	kg
W Water	105	g	Weight of Container	86.1	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	196.5	g
W Mold + Soil	5.262	kg	Weight of Container and dry soil	188.6	g
Target Moisture Content of 8%					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.5	kg	Total weight of soil	1.5	kg
W Sand	1275	kg	Weight of Sand	1275	kg
W Clay	225	kg	Weight of Clay	225	kg
W Water	120	g	Weight of Container	86.6	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	195.3	g
W Mold + Soil	5.265	kg	Weight of Container and dry soil	187.6	g
Target Moisture Content of 9 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.5	kg	Total weight of soil	1.5	kg
W Sand	1275	kg	Weight of Sand	1275	kg
W Clay	225	kg	Weight of Clay	225	kg
W Water	135	g	Weight of Container	86.7	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	171.7	g
W Mold + Soil	5.313	kg	Weight of Container and dry soil	164.96	g
Target Moisture Content of 11%					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.5	kg	Total weight of soil	1.5	kg
W Sand	1275	kg	Weight of Sand	1275	kg
W Clay	225	kg	Weight of Clay	225	kg
W Water	165	g	Weight of Container	87.1	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	186.7	g
W Mold + Soil	5.321	kg	Weight of Container and dry soil	177.4	g
Target Moisture Content of 13%					
Proctor Compaction			**Moisture Test**		

W Total Soil	1.5	kg	Total weight of soil	1.5	kg
W Sand	1275	kg	Weight of Sand	1275	kg
W Clay	225	kg	Weight of Clay	225	kg
W Water	195	g	Weight of Container	85.7	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	231.8	g
W Mold + Soil	5.345	kg	Weight of Container and dry soil	216.8	g

Table 13. Measurements from Laboratory, Sand 70% Clay 30%

DESIGN MIX PROPORTIONS • **Sand** → 70 % • **Clay** → 30 %					
Target Moisture Content of 6 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	96	g	Weight of Container	86.53	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	136.87	g
W Mold + Soil	5.251	kg	Weight of Container and dry soil	133.96	g
Target Moisture Content of 8 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	128	g	Weight of Container	87.04	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	153.44	g
W Mold + Soil	5.335	kg	Weight of Container and dry soil	148.64	g
Target Moisture Content of 9 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	144	g	Weight of Container	86.71	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	186.13	g
W Mold + Soil	5.388	kg	Weight of Container and dry soil	178.02	g
Target Moisture Content of 10 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	160	g	86	86.52	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	186.44	g
W Mold + Soil	5.396	kg	Weight of Container and dry soil	177.33	g

Table 14. Measurements from Laboratory, Sand 70% Clay 30% with added points

DESIGN MIX PROPORTIONS • **Sand** →70 % • **Clay** → 30 %					
Target Moisture Content of 6 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	96	g	Weight of Container	86.53	g
W Mold No Collar	3.978	kg	Weight of Container and Wet soil	136.87	g
W Mold + Soil	5.251	kg	Weight of Container and dry soil	133.96	g
Target Moisture Content of 7 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	112	g	Weight of Container	85.89	g
W Mold No Collar	3.978	kg	Weight of Container and Wet soil	150.77	g
W Mold + Soil	5.298	kg	Weight of Container and dry soil	146.7	g
Target Moisture Content of 8 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	128	g	Weight of Container	87.04	g
W Mold No Collar	3.978	kg	Weight of Container and Wet soil	163.1	g
W Mold + Soil	5.363	kg	Weight of Container and dry soil	157.52	g
Target Moisture Content of 9 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	144	g	Weight of Container	86.71	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	186.13	g
W Mold + Soil	5.388	kg	Weight of Container and dry soil	178.02	g
Target Moisture Content of 10%					
Proctor Compaction			**Moisture Test**		

W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	160	g	86	86.52	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	186.44	g
W Mold + Soil	5.396	kg	Weight of Container and dry soil	177.33	g
Target Moisture Content of 13 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	208	g	86	87.66	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	200.98	g
W Mold + Soil	5.375	kg	Weight of Container and dry soil	188.46	g

Table 15. Measurements from Laboratory. Control Group, Sand 70% Clay 30% using 0% of cement.

DESIGN MIX PROPORTIONS CONTROL GROUP • **Sand** → 70 % • **Clay** → 30 % • **Cement** → 0 %					
Target Moisture Content of 7 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	112	g	Weight of Container	86.53	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	163.3	g
W Mold + Soil	5.370	kg	Weight of Container and dry soil	158.76	g
Target Moisture Content of 8 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	128	g	Weight of Container	86.3	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	165.5	g
W Mold + Soil	5.396	kg	Weight of Container and dry soil	160.0	g
Target Moisture Content of 9 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	144	g	Weight of Container	86.20	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	159.2	g
W Mold + Soil	5.403	kg	Weight of Container and dry soil	153.4	g

Table 16. Measurements from Laboratory, Sand 70% Clay 30% using 6% of BSCA cement.

DESIGN MIX PROPORTIONS • **Sand** →70 % • **Clay** → 30 % • **BSCA** →6%					
Target Moisture Content of 7 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	112	g	Weight of Container	86.70	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	13128.7	g
W Mold + Soil	5.309	kg	Weight of Container and dry soil	127.1	g
Target Moisture Content of 8 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	128	g	Weight of Container	87.0	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	159.9	g
W Mold + Soil	5.339	kg	Weight of Container and dry soil	155.3	g
Target Moisture Content of 9 %					
Proctor Compaction			**Moisture Test**		
W Total Soil	1.6	kg	Total weight of soil	1.6	kg
W Sand	1120	kg	Weight of Sand	1120	kg
W Clay	480	kg	Weight of Clay	480	kg
W Water	144	g	Weight of Container	86.6	g
W Mold No Collar	3.979	kg	Weight of Container and Wet soil	131.4	g
W Mold + Soil	5.057	kg	Weight of Container and dry soil	128.9	g

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