A Mechanical Shaker for Sieving Dry Soil Samples

C. Eccles[1]
E.I. Ekwue[2]

The design, construction and testing of a soil dry sieving apparatus, which could be used to effectively determine the particle size distribution curves of dry soil samples is described. The design required that a means be developed to agitate soil samples placed on two stacks of sieves, each arranged in decreasing sizes. The apparatus was designed to utilize a horizontal and vertical motion of 32 mm in both directions along with a tapping action. This was obtained by incorporating an arm and follower into the design. Three soils were used to test this equipment. These results were then compared to tests performed on an existing commercial mechanical sieve shaker. The results obtained for these tests showed that the constructed shaker performed very well in comparison with the commercial shaker and was much quieter in operation and more user-friendly. The major advantage of the constructed mechanical sieve shaker is that two stacks of sieves are incorporated into the design, cutting by almost half, the normal time required for particle size analysis using the existing commercial shakers which all utilize single sieve stacks.

Keywords: *Soil, Sieving, Machine, Shaker*

1. Introduction

Determining the particle-size distribution of a soil helps the engineer, geologist, or an agriculturist to understand many soil properties such as how much water, heat, and nutrients the soil could hold, how fast water and heat will move through the soil, and what kind of structure, bulk density and consistence the soil will have. Particle size distribution of soils affects soil erodibility [1, 2] and soil compaction since soils with uneven particle size distribution are expected to pack more closely than those with uniform distribution [3]. Particle size distribution of soils is normally determined by wet sieving [4] or dry sieving [5]. While wet sieving is used to determine the proportion of stable aggregates resistant to water disruption during rainfall [6], dry sieving is utilized mainly to relate particle sizes to soil erosion by wind [1].

Determining particle size distribution of a soil by hand is a very tedious process, hence, the use of mechanical shakers which makes the process a much simpler one. From a search of literature, six major types of commercial mechanical sieve shakers were identified (see Section 1.1). 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 particle size distribution of soils. The mechanical sieve shakers utilize different types and natures of agitating forces to sieve the soil. Due to intense competition among sieve shaker designers, however, the dynamics of these methods are usually not widely known, unless patented. One distinct disadvantage of present commercial mechanical shakers is that they are very expensive due to complicated operative process and only sieve one stack of soil at a time. This makes the analysis of several soil samples a very time consuming process.

The present design sought to provide a means by

[1] Mechanical Engineer, BP Trinidad & Tobago LLC, Port of Spain, Trinidad, W.I. Email: Cheeriche.Eccles@bp.com
[2] Professor, Faculty of Engineering, The University of the West Indies, St Augustine, Trinidad, WI. Edwin.Ekwue@sta.uwi.edu

which this testing time could be reduced by sieving two soil samples simultaneously utilizing two stacks of sieves as well as to reduce the cost of the device by using a simple operative process.

1.1 Existing Commercial Mechanical Shakers

1.1.1 Tyler Ro-Tap sieve shaker [7]

This mechanical sieve shaker was developed by one of the leading producers of mechanical shakers. Mechanical action is applied to the test sieves in two dimensions, first a horizontal circular motion and then a vertical tapping motion.

1.1.2 Gilson SS-15 sieve shaker [8]

This shaker utilizes back and forth lateral motion combined with up and down and tilting motions to cause test material to travel in an orbit on the sieve surfaces. The back and forth lateral motion is achieved by the use of belt systems on either side of the base of the sieve frame. The up and down tilting motion is achieved by an offset circular cam. This forced travel assures full use of sieve mesh area.

1.1.3 KS 300 mechanical sieve shaker [9]

This device is an electrical motorized portable sieve shaker which utilizes a rapid vertical action to sieve the soil sample. This rapid vertical movement also assists in clearing the apertures.

1.1.4 Digital sieve shaker [7]

This shaker as the name states is digital complete with auto sieve windows software for automatic calculation of sieving curves and statistics. The results obtained are also archived.

