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A Three-Stack Mechanical Sieve Shaker for Determining Aggregate Size Distribution of Soils

Emir Ali[a], Edwin I. Ekwue[bΨ], Jacqueline Bridge[c], and Robert Birch[d]

[a] Neal and Massy Wood Group Limited, Guardian Life Building, Digi Lane, Endeavour Industrial Estate, Chaguanas, Trinidad and Tobago, West Indies; E-mail: Emirproject@hotmail.com

[b,c,d] Department of Mechanical Engineering, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies; E-mails: Edwin.Ekwue@sta.uwi.edu; Jacqueline.Bridge@sta.uwi.edu; Robert.Birch@sta.uwi.edu;

[Ψ] *Corresponding Author*

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Abstract: *The design, construction and testing of a soil dry sieving apparatus is described. It could be used to effectively determine the aggregate size distribution curves of three dry soil samples simultaneously. The design required that a means be developed to agitate soil samples placed on three stacks of sieves. Both vertical and slight outward movements of the soils in the sieve nest were obtained in this particular design. Three soils were used to test this equipment using the operating parameters of three vibration frequencies and three sieving times. Best sieving of the three soils was obtained at 1.75 Hz frequency for a sieving time of 15 minutes. Results obtained at this best operating condition were then compared to those obtained from an existing commercial mechanical sieve shaker at the same 15 minutes sieving time. The results showed that the constructed three-sieve shaker performed very well in comparison with the commercial shaker; in addition it was quieter and easier to operate. The major advantage of the constructed three-sieve mechanical sieve shaker is that three stacks of sieves are incorporated into the design. This decreases by almost three times, the normal time required for aggregate size analysis using the existing commercial shakers, which all utilise single sieve stacks.*

Keywords: *Soil, sieve, stack, shaker*

1. Introduction

The size distribution of dry soil aggregates is of importance to many professionals involved in soils research. It provides information on the soil's physical structure (bulk density, consistency), and its susceptibility to wind and water erosion (Chepil, 1942; Wischmeier and Smith, 1978). It also determines the soil's suitability for specific crops based on its capacity for water, nutrient and heat, infiltration and aeration. Adequate knowledge of aggregate size-distribution and texture may be used to inform interested parties of appropriate land-use. Better retention walls can be built and residences and road works can be more suitably located in mountainous areas. Aggregate-size distribution also affects soil compaction since soils with uneven aggregate size distribution are expected to pack more closely than those with uniform distribution (Brady and Weil, 1999).

Aggregate size distribution of soils is usually determined by either wet sieving (Kemper and Koch, 1966) or dry sieving (Chepil and Bisal, 1943). While wet sieving is used to determine the proportion of stable aggregates resistant to water disruption during rainfall (Ekwue, 1990), dry sieving is utilised mainly to relate aggregate sizes to soil erosion by wind (Chepil, 1942).

Determining aggregate size distribution of a soil by hand is a very laborious process; consequently, mechanical shakers have been developed to simplify the process. There is no universal agreement on the method to be used in dry sieving soils. Over the years, different methods of sieving have been developed and have proven extremely effective in determining the aggregate size distribution of soils. Six major types of commercial mechanical sieve shakers were identified by Eccles and Ekwue (2008). Mechanical sieve shakers utilise different types and modes of agitating forces to sieve the soil. These are discussed in Section 2. One distinct disadvantage of the present commercial mechanical shakers is that they are very expensive due to complicated operation process and only sieve one stack of soil at a time. This makes the analysis of several soil samples a very time consuming process. To enhance the effectiveness of these machines, Eccles and Ekwue (2008) produced a mechanical sieve shaker that could sieve two soil samples at a time.

The current design examines a way of making mechanical sieving even less time consuming by sieving three soil samples simultaneously by using three stacks of sieves. The cost of the machine is also decreased by simplifying its design as well as its principle of operation.

2. Existing Commercial Mechanical Shakers

To establish the necessary design specifications for the sieving machine, a product research was conducted which involved an analysis of ten commercial sieving machines (see Table 1). Data were collected on the size of the machines, the form and amplitude of their sieving motion, the size of the sieve stack, the maximum number of sieves possible and the measuring range/timing interval. This information was used for comparison and bench marking to assist in determining the product performance requirements. The main drawback in all the products except the two-stack mechanical sieve shaker was that each device could only process one batch of soil at a time. This meant that if many samples of soil were to be tested, then the process could be very time-consuming.

In determining the requirements of the constructed mechanical shaker, some of the more important design parameters were the maximum number of soil samples able to be sieved at a time, the time required to complete the process, the size of the device, the cost of the device and the effectiveness of the design. Consequently, the design should:

- Allow for an adjustable number of sieve pans in the stack in order to vary the number of samples that can be sieved at a time.
- Be relatively compact and inexpensive.
- Reduce the time taken to sieve a given number of samples of soil.
- Be as effective as the commercially available mechanical sieve shakers.

The device described in the following section satisfies these requirements.

3. Description of the Constructed Three-Stack Mechanical Sieve Shaker

3.1 Construction

Figure 1 shows the construction of the sieving machine. There is the rigid immobile load-bearing frame which consists of the base frame, the front support, the vertical support, the U support and the top bar to which a three arm sub-assembly is welded.

Table 1. Comparison of existing soil sieving machines

Product Name	Sieve Diameters	Max sieve Height	Sieving Motion	Max. Batch	Max Number of sieves	Max Sieve Mass	Amplitude of Motion	Measuring Range/Interval Operation
Retsch AS 450	400/ 450 mm	963 mm	6 electromagnetically driven springs give rise to a throwing motion with angular momentum – 3D motion	25 kg	13/9	50 kg	0.2 – 2.2 mm	25 µm – 125 mm/ 10 - 99s
Ro-Tap Sieve Shaker RX-29	200 mm	Full height 65 /50 mm each half height 40/25 mm each	Electromagnetic drive performing 278 oscillations per minute as well as 150 taps per minute	5 kg	6/13	*NS	NS	45 µm - 25 mm / 20 -30 min
Fritsch	200 mm	550 mm Both full and half height sieves	Electromagnetic drive – vertical; line frequency 60 Hz	2 kg	10/16	3kg	0-3 mm	25 – 63 mm /3 – 20 min
Meinzer II Sieve Shaker	200 mm	Both full and half height sieves	Electromagnetic drive – vertical and horizontal motion; line frequency 60 Hz	NS	8/15	NS	NS	60 min timer
Gilson SS-15 Sieve Shaker	8 inch	Both full and half height sieves	Back and forth lateral motion is combined with up and down and tilting motions to cause test material to travel in an orbit on the sieve surfaces. Delivered by ¼ hp motor	NS	6 / 13	NS	NS	NS
Analysette 3-Spartan Digital Sieve Shaker	NS	NS	Vertical oscillation generated by an electromagnetic drive.	5 kg	Up to 10	NS	NS	20 µm - 25 mm / ~20 min
DuraShake Sieving Machine	NS	Full height 304.8 mm each Half height 203.2 mm ea	Rotates soil at an angle and taps it using a series of nylon blocks, all controlled by a 1/3 hp motor.	NS	5/9	NS	NS	NS
Two-Stack Mechanical Sieve Shaker	200 mm		Vertical & Horizontal Motion, together with a tapping motion generated by an arm-follower approach. Two sieve-stacks are shaken simultaneously.	NS	8	NS	32 mm in each direction	75 µm – 4.75 mm / 10 min

Remarks: NS - not specified in product literature.

3. Description of the Constructed Three-Stack Mechanical Sieve Shaker

3.1 Construction

Figure 1 shows the construction of the sieving machine. There is the rigid immobile load-bearing frame which consists of the base frame, the front support, the vertical support, the U support and the top bar to which a three arm sub-assembly is welded. There are 3 pins rigidly attached to the base frame which support a big ring. This ring has a series of evenly spaced “cam-like” elevations with a symmetric parabolic profile of height 25.4 mm and length 133.4 mm.

Energy is transferred from a ¼ hp motor to the driven shaft via a linked belt and pulley system. The driven shaft has a disc keyed to it; the disc rigidly supports three soil sieve stack bases beneath each of which is a roller follower. The keyway prevents relative rotation of the disc with respect to the shaft; however, it allows for appreciable axial motion of the disc. The soil sieve bases support a stack guide with adjustable stack caps.

Each soil sieving stack consists of 7 sieves ranging from sieve number 4 (4.75 mm diameter mesh) to sieve number 200 (0.075 mm diameter mesh). The largest sieve opening (4.75 mm) was placed on top and the receiving pan on the bottom. The top bar of each stack guide has a pin which passes freely through a central bore of each arm sub-assembly. A compression spring is placed between the top bar of each stack guide and the underside of its associated arm sub-assembly.