1.1. 5 Heavy-Duty Sieve Shaker [10]

This is used to sieve heavy or bulky samples. It imparts a circular motion to the material being sieved so that it makes a slow progression over the surface of the sieve. At the same time, a rapid vertical movement agitates the sample and assists in clearing the apertures. It is a powerful test sieve shaker specially designed to handle larger sieves up to 450mm diameter. It overcomes problems that would otherwise be encountered if large amounts of material were to be sieved using small shakers. This is because over-loading of a light sieve system can impair performance and cause results to be unreliable. The Heavy-Duty shaker is fitted with two powerful motors offset at strategic angles transmitting exactly the right vibration frequency and movement to the sample for optimum performance. At the end of the cycle the motors are braked to produce a gentle stopping action.

1.1.6 Octagon Sieve Shaker [11]

This sieve shaker was designed for quiet operation and trouble free maintenance since the electromagnetic mechanism has no moving parts to replace. A unique vibratory/pulse action is used to ensure efficient particle analysis while the rapid vertical movements also help to keep the apertures from binding. In order to complete the sieving motion the up-and-down motion produced by the electromagnet was taken and a circular/twisting motion added to it. A unique composite material was used that when mounted at an angle gave the sieve stack a motion that forced the material over the sieves in a circular motion.

2. Description of the Constructed Mechanical Sieve Shaker

The design shown in Figures 1, 2 and 3 consists of a pulley system which is supported by means of shafts (Figure 2). Bearings were used to facilitate the rotation of the base pulleys and gears which were connected directly to the base of the design via welding. The arm was attached to the shaft extending the upper pulleys via welding and fed via a bushing directly to the base of the sieve supports (Figure 3). The type of sieving action produced by this system is a lateral and vertical oscillation of 32 mm in each direction. This was achieved by use of a follower situated at the base of each sieve support (Figure 1). The motion of the follower was provided by an arm offset to a circular plate which was connected via a bushing directly the sieve support base. This bushing was used as a noise reducer as the drive was transmitted from the motor.

The bushing is offset to the circular plate (Figure 2) and fed through to the base of the sieve supports as shown which caused the lateral and vertical sieving action produced by the follower. At each change of direction, a slight tapping or jerking motion was achieved which was similar to the tapping motion produced in hand sieving. Motion was applied to each sieve support individually (Figure 3). This was done by means of two sets of pulley systems earlier described (Figure 2), which transmitted rotary motion from the motor.

It was required for balance, however, that the two sieve supports rotate in opposite directions. This was achieved by means of gears which were attached directly in front of each pulley that were connected directly to the motor shaft (Figure 2). Each sieve support was supported by an iron backing which was connected by welding directly to the back of the design casing. Whenever the motor is started for the commencement of dry sieving, the belt drive system transmits the rotary action, which would be transformed into an elliptic type motion by the follower, causing the oscillation of each of the two sieve supports in the desired opposite directions.

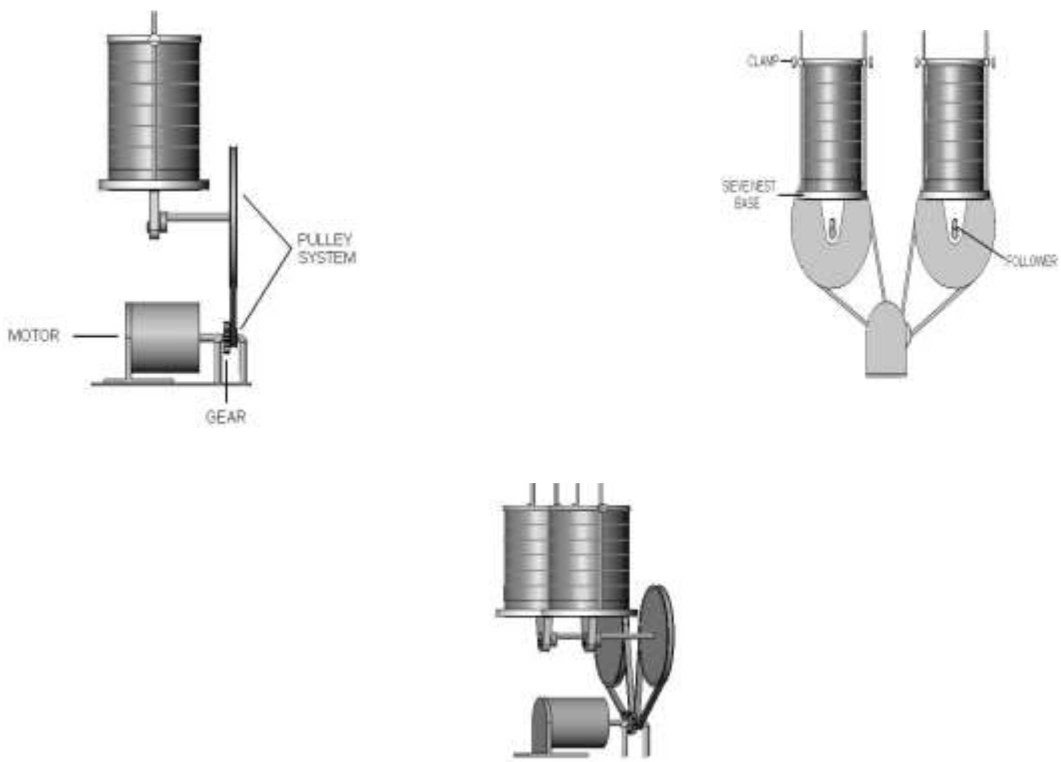


FIGURE 1: Design sketches of the constructed mechanical sieve shaker