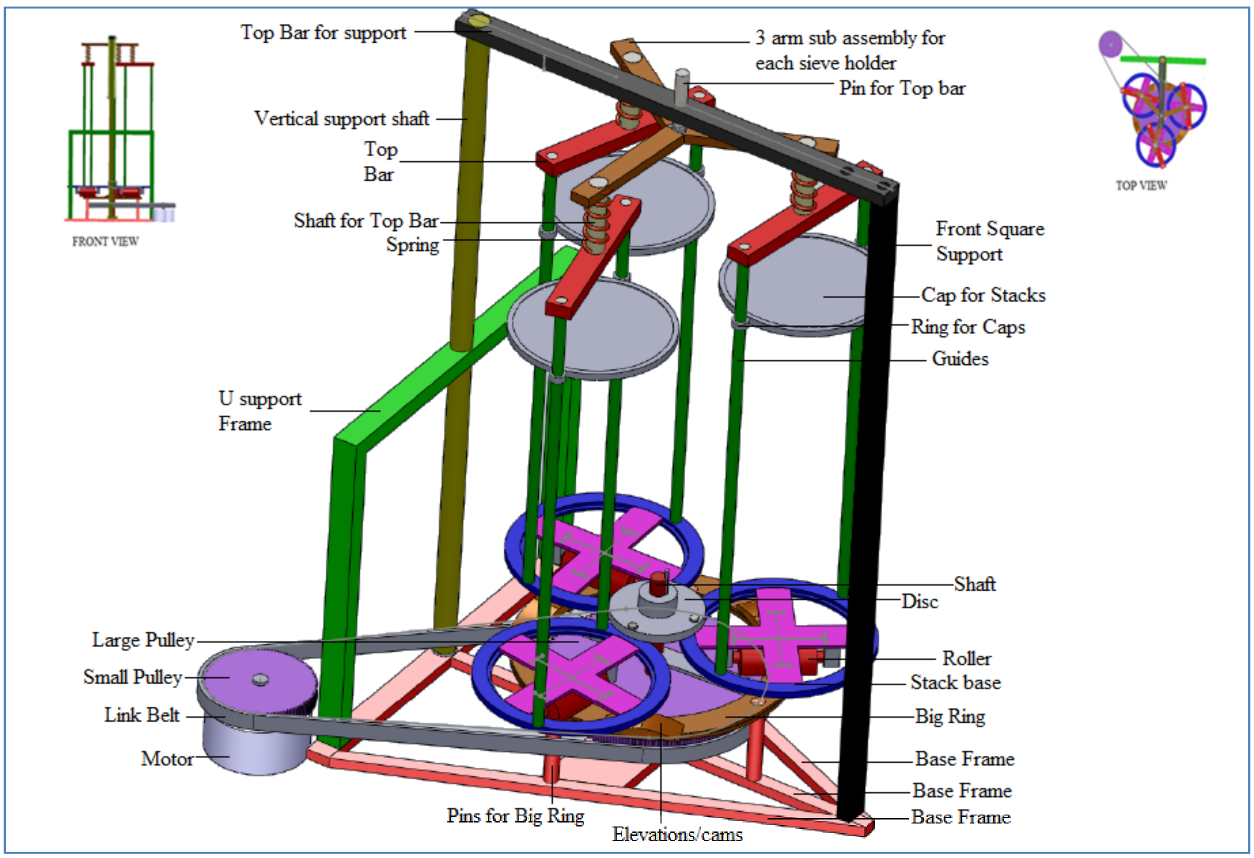

Figure 1. Views of the three-stack mechanical soil sieve shaker

3.2 Principle of Operation

A sample of soil to be sieved is placed in the top bowl of each stack. The stack is then loaded into the stack holder and constrained by the stack cap. Next, the motor is turned on. Energy is transferred to the shaft with the attached disc – soil sieve bases assembly. As the bases rotate, their roller followers move around the large ring. When they encounter the elevations, they force the sieve to be subjected to a reciprocating up-down motion. Two key components which facilitate this motion are the keyway between the shaft and the disc (which allows axial motion) and the holder’s top support pin which can freely move within the bore of its arm sub-assembly. The reciprocating vertical motion provides the sieving action; once the frequency is high enough, contact is lost between the soil and the sieve chamber. This agitating action allows the smaller loose particles to pass through the sieve into a lower sieve.