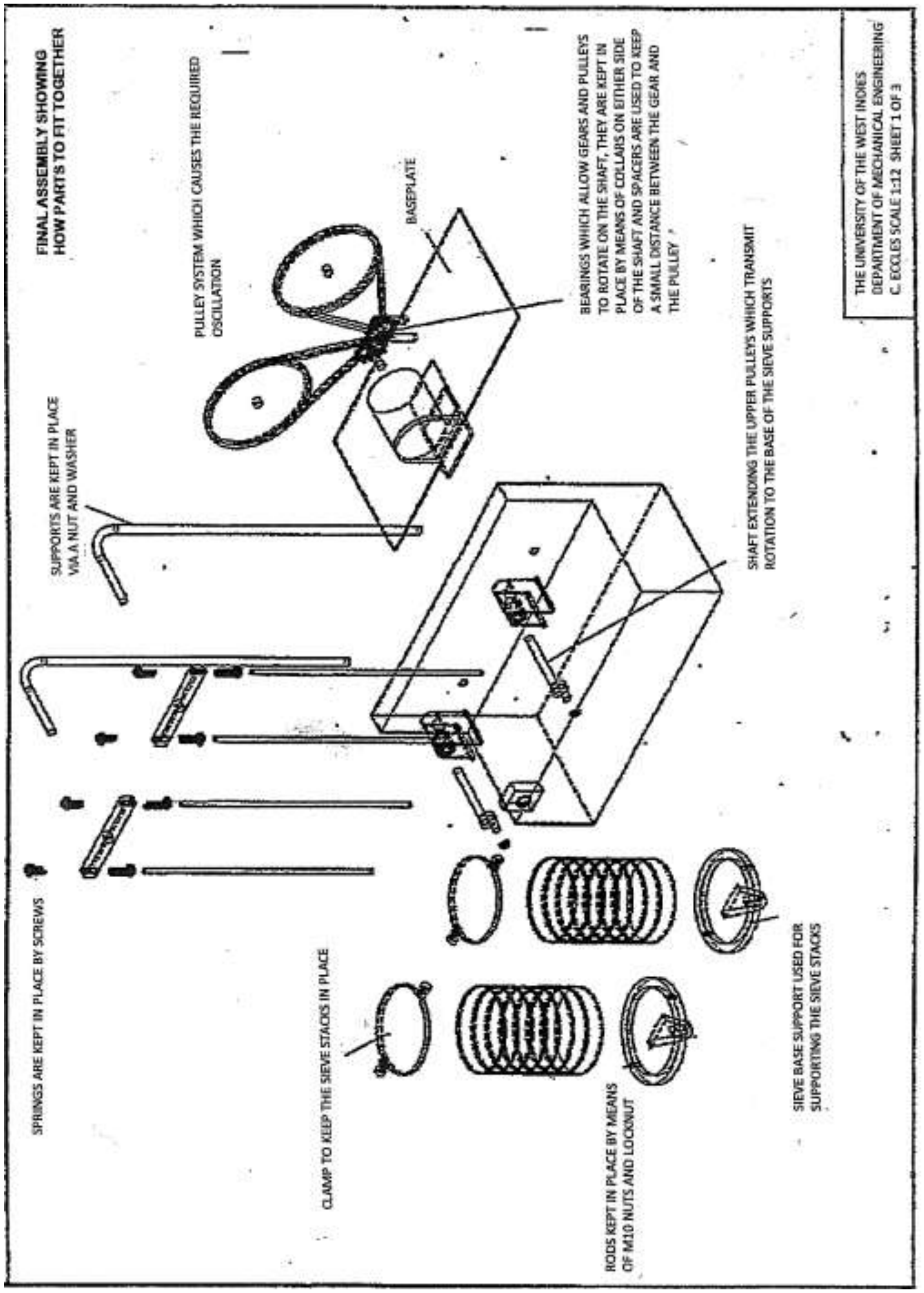
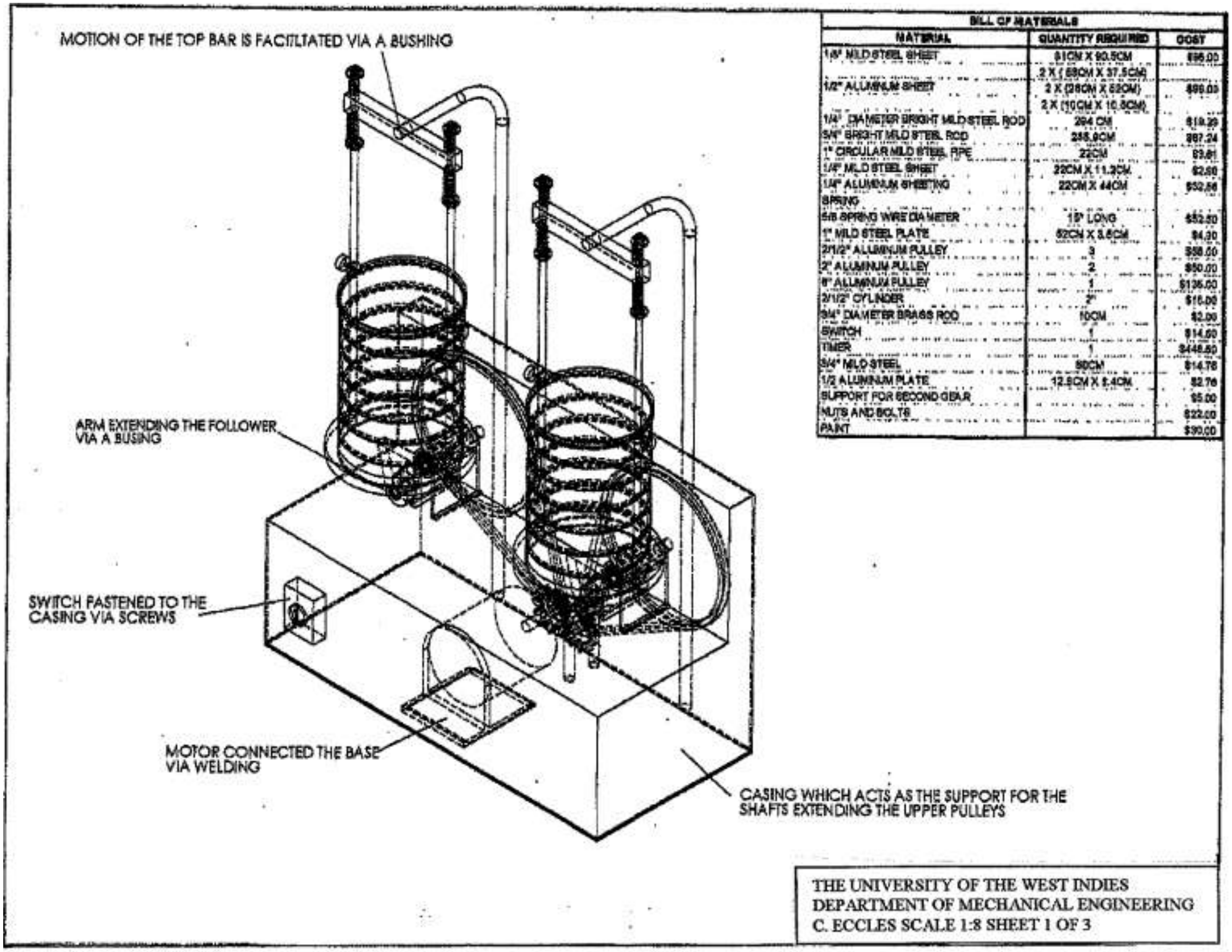