If the system is shaken long enough, eventually only soil particles which are larger than the mesh size (or very close to it) will be left in each sieve. The increase in compression of the spring as the stack moves over the elevations generates forces which push the soil stack holder down, and is transmitted to the sieve stacks thereby increasing the sieving action. Since there are three elevations on the big ring, the frequency of the reciprocating motion is three times the rate of rotation rate of the driven shaft.

One main advantage of this design is the compactness of the machine. It does not take up much space and the user can place and remove stacks very easily from the holders.

4. Testing of the Constructed Three-Stack Mechanical Soil Sieve Shaker

4.1 Purpose of the tests

Tests were conducted to investigate the best vibration frequency and time of sieving for the constructed three-stack machine. The frequency of vibration of the mechanical shaker in Hz was described as the number of events (up-down motions of the soil stack) within a given time frame. The machine design requires a judicious use of the frequency. If the frequency is too low, the particles will not be agitated enough to ensure the finer soil passes through the mesh. However, if the frequency is too large, the shaking effect may become too vigorous and cause the soil to "break-up" which is undesirable when trying to determine *in-situ* soil composition. Since the vibration frequency that could yield the best sieving of the soil for the constructed machine was not known *a priori*, the machine was tested at output speeds of 25, 35 and 45 rpm which corresponded to frequencies of 1.25, 1.75 and 2.25 Hz, respectively.

The time required for sieving is also an important design parameter. Whitby (1959) indicated that within a given sieve of the stack, the process may be considered to consist of two different sieving regimes. When the sieving begins, there are many particles within the chamber which are much less than the sieve size. During the first seconds within the first sieving regime, as the soil is agitated, most of the smaller particles fall through the sieve. After this time, regime two of the sieving occurs; most of the soil particles within each sieve are larger than the sieve mesh size. Any particles remaining which are theoretically able to pass through the mesh are very close to the mesh size.

The cumulative distribution of the soil passing through the sieve follows the pattern of log normal distribution (Hagen et al., 1987). The sieving process must be long enough so that each sieve could reach its individual regime two process. However, there is also an upper limit on the time taken for processing after which the clods of soil begin to break up; this is undesirable when trying to determine the in-situ soil composition. Sieving times of 5, 15 and 15 minutes were utilised so as to determine the best time for sieving.

The machine was tested for repeatability of results; consequently, each soil sample was sieved or tested three times. Tests were also carried out to compare the accuracy of the device in relation to existing commercial mechanical sieve shakers. The results obtained by using the constructed three-stack mechanical sieve shaker to obtain the aggregate size distribution by dry sieving were compared to those obtained using an existing commercial mechanical shaker: the RoTap machine (Laval Lab Incorporated, 2005). The RoTap sieving machine utilises a rotary motion and a slight tapping at the top of the sieve set every second. The machine holds one set of soil sieves at a time.

4.2 Procedure for soil testing

Three common agricultural soil samples in Trinidad (see Table 2) were utilised for the tests: Piarco sandy loam, Maracas clay loam and Talparo clay. The mechanical analysis of the soils was carried out using the hydrometer method (Lambe, 1951) while the organic matter contents were determined using the Walkley and Black method (1943). The soil materials to be tested were first air-dried. Soil aggregates or lumps were then thoroughly broken up with fingers or with a mortar and pestle. The aim here was to make sure that the soil sample consisted of individual aggregates. 2000 grams of soil were used for each test.

The actual tests for the three-stack mechanical sieve shaker were a full factorial experiment involving the three soils at three vibration frequencies (1.25 Hz, 1.75 Hz and 2.25 Hz) with operating times of 5, 10 and 15 mins. Each test was replicated three times to give a total of 81 tests.

Table 2. Classification, organic matter, and the aggregate size distribution (%) of the soils

Soil Series	Classification*	Organic Matter Content (%)	Aggregate Size Distribution (%)		
			Sand (0.06-2 mm)	Silt (0.002-0.06mm)	Clay (<0.002mm)
Piarco sandy loam	Aquoxic Tropudults	1.7**	64.9	17.0	18.1
Maracas clay loam	Orthoxic Tropudults	4.7	44.7	24.7	30.6
Talparo clay	Aquentic Chromuderts	2.7	25.4	28.3	46.3

Remarks: * - Classification according to the Soil Taxonomy System (Soil Survey Staff, 1999).
** - All values are means of three replicates

The soil samples were then transferred into the top of a stack of sieves arranged in opening sizes of sieves (0.075 to 4.75 mm diameter) and put on the shaker, where they were sieved for 5, 10 or 15 min each. When the oscillation of the mechanical shaker was completed, the sieve stacks were removed and carefully disassembled. The mass of soil retained in each sieve was determined by weighing and the percentage of soil that passed through each sieve was determined. The full mechanical sieving process and the analysis of results were fully described by Lambe (1951) and Eccles and Ekwue (2008).

5. Results and Discussion

5.1 Operation

During the testing, it was observed that the constructed three-stack mechanical shaker produced a smooth oscillating motion; there was no apparent noise generation and little or no visible vibration. Removal and placement of the sieves was easier using the new machine than the RoTap mechanical shaker. There was also greater flexibility in the adjustment of its operating parameters.

5.2 Repeatability of results

The results were examined for repeatability. Table 3 shows the results obtained when three different tests were conducted on Talparo soil with the three-stack sieve at 1.25 Hz frequency for 5 minutes of operation. It shows that the distribution curves obtained over the three tests were close to each other. In fact, the minimum coefficient of determination between any two of the soil distribution data was 0.999 (perfect fits correspond to a coefficient of determination of 1). Hence the machine had repeatable results.

In addition, the percentages of soil that passed through each sieve size were determined and these were used to plot the aggregate size distribution curves for each soil sample. Figure 2 shows the distribution curves for each of the three soil types when the sieving machine was operated at 1.75 Hz for 15 minutes. The distribution curves obtained for different combinations of frequency and sieving time are similar in format. Three basic soil parameters (effective size, uniformity coefficient and coefficient of gradation) were obtained from the distribution curves and used to classify the sieved soil samples. Table 4 details the values of these basic soil parameters of the soils tested with the three-stack mechanical sieve shaker for the three experimental factors of soil type, vibration frequency and sieving time. The effective size of a soil is defined as the diameter in the aggregate size distribution curve corresponding to 10% finer and is denoted as D_{10} (Das, 2002).

Since all the D_{10} values are less than 0.25 mm, all the soil samples were sieved to their fine states by the constructed three-stack mechanical sieve shaker. The uniformity coefficient (UC) is a measure of the aggregate size range. It is the ratio of the diameter corresponding to 60% finer (D_{60}) to the effective size (Das, 2002). A high uniformity coefficient indicates that the fine and coarse materials are more thoroughly blended i.e. the sample is more non-uniform.

All the sieved Talparo clay soil samples can be classified as non-uniform since they all have uniformity coefficients greater than 5. For the other two soils, some of the UC values were more than 5 showing non-uniformity. The coefficient of gradation is the measure of the shape of the aggregate size curve (Das, 2002) and is defined as shown in Table 4. Since many of the sieved samples had the coefficient of gradation within the range of 1 to 3, they are classified as well-graded. This means that the smaller aggregates will pack between the larger ones. There is fairly even distribution of the proportions of all the different aggregate sizes.

Table 3. Repeatability of results from the three-stack sieving machine for the three tests on Talparo clay soil at 1.25 Hz and 5 minutes sieving time

Sieve Number	Diameter of Sieve (mm)	Mass of soil retained and percentage of soil passing each sieve					
		Test 1		Test 2		Test 3	
		Mass Retained (g)	% Passing	Mass Retained (g)	% Passing	Mass Retained (g)	% Passing
4	4.750	2.9	98.83	6.2	97.50	5.53	97.78
6	3.350	46.5	80.05	48.6	77.89	49.4	77.91
10	2.000	79.9	47.78	81.6	44.97	81.6	45.11
50	0.300	50.9	27.22	47.8	25.69	49.0	25.40
70	0.212	28.6	15.67	26.5	15.00	27.1	14.51
140	0.106	21.6	6.95	19.7	7.05	19.9	6.50
200	0.075	16.1	0.44	15.0	1.00	13.2	1.19
PAN		1.1	0.00	2.47	0.00	3.0	0.00