FIGURE 1: Final assembly showing how parts fit together



MATERIAL	QUANTITY REQUIRED	COST
1/8" MILD STEEL SHEET	81CM X 90.5CM	$95.00
	2 X (58CM X 37.5CM)	
1/2" ALUMINUM SHEET	2 X (28CM X 52CM)	$99.00
	2 X (10CM X 10.5CM)	
1/4" DIAMETER BRIGHT MILD STEEL ROD	294 CM	$19.29
5/4" BRIGHT MILD STEEL ROD	255.9CM	$87.24
1" CIRCULAR MILD STEEL PIPE	22CM	$3.61
1/4" MILD STEEL SHEET	22CM X 11.2CM	$2.50
1/4" ALUMINUM SHEETING	22CM X 44CM	$32.56
SPRING		
5/8 SPRING WIRE DIAMETER	15" LONG	$52.50
1" MILD STEEL PLATE	52CM X 3.5CM	$4.30
2/1/2" ALUMINUM PULLEY	3	$58.00
2" ALUMINUM PULLEY	2	$50.00
8" ALUMINUM PULLEY	1	$135.00
2/1/2" CYLINDER	2"	$16.00
3/4" DIAMETER BRASS ROD	10CM	$2.00
SWITCH	1	$14.60
TIMER	1	$448.50
3/4" MILD STEEL	50CM	$14.78
1/2 ALUMINUM PLATE	12.5CM X 5.4CM	$2.76
SUPPORT FOR SECOND GEAR		$5.00
NUTS AND BOLTS		$22.00
PAINT		$30.00

FIGURE 3: Isometric assembly

3. Testing of the Constructed Mechanical Sieve Shaker.

3.1 Purpose of the tests

Tests were conducted to:-

a) Ensure that the constructed mechanical sieve shaker gave repeatable results for every test performed on a particular soil; hence each soil sample was sieved or tested three times.

b) Find the accuracy of the device in relation to existing commercial mechanical sieve shakers hence the results obtained by using the constructed mechanical sieve shaker to obtain the particle size distribution by dry sieving were compared to those obtained using an existing commercial mechanical shaker currently used in the Civil and Environmental Engineering Soil Mechanics Laboratory in the University of the West Indies. This mechanical sieve shaker utilized a rapid vertical motion along with a circular rotation.

3.2 Procedure for testing some soil properties.

Three common agricultural clay soil samples in Trinidad (Table 1) were utilized for the tests. Clay soils were used since they are more prevalent in Trinidad than the sandy soils. The mechanical analysis of the soils (<2 mm size) was carried out by adding a dispersing agent to prevent flocculation and removing the coarse soil aggregates by washing the soil through a 0.05 mm sieve. The material retained on the sieve was air-dried and treated as total sand (Table 1) while the washed water was then subjected to sedimentation and the proportion of silt and clay were determined by the hydrometer method [13]. Organic matter contents (Table 1) were determined using the Walkley and Black method [14]. The field bulk densities (Table 1) were determined using the method of Blake and Hartge [15].

TABLE 1: Some properties of soils used in the test

Soil series	Classification*	Organic matter (%)	Clay ** % (< 0.002 mm)	Silt % (0.05-0.002mm)	Total sand % (2- 0.05 mm)	Field bulk density (Mg m^{-3})
Princes Town clay	Aquentic Chromuderts	1.9	71.3	11.4	17.3	1.34
Navet clay	Aeric Tropaquepts	4.2	67.3	19.4	13.3	1.05
Sevilla clay	Aquentic chromuderts	1.1	67.3	20	12.7	1.41

*Classification according to the Soil Taxonomy System [12].
**A dispersing agent was used to prevent flocculation of particles

3.3 Procedure for soil dry sieving

The test procedure followed was the BS 1377 Standard as described by Das [16]. The soil material to be tested was first air-dried. Aggregations or lumps were then thoroughly broken up with fingers or with mortar and pestle. The aim here was to make sure that the soil sample consisted mainly of individual particles. A dispersing agent was not used so unlike in the soil mechanical analysis described in section 3.2, the flocculation of soil particles still occurred during the dry sieving of the coarse fractions of the soil. The following procedure was followed:

a) The samples were oven dried, allowed to cool and the required 1500 grams of soil were measured.

b) The sieves were then placed in a stack arranged in decreasing opening size of sieves (Table 2), on the shaker. The largest sieve opening (4.75 mm) was placed on top and the receiving pan on the bottom.

c) The soil sample was poured into the top of the sieve stack and the cover tightly secured.

d) The machine was then turned on and was set to oscillate for ten minutes on the timer. Ten minutes is the time used for many sieve shakers.

e) When oscillation was completed, the sieve stack was removed and carefully disassembled.

f) The mass of soil retained in each sieve was determined by weighing and the percentage of soil that passed each sieve was determined as shown in Table 2.

TABLE 2: Particle size distribution* of the three soils using the commercial and the constructed mechanical sieve shakers

Sieve No.	Diameter of Sieve (mm)	Percentage of soil passing each sieve					
		Princes Town clay		Navet clay		Sevilla clay	
		Civil Eng. Shaker	Constructed Shaker	Civil Eng. Shaker	Constructed Shaker	Civil Eng. Shaker	Constructed Shaker
4	4.75	100	100	93.3	91.1	100	100
8	2.36	67.3	65.6	66.6	63.0	64.7	65.0
16	1.18	43.5	40.8	43.3	39.4	41.8	41.8
30	0.60	26.9	24.6	27.0	23.7	26.3	26.7
50	0.30	14.0	13.4	13.6	11.5	13.7	13.8
100	0.15	6.6	6.4	5.2	4.5	6.5	6.7
200	0.075	1.9	1.8	0.4	0.6	2.4	2.2
Pan	-	0.1	0.1	0.1	0.1	0.1	0.1

* A dispersing agent was not used so flocculation of particles still occurred

4. Results and Discussion

During the testing, it was observed that the constructed mechanical shaker produced the desired motion in a manner that was quiet and with little or no vibration. The design also facilitated easy use by making the removal and placement of sieves easier than that of the Civil Engineering mechanical shaker. The percentages of soil that passed each sieve size are shown in Table 2 for each soil and these were used to plot the particle size distribution curves for each soil (Figure 4). Particle size values in Table 2 differed from those in Table 1 since the latter table reports the result of a test where a dispersing agent was used to prevent the flocculation of primary soil particles. Results showed that the curves produced using the three tests of constructed mechanical shaker were very close to each other which emphasized the ability of the constructed shaker to produce repeatable results. Also, the three curves obtained for each soil using the constructed shaker were close to the ones obtained using the Civil Engineering shaker (Figure 4) which showed the ability of the constructed shaker to produce accurate results. These results were particularly very promising for the Sevilla clay and the Princes Town clay where the distribution curves obtained were extremely close to each other.

It was seen that the Civil Engineering Shaker generally produced curves that were slightly higher those obtained using the constructed shaker in the case of Navet clay. As a higher curve usually indicates a better sieving action, this means that the Civil Engineering shaker gave slightly better results for this soil. This meant that the design shaker probably needed a more vigorous shaking action to produce equivalent or better results than the Civil Engineering shaker. Adjusting the motor output to obtain a faster sieving action or increasing the time for sieving from ten to say twelve minutes could achieve this. The results obtained by the constructed shaker at present are, however, greater than satisfactory in determining the particle size distribution of any soil.