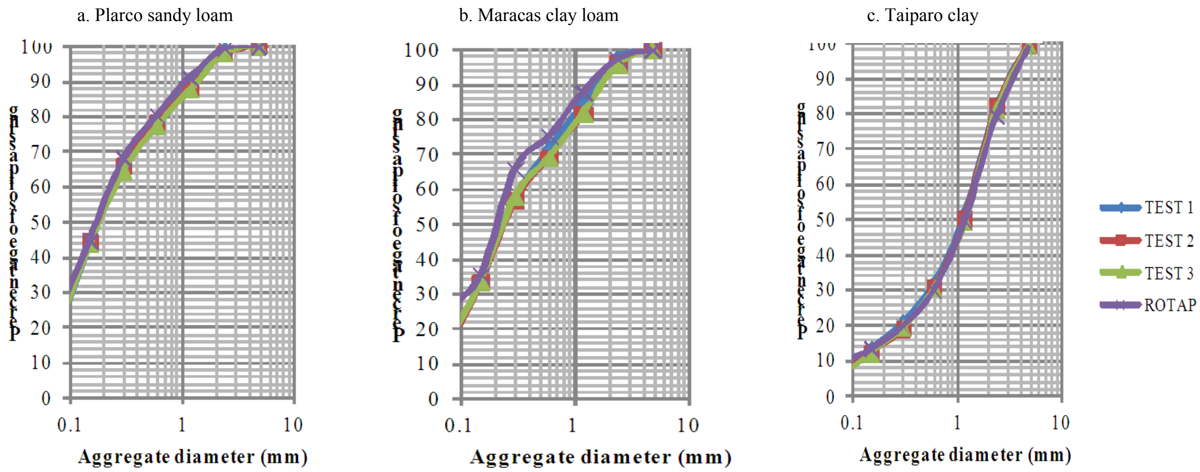

Figure 2. Aggregate-size distribution of the three soils for a 1.75 Hz vibration frequency of the three-stack mechanical soil sieve shaker compared with the RoTap shaker. Sieving time was 15 minutes.

Table 4. Values of some aggregate size parameters of the soils obtained by the constructed three-stack mechanical soil sieve shaker operating at different vibration frequencies and sieving times

Soil Type and Moisture Content	Sieving Time	D_{10}[a]	D_{30}	D_{60}	Cu[b]	Cz[c]
Piarco sandy loam:						
1.25 Hz Frequency	5	0.07	0.14	0.30	4.29	0.93
	10	0.06	0.13	0.29	4.83	0.97
	15	0.04	0.11	0.26	6.50	1.16
1.75 Hz frequency	5	0.04	0.11	0.27	6.75	1.12
	10	0.05	0.12	0.28	5.60	1.03
	15	0.04	0.11	0.26	6.50	1.16
2.25 Hz frequency	5	0.07	0.13	0.28	4.00	0.86
	10	0.06	0.12	0.27	4.50	0.89
	15	0.04	0.11	0.27	6.75	1.12
Maracas clay loam:						
1.25 Hz Frequency	5	0.10	0.18	0.42	420	0.77
	10	0.09	0.15	0.38	4.22	0.66
	15	0.07	0.13	0.36	5.14	0.67
1.75 Hz Frequency	5	0.07	0.14	0.36	5.14	0.78
	10	0.05	0.13	0.34	6.80	0.99
	15	0.05	0.14	0.36	7.20	1.09
2.25 Hz Frequency	5	0.09	0.16	0.43	4.78	0.66
	10	0.07	0.13	0.38	5.43	0.64
	15	0.06	0.13	0.38	6.33	0.74
Talparo clay:						
1.25 Hz Frequency	5	0.12	0.57	1.54	12.83	1.76
	10	0.14	0.61	1.60	11.43	1.66
	15	0.10	0.54	1.51	15.10	1.93
1.75 Hz Frequency	5	0.12	0.60	1.59	13.25	1.89
	10	0.10	0.52	1.45	14.50	1.86
	15	0.07	0.50	1.45	20.71	2.46
2.25 Hz Frequency	5	0.14	0.53	1.44	10.29	1.39
	10	0.12	0.55	1.52	12.67	1.66
	15	0.11	0.54	1.50	13.64	1.77

Remarks: [a] Diameter (mm) of the aggregate to which 10% is finer is defined as effective size
[b] Uniformity coefficient, $Cu = D_{60}/D_{10}$
[c] Coefficient of gradation, $Cz = D_{30}^2/(D_{60} \times D_{10})$