Three basic soil parameters [16] were obtained from the distribution curves and used to classify the soils. These parameters are effective size, uniformity coefficient and coefficient of gradation. The effective size of a soil is defined as the maximum particle size of the smallest 10 percent and is denoted as D_{10} [17]. The uniformity coefficient is a measure of the particle size range. It is the ratio of the maximum particle size of the smallest 60 percent to the effective size [17]. All the soils can be classified as non-uniform since they all have uniformity coefficients greater than 3 [17]. The coefficient of gradation is the measure of the shape of the particle size curve [16] and is defined as shown in Table 3. Since all the soils had the coefficient of gradation of 1 to 3, they are all classified as well-graded [16]. This means that the smaller particles will pack between the larger ones. There is a fairly even proportion of all the different particle sizes. The constructed mechanical shaker gave similar classification results to the Civil Engineering sieve shaker.

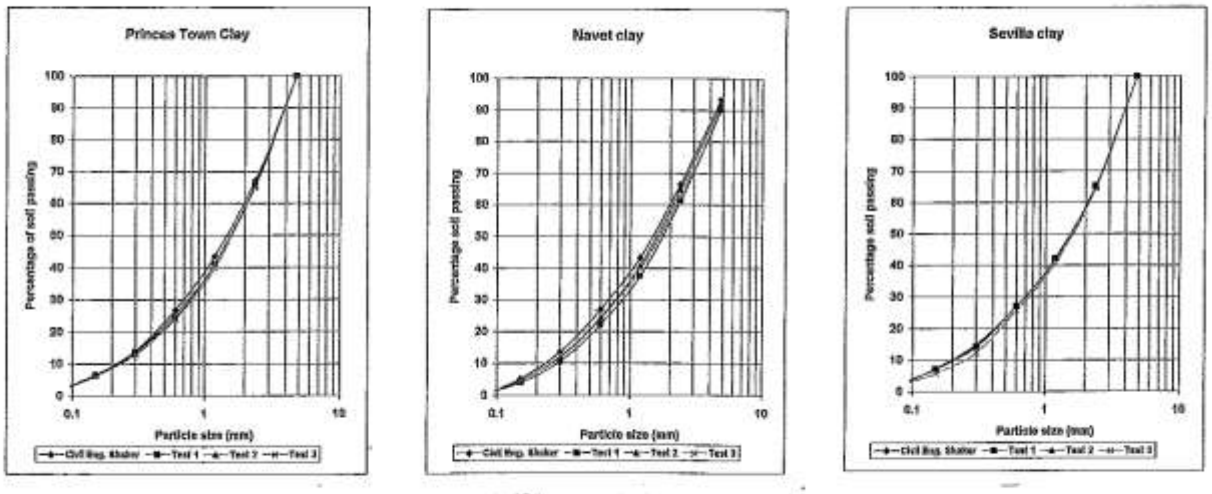


FIGURE 4: Particle-size distribution curves for the three soils obtained using the Civil Engineering sieve shaker and the three tests using the constructed sieve shaker

TABLE 3: Some particle size parameters[a] of the soils obtained using the commercial and the constructed mechanical sieve shakers

Soil and shaker Types	D_{30} (mm)	D_{60} (mm)	[b]Effective size , D_{10}	[c]Uniformity coefficient, C_u	[d]Coefficient of gradation, C_z
Princes Town Clay					
Civil Eng. shaker	0.70	1.94	0.21	9.24	1.20
Constructed shaker	0.76	2.03	0.22	9.23	1.29
Navet Clay					
Civil Eng. shaker	0.72	1.95	0.21	9.29	1.27
Constructed shaker	0.80	2.15	0.23	9.35	1.29
Sevilla clay					
Civil Eng. Shaker	0.70	2.05	0.21	9.76	1.14
Constructed shaker	0.72	2.08	0.22	9.45	1.13

[a]Values of Particle Size parameters were read from Table 2.
[b]Diameter of the particle to which 10% is finer is defined as effective size or D_{10}. [c]Uniformity coefficient, $C_u = D_{60}/D_{10}$