5.3 Effect of the experimental factors on soil aggregate size parameters

Table 5 shows the mean values of the basic soil parameters for the three experimental factors. Results showed that mean effective size, D_{10}, D_{30} and D_{60} increased with increasing clay content in the soils. This is expected because soils with greater levels of clay content are expected to be more aggregated. Values of D_{10}, D_{30} and D_{60} were lowest for the 1.75 Hz frequency of vibration and 15 mins sieving time in all cases. This shows that at this frequency and time of sieving, the soil stacks were well shaken and the best sieving of soils took place in the constructed shaker. In Table 5, it shows that the uniformity coefficient and the coefficient of gradation were the highest for this combination. This further confirms that of all the combinations tested, a 1.75 Hz frequency and a 15 min sieving time gives the best operating condition for the constructed three stack mechanical sieve shaker. At the operating frequency of 1.25Hz, it was observed that the soil and the stacks raised and fell as a unit. In other words, the operating frequency was too low to ensure that the acceleration of the reciprocating motion exceeded that due to gravity. The contact between the soil and the sieve was therefore lost. Consequently, there was no effective agitating action which was required to sieve the soil aggregates. The opposite was true for the 2.25Hz. The speed of the three stacks at this frequency pushed the soil outwards and gave it insufficient time to pass through the sieves.

5.4 Accuracy of the constructed sieving machine

Results obtained by operating the three-stack soil mechanical sieve shaker at 1.75 Hz and 15 minutes sieving time (the most efficient combination of operating conditions as described above) were compared with those obtained from using the RoTap sieve shaker at 15 minutes. The distribution curves produced (Figure 2) were very close to each other. This closeness was verified by the coefficients of determination obtained between the average soil distribution data used to plot the curves for Piarco sandy loam, the Talparo clay soil and the Maracas clay loam. In each case, the results were compared with those from the RoTap machine, which were 0.996, 0.996 and 0.974, respectively. This indicates that the machine is able to produce results with a high degree of accuracy.

It was seen that the RoTap Shaker generally produced curves that were slightly higher than those obtained using the constructed shaker in the case of Maracas clay loam and the Piarco sandy loam. As a higher curve usually indicates a better sieving action, this means that the RoTap shaker gave slightly better results for these two soils. This meant that the constructed shaker probably needed a more vigorous shaking action to produce equivalent or better results than the RoTap shaker. There are several parameters which could be varied to determine the effect on this shaking action. The first two (the height and length of the parabolic elevations on the big ring) have not been examined in this article. However, each of these has an effect on the vertical component of the acceleration of the sieve stack which in turn affects the agitation properties. The frequency of events could also be adjusted. This could be done by varying the number of elevations on the big ring or by adjusting the motor speed. However, as discussed in the principle of operation, it is important to realise that if the frequency is too high the sieving action can be compromised. Finally, the sieving time could be adjusted to obtain better results.

The basic soil parameters obtained from the distribution curves in Figure 2 are shown in Table 6. The constructed three-stack mechanical shaker gave similar classification results to the RoTap sieve shaker although the D_{10}, D_{30}, D_{60} obtained for the RoTap sieve shaker were a bit lower than those for the constructed three-stack sieve shaker indicating a better sieving action in the former. In general, the RoTap mechanical shaker also gave higher uniformity coefficients and coefficients of gradation indicating that the soils were better sieved and had higher chances of being non-uniform. The values obtained from the two mechanical sieving machines were, however, enough to classify all the three soils tested in similar categories. The results obtained by the constructed shaker at present are, therefore, greater than satisfactory in determining the aggregate size distribution of any soil.

Table 5. Mean[a] values of D_{10}, D_{30}, D_{60}, uniformity and coefficient of gradation for the three experimental factors of the three-stack mechanical soil sieve shaker

Factor Level	Mean D_{10} (mm)	Mean D_{30} (mm)	Mean D_{60} (mm)	Mean Uniformity Coefficient	Mean Coefficient of Gradation
Soil Type					
Piarco (Sandy Loam)	0.05	0.12	0.27	5.40	1.07
Maracas (Clay Loam)	0.07	0.14	0.38	5.43	0.74
Talparo clay	0.11	0.55	1.50	13.64	1.83
Frequency of Vibration					
1.25 Hz	0.09	0.28	0.73	8.11	1.19
1.75 Hz	0.06	0.26	0.70	11.67	1.61
2.25 Hz	0.08	0.27	0.72	9.00	1.27
Time of Sieving					
5 minutes	0.09	0.28	0.73	8.11	1.19
10 minutes	0.08	0.27	0.72	9.00	1.27
15 minutes	0.06	0.26	0.71	11.83	1.59

Remarks: [a] Mean values for each factor were obtained by averaging the measured values over the levels of the other two experimental factors. Number of experimental points is 81 representing a factorial experiment with 3 soil types, 3 frequencies of vibration, 3 times of sieving and 3 replications.