[d]Coefficient of gradation, $C_z = \frac{{D_{30}}^2}{D_{60}.D_{10}}$

5. Conclusion

Based on experimental testing, the constructed mechanical sieve shaker was found to be user-friendly and easy to operate. It was also well suited for laboratory work. It was ensured that the displacement of the sieves in any direction did not exceed 50 mm. The machine was found to operate effectively and efficiently and conformed to all of the design specifications. Each sieve stack was found to effectively sieve the soil samples. The machine was also found to give repeatable results. On comparison with the Civil Engineering sieve shaker, the constructed shaker was found to give results that were very close to it. It was more than sufficient to sieve and effectively or correctly grade any soil sample.

Cost minimization was also an important factor of the design. As such materials were chosen which would reduce the cost of the design, however these materials were also chosen so that the long life of the design was ensured. The total cost of the device was approximated at TT$ 5, 000 which is very good in comparison to about TT$15,000 for a single stack shaker. Hence this design was able to provide a mechanical shaker which could do twice about the work in half the time at one third the price of existing shakers. However, the cost of the constructed sieve shaker represents only the cost of materials (TT$ 1350, Figure 3) and estimated cost of labour (TT$ 3,650) and does not include other costs involved. The prices quoted under the bill of materials in Figure 3 are TT$ (1 US$ = 6.3 TT $) and represent the unit prices of items. The costs of the motor and the stack of sieves are excluded.

References

[1] Chepil, W.S. (1942). Relation of wind erosion to water-stable and dry clod structure of soil. Soil Science 55: 275-287.

[2] Wischmeier, W.H. and Smith, D.D. (1978). Predicting rainfall erosion losses from cropland east of the Rocky Mountains. Agricultural Handbook No. 537, USDA, Washington, D.C.

[3] Brady, N.C. and Weil, R. R. (1999). The Nature and Properties of Soils, 12th. Edition. London: Prentice-Hall.

[4] Kemper, W.D. and Koch, E.J. (1966). Aggregate stability of soils from Western United States and Canada. ARS, USDA, Technical Bulletin, No. 1355.

[5] Chepil, W.S. and Bisal, F. (1943). A rotary sieve method for determining the size distribution of soil clods. Soil Science 56: 95 – 100.

[6] Ekwue, E.I. (1990). Effect of organic matter on splash detachment and the processes involved. Earth Surface Processes and Landforms 15: 175 – 181.

[7] Laval Lab Incorporated (2005). Ro-Tap Sieves. http://www.lavallab.com/particle-size/rotap_sieve_shaker.htm 2/03/07.

[8] Legend Incorporated (2005). Gilson SS-15 Sieve Shaker. http://www.lmine.com/minesupply/m73.htm 2/03/07.

[9] Intec Marketing Services (2002). KS 300 Mechanical Sieve Shaker. http://www.intec.com.my/product/soilequip/ks300.html 2/03/07.

[10] Keison International PLC (2005). Heavy Duty Sieve. http://www.keison.co.uk/endecotts/endecotts4.htm 2/03/07.

[11] CSC Scientific Company Incorporated (2003). Octagon Sieve Shaker. http://www.cscscientific.com/html/design_octagon.html 2/03/07.

[12] Soil Survey Staff (1999) Soil taxonomy: A basic system for making and interpreting soil surveys, 2nd Edition, Agriculture Handbook 436: 128 – 129. USDA, Washington-DC. US Govt. Printing Office.

[13] Lambe T. W. (1951). Soil Testing for Engineers. New York: John Wiley.

[14] Walkley A., and I. A. Black (1934). An examination of the effect of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37: 29-38.

[15] Blake, G.R., and K.H. Hartge. 1986. Particle density. P. 377 – 382. In A. Klute (ed.) Methods of Soil Analysis. Pt. 1. 2nd. Ed. Agronomy Monogram 9, ASA and SSSA, Madison, WI.

[16] Das, B.M. (2002). Principles of Geotechnical Engineering, 5th. Edition, Pacific Grove, California: Brooks/Cole.

[17] Smith, G.N. (1990). Elements of Soil Mechanics, 6th. Edition, London: Blackwell Science.