Table 6. Mean values of D_{10}, D_{30}, D_{60}, uniformity coefficient and coefficient of gradation for the three-stack mechanical soil sieve shaker operating at 1.75 Hz vibration frequency and for the RoTap shaker at 15 mins sieving time

Soil and Mechanical Shaker Types	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	Uniformity Coefficient	Coefficient of Gradation
Piarco sandy loam:					
Three-stack shaker	0.04	0.11	0.26	6.50	1.16
RoTap shaker	0.03	0.10	0.25	8.00	1.33
Maracas clay loam:					
Three-stack shaker	0.05	0.14	0.36	7.20	1.09
RoTap shaker	0.03	0.11	0.27	9.00	1.49
Talparo clay:					
Three-stack shaker	0.07	0.50	1.45	20.71	2.46
RoTap shaker	0.06	0.44	1.36	22.67	2.37

6. Conclusions

The following could be concluded from the study:

- The constructed three-stack mechanical sieve shaker was found to be user friendly and easy to operate.
- It was well suited for laboratory work.
- The machine was found to be sufficient to sieve and effectively or correctly grade or classify the three soil samples investigated.
- It produced consistent results for each type of soil examined.
- The best sieving action was obtained with a frequency of vibration of 1.75 Hz and a 15-minute sieving time.
- The constructed shaker performed with a degree of accuracy just below that of the RoTap machine.
- The total cost of the device was approximately TT$6,200.00 (approximately US$1,000.00), just over 40% of the cost of a commercial grade single stack shaker.

Future work will be carried out on the machine to determine the most appropriate sieving time, "cam-like" elevation parameters and frequency of operation.

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Authors' Biographical Notes:

Emir Ali *is a graduate of the Faculty of Engineering, The University of the West Indies in 2012 majoring in Engineering Design and Manufacturing Engineering. He is a Mechanical Engineer with the Neal and Massy Wood Group Limited, Chaguanas. His major interests are rotating equipment, inspection and working with hands-on- mechanical devices.*

Edwin I. Ekwue *is presently the Head of the Department of Mechanical and Manufacturing Engineering and Professor in charge of the Biosystems Engineering program at The University of the West Indies, St Augustine, Trinidad and Tobago. He is a member of the Editorial Board of the West Indian Journal of Engineering. His specialty is in Water Resources, Hydrology, Soil and Water Conservation and Irrigation. His subsidiary areas of specialisation are Structures and Environment, Solid and Soil Mechanics, where he has teaching capabilities. Professor Ekwue has published widely. He had served as the Deputy Dean (Undergraduate Student Affairs), the Deputy Dean (Post-graduate Affairs and Outreach), the Chairman of Continuing Education Committee, and the Manager of the Engineering Institute in the Faculty of Engineering at UWI.*

Jacqueline Bridge *is a Lecturer in the Department of Mechanical and Manufacturing Engineering at The University of the West Indies, St. Augustine, Trinidad and Tobago. Her research and teaching interests fall in the area of Applied Mechanics, with special emphasis on Mechanical Vibrations, Nonlinear Dynamical Systems Theory and Finite Element Methods.*

Robert Birch *is an Instructor in the Department of Mechanical and Manufacturing Engineering at The University of the West Indies, St Augustine, Trinidad and Tobago. He is a registered Professional Engineer (R.Eng) and Project Management Professional (PMP) with over sixteen years of industrial and teaching experience. He has a BSc. (Eng) and MPhil in Agricultural Engineering from The University of the West Indies and is presently pursuing a PhD in Mechanical Engineering. Mr. Birch is a member of the Institution of Agricultural Engineers (UK). His interests are in Field Machinery and Heavy Equipment Design, Fluid Power Technology and Soil-Machine interaction.*

